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NANOTECHNOLOGY INNOVATIONS & BUSINESS OPPORTUNITIES IN RENEWABLE ENERGY SECTOR

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Abstract:

Nanotechnology, being anticipated general purpose breakthrough technology of 21st century, has potential to solve problems related to human civilizations pertaining to both basic needs and aspirations for comfort life. Out of basic needs of human which include food, drinking water, energy, cloth, shelter, health and clean environment, perhaps, solving energy problem by providing a way to generating, storing, and converting it to required form at any time and any amount of time called 'ubiquitous energy' is the opportunity and the challenge for scientific world and for human prosperity. In this paper, we have discussed the challenges and opportunities of nanotechnology innovations and business opportunities in energy sector. The nanotechnology impact on seven areas of energy sector including solar energy, wind energy, nuclear energy, oil-fuel based energy, artificial photosynthesis,energy storage and effective energy management to promote nanotechnology based energy as ubiquitous energy are discussed and reviewed.The paper includes possible innovations and research opportunities in nano-modified solar cells, Nano-influenced Fuel storage cells, and nanotech based artificial photosynthesis. We have also used ABCD analysis to discuss the business opportunities by studying the advantages, benefits, constraints and disadvantages of nanotechnology based energy solutions.Finally, a futuristic possible solution is proposed for the problem of how to solve ever demanding energy crisis using Molecular Nanotechnology model.

Index Terms: Ubiquitous energy, Nanotech based energy solutions, Business opportunities in nanotech energy sector, Futuristic molecular nanotech model.

1. Introduction:

Technological innovations have changed the lifestyle of human beings since many years and solved their basic problems and provided happy & comfort life. Many killer technologies have been invented in the history which have become essential to lead life of common man. Killer technologies are those technologies invented in the society and penetrated common man's lifestyle in such a way that without them the life of human being is going to be miserable. For example, invention of wheel, mechanical engine, electricity, automobile, telephone, radio, television, computer, mobile phone, windows operating system, android based smart phones etc. are examples for killer application technologies. Many of the killer application technologies became general purpose technologies and spread their arms to all areas of the organizations and the society. For example computer technology, informationand communication technologies transformed themselves into general purpose technologies and became essential in the progress of all other fields and became part and parcel of human life.

Recently, during last 20 years, another technology is growing as killer application technology and due to its importance and potential advantages, growing as another general purpose technology and expected to change the society substantially. Nanotechnology deals with the manipulation of matter at near atomic level to produce new materials, structures, devices and systems that exhibit properties and phenomenon that are unique at these scales. Nanotechnologyis not only general purpose technology – it is also technology that enables the creation of new devices and new ways to improve

the quality of life. Nanotechnologyis used in existing industries and new research areas are developed within existing areas, transforming them from microelectronics to nano-electronics, from photonics to nano-photonics, from biotechnology to nano-bio-technology, and from energy to nano energy. Business firms are exploring new ways to address consumer needs, new business models based on the changes nanotechnologies could enable in existing industries. Huge amount of investments in nanotechnology to support scientific and technological researches, the creation of technological and industrial platforms and infrastructures have led to more than two million articles related to nanotechnologies being published, and over one million application patents were lodged by the year 2015 [1].

To realize the ideal technology [2] in practice, we need to identify a general purpose technology that should manipulatethe fundamental nature of matter. The technology should be microscopic and able to provide solutions to the problemsand challenges of fundamental needs of human beings and also support the processes required to enhance the comfort ability of the people. The products/services developed through such technology should have properties, at leastclose to Ideal technology properties. The presently developed technologies like agricultural technology, spacetechnology, computer technology, electronics & communication technology, Automobile technology, bio-technology,laser technology are unable to show all the characteristics which are close to ideal technology characteristics mentionedabove. But it is expected that using the innovations in nanotechnology can solve the basicneeds of human being are food, drinking water, energy, cloth, shelter, health and environment and the comfort needsare realizing the automation in every field, space travel and expanded life-span and so on [3].

Nanotechnology is considered as one of the anticipated breakthrough technology of 21st century along with supporting some other interrelated Killer application technologies like Optical Computation, Embedded Intelligence, Chameleon Chips, Flying cars, Immortality through nano-bio-technology, and Space travel [1]. Nanotechnology will play major role in solving all the problems of humans like food, drinking water, energy, health, environment and many other areas including life span expansion. Some of the Application areas of Nanotechnology are [4-6] :

Agriculture & Food: This include contamination sensor, antimicrobial packaging, enhanced nutrient delivery, green packaging, pesticide reduction, tracking & brand protection, texture, food flavor, bacteria and virus identification & elimination etc.

Potable Water: This include water cleaning nanotechnology devices, nanotubes as the pores in reverse osmosis membranes, and nanotech based water purifiers for polluted water, sewage water and even sea water in large scale.

Cleaner Air& Environment: This includes pollution control, nanotech windmill blades, nanostructure membranes, nanoparticle catalysts, removal of carbon dioxide from industrial smoke stacks.

Renewable Energy: This includes inexpensive solar cells, devices for capturing, storage, & use of energy optimally.

Electronics: This includes development of nanotransistors, nanogates, nanodevice based integrated circuits, nanoemmissive display panels, nanomemories, nanowires, nanophotonic devices, Nano-optical computers etc.

Batteries & Fuel Cells: This include nanostructure fuel cells, hydrogen nanofuel cells, nanotech alternative fuel cells, long life high storage capacity fast rechargeable nanotech batteries etc.

Health & Medicine: This include drug delivery, therapy techniques, diagnostic techniques, antimicrobial techniques, cell repair, cancer detection & curing, gene therapy, nanotech in regenerative medicine & tissue engineering, life span extension etc.

Automobile: This includes nanomaterial based automobile parts to increase working life of the automobiles, to decrease running cost and maintenance cost, and to decrease the environmental degradation to zero level.

Sensors & Detectors: This includes chemical sensors, MEMS based sensors, nano-hydrogen sensors, Nanocantilevers etc.

Consumer Products: Devices like sporting goods, fabrics & textiles, cosmetics, skin care products, sunscreens, flame retardants, nanocleaning products, nanopaints, and any other products based on nanotechnology.

Defense: This include concepts like nano for the soldier, nano for defense vehicles, nano for aeronautics, nano for naval vessels, nanotechnology for weapon systems, nano for satellites, nano for logistics, nano for security, nano for military operations at land, nano for military operations in the air, nano for military operations at sea, nanotechnology for urban operations etc.

Civil & Mechanical Engineering Manufacturing: This includes nano-material technology, nano-processing technology, nano-assembly technology, nano-coating technology, and nano-measurement technology in mechanical manufacturing. This also include nanorobotics, Micro-Electro Mechanical Systems (MEMS) for accelerometer chips, inkjet nozzles, pressure sensors, microphones, RF switches, gyroscope, oscillators etc.

Building Materials: This includes various future building materials like aerogels, nanotube mixed concrete, nanopaints, building integrated photovoltaics, nanophotonic materials as building cooler. Nanotechnology on construction, and fire protection etc.

Pharmaceutical Industry: The major goal of the nanotechnology is to improve the present way to drugs administration for efficient way of recovery of the patient. This include the creation of new drugs with a specific function till the fabrication of new drug delivery systems for the movement of different barriers in the human body with special care of increase the efficiency of drugs in terms of solubility. Nano-drugs can cure dreadful diseases like AIDS, cancer, tuberculosis, diabetes, malaria, prion disease, etc.

Aircraft, Rocket and Space Technology: This includes low cost, less weight, high strength space elevators, weight reduction in spaceships and spacesuits, solar power satellites, bio-nano-machines for space applications, new breed of robots to explore the planets etc.

Lifespan Expansion: The two possible ways to extend the lifespan of human being are either by helping to eradicate life-threatening diseases such as cancer, and the other is by repairing damage to our bodies at the cellular level--a nano version of the fountain of youth. Techniques for building nano-robots are being developed that should make the repair of our cells possible.

2. Possible Impact of Nanotechnology on Energy Sector:

Out of basic needs of human which include food, drinking water, energy, cloth, shelter, health and clean environment, perhaps, solving energy problem by providing a way to generating, storing, and converting it to required form at any time and any amount of time called 'ubiquitous energy' is the opportunity and the challenge for scientific world and for human prosperity.The potential of nanotechnology in energy sector involves generation of different form of energy, transition of generated energy from one place to another, storage of energy in different form to minimize the loss, and usage of stored or instantaneous produced energy for useful work using

nanotechnology principles. While analysing any system, it is customary to compare it with ideal system of that kind [2, 7-12]. As per the definition of ideal energy system, it should provide infinite amount of energy to the user continuously and it should able to convert one form of energy into another form without any internal loss i.e., ideal energy system has 100% efficiency. Nanotechnology is also expected to play a major role in the process of conversion of energy from one form to another with up to 100% efficiency. Such invention leads to easy accessibility of energy for individuals, homes, offices, companies, and industries at almost zero cost, ubiquitously and makes major impact on economy of every country.

Energy Sources: The possible impact of nanotechnology on energy generation is multi-fold. Nanotechnology supports efficient generation of electrical energy by converting other form of energy in nature. This includes conversion of light/electromagnetic energy into electrical energy by means of photo-electric converters, conversion of wind energy into electrical energy by means of wind turbines optimized using nanotechnology, conversion of mechanical energy of motion into electrical energy efficiently using hydro-electric turbines optimized using nanotechnology, conversion of gravitational energy into electrical energy, or conversion of nuclear energy into electrical energy using steam based turbines optimized their efficiency using nanotechnology etc. Out of different types of energies, electrical energy is most convenient energy to be used for useful work and to be stored by means of existing technologies. Progress in nanotechnology research focus on how all other forms of energies can be converted in to electrical form for easy transmission, utilization and storage. Nanotechnology provides easy way to convert heat energy into electrical energy, light energy into electrical energy, sound energy into electrical energy, mechanical energy into electrical energy, Wind energy into electrical energy, Geothermal energy into electrical energy, Atomic and nuclear energy into electrical energy at optimum cost & efficiency, leading to a concept of “unification of energy”.

Energy Transmission: The possible impact of nanotechnology on energy transmission isimproving the efficiency by minimizing the loss. Nanotechnology based transmission cables are already proven their enhanced efficiency and leading towards zero transmission loss. Nanotechnology based transmission cables are also expected to reduce the cost, increase the durability, and to be environmental friendly. Research is also progressing on developing wireless energy transmission systems for transmission of electrical energy with minimum loss between distant points on the surface of earth as well as between space and earth surface and will get boost and viability through nanotechnology. Once we reach such stage of wireless transmission of energy between distant points, huge amount of solar energy can be taped by sending large number of solar space stations sent very near to sun and convert into electrical energy and transmitted to earth to solve the energy crunch of civilized society.

Energy Storage: The possible impact of nanotechnology on energy storage isdevelopment of batteries and fuel cells with small size, low weight, low cost, huge storage capacity, and long durability. Nanotechnology supports to develop and maintain ideal batteries to store huge amount of electricity in a small battery. Fuel cells generate electricity instantaneously depending on requirement and nanotechnology supports developments of fuel cells having ideal characteristics. The nanotechnology based batteries and fuel cells are going to make revolution in automobiles, electronic communication, industrial production, aircraft technology, and space technology leading to new industrial revolution.

Energy Utilization: The possible impact of nanotechnology on energy utilization is improvement in systems performance due to improved efficiency of the systems. Since the nanotechnology based systems are expected to be very close to ideal systems with ideal characteristics, their performance efficiency is always close to 100%. Hence they need very low energy for their functions. In such scenario of both the energy supply and the energy utilizing system shows optimum performance with least energy usage. Thus, nanotechnology based energy sources and systems are going to be best systems in the nature to keep the entropy of the universe at lowest level.

3. Seven areas of Nanotechnology Impact on Energy Sector:

The nanotechnology impact on seven areas of energy sector including solar energy, wind energy, nuclear energy, oil-fuel based energy, artificial photosynthesis, energy storage and effective energy management to promote nanotechnology based energy as ubiquitous energy system (figure 1) and are reviewed as given below. Ubiquitous energy system is a concept of integrated energy system provides energy to everybody, anywhere, anytime, and any amount of time like ubiquitous banking in banking system [13-14].

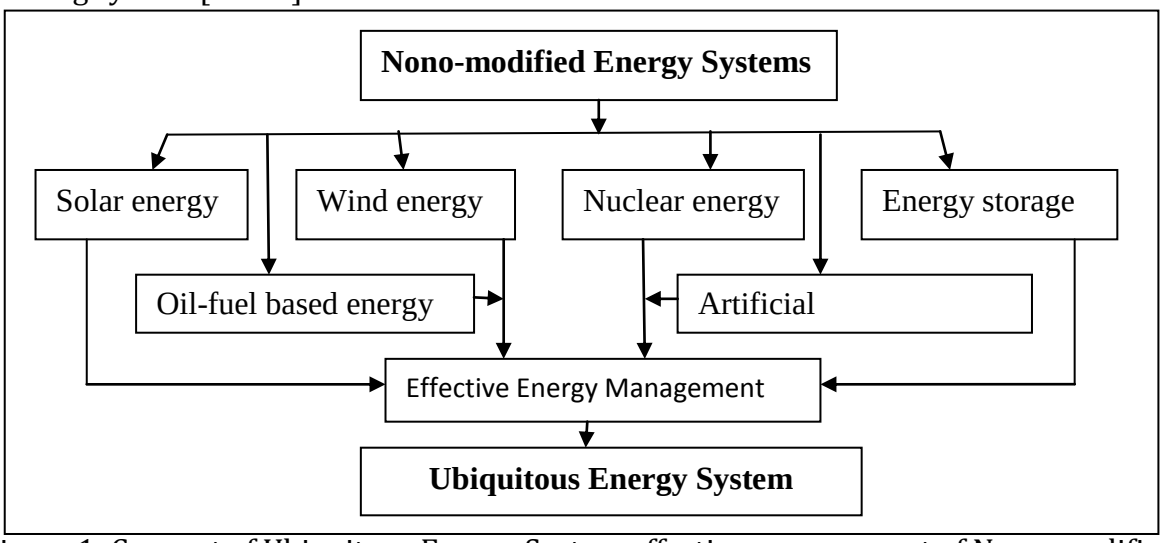

Figure 1: Concept of Ubiquitous Energy System effective management of Nano-modified energy systems.

3.1 Solar Energy: Advances in nanotechnology based solar cells can lead to higher efficiencies and lower costs. Nanotechnology can increase the efficiency problem, by tinkering with solar power cells at a fundamental level to boost their ability to convert sunlight into power, and by providing the industry to use less expensive materials. One of the methods used in nanotechnology is to reduce the amount of light reflected back from solar cell surface by increasing the absorption at the outer surface. Other methods are using organic solar cells with quantum dot sensitized, and dye sensitized solar cells with various permutations and combinations to increase the efficiency with low cost and long durability. Research in solar collecting paint based on nanotechnology is also under progress which uses a stable, electricity-conducting liquid filled with solar-collecting nanocrystals, which can be painted or printed like an ink onto surfaces such as window glass or plastic roof panels. Leads to smart houses with self-sustainable electrical systems. Table 1 contains the summery of review on nanomaterial usage and their advantages in solar cells research.

Table 1: Review on Nanomaterial usage in solar cells research

S.No	Nanomaterial Usage	Advantage	References
1	Quantum Dot Solar	An average PCE of 11.66% and a	[15]

	Cells based on these Zn–Cu–In–Se QDs	certified PCE of 11.61% have been demonstrated	
2	Silicon nanowire-based solar cells on silicon wafers	From a partially illuminated area of 0.6 cm^2 open-circuit voltages in the range of 230–280 mV and a short-circuit current density of 2 mA cm^{-2} were obtained.	[16]
3	Nano-structured ZnO	dye-sensitized solar cells with enhanced efficiency	[17]
4	Quantum dot-sensitized solar cells	Efficiency is further boosted to as high as 5.38%.	[18]
5	Dye Sensitized Solar Cell (DSSC)	It was observed that incorporating graphene sheets of various sizes in the photo anode helped to improve the efficiency of DSSC significantly, giving a maximum efficiency of 6.62%. In case of novel dyes used in the DSSC fabrication the D-A-pi-A indoline dyes showed a great enhancement in the cell efficiency, with efficiency of up to 6.9%. Incorporation of Pt in counter electrodes and 3D-CE also showed notably good efficiency in DSSC, the efficiency improving up to 8.8%.	[19]
6	Quantum Dot Sensitized Solar Cells	Amorphous TiO_2 Buffer Layer Boosts Efficiency of Quantum Dot Sensitized Solar Cells to over 9%	[20]
7	Plasmon enhanced absorption in dye sensitized solar cells (DSSC) over a broad wavelength range.	45% enhancement in the power conversion efficiency is observed with the inclusion of plasmonic gold nanoparticles (NPs).	[21]
8	Graphene in perovskite solar cells	Achieved 7.8 percent conversion of sunlight to electricity.	[22]
9	Discovered radical new properties in a nano-metamaterial which opens new possibilities for highly efficient thermo photovoltaic cells,	This nano-metamaterial harvest heat in the dark and turn it into electricity.	[23] & [24]
10	CdS/CdSe quantum dot sensitized solar cells with a ZnSe passivation layer	Doubling the power conversion efficiency	[25] & [26]

3.2 Wind Energy: The global wind turbine manufacturing industry growing industry and there is increasing interest in manufacturing new types of turbine blades with

enhanced properties. It is essential to design and produce blades with good fatigue resistance and good stiffness properties to ensure operational longevity. Nanotech polymer matrix composites dominate the wind turbine blade market because of their low-cost, lower weight-to-power ratios, superior fatigue characteristics, high specific strength and modulus, and ability to make complex geometries. Wind turbine blade manufacturers are faced with the challenge of constructing technologically increasingly robust, more sophisticated, larger wind turbines with the total production cost per turbine as low as possible. Nano-particle lubricant additives for wind turbine gearbox will increase the power generation by decreasing rotation resistance for the turbines. Table 2 contains a review on various nanomaterials used in wind mills research.

Table 2: Review on Nanomaterial usage in wind mills research

S.No	Nanomaterial Usage	Advantage	References
1	Reinforcing wind turbine blades with carbon nanofibers	Larger, more resilient wind energy conversion (WEC) systems	[27]
2	Boron based surface treatment and nano-particle lubricant additives for wind turbine gearbox applications.	Nano-particle lubricant additives for wind turbine gearbox decreases Friction and wear.	[28]
3	Multifunctional carbon nanofiber (CNF) paper-based nanocomposite coating was developed for wind turbine blades.	Shows great promise for usage with wind turbine blades, owing to its excellent damping properties, great friction resistance, and super hydrophobicity.	[29]
4	Carbon nanotubes / polymer nanocomposites used in wind turbine blade	Good fatigue resistance and good stiffness properties to ensure operational longevity	[30]
5	Carbon nanotubes, are a potential candidate to be incorporated into marine current turbines.	Structural reinforcement, fouling release coating, structural health monitoring, high performance wires/cables and lubrication.	[31]

3.3 Nuclear Energy: Nuclear energy generated using nanotechnology can be more efficient, safer and generate less radioactive waste than current technologies. Nanomaterials and nanotechnologies are useful for advanced nuclear fuel fabrication, spent nuclear fuel reprocessing, nuclear waste disposal and nuclear environmental remediation. Table 3 contains a review on various nanomaterials used in nuclear reactors research.

Table 3: Review on Nanomaterial usage in nuclear reactors research

S.No	Nanomaterials Used	Advantage	References
1	Nanostructured sorption materials (carbon materials included)	Purification of radioactive waste.	[32]
2	Alumina nanoparticles	Maximizing heat transfer efficiency	[33]

		in nuclear reactors	
3	Zero-valent iron nanoparticle and its graphene composite	Efficient removal of uranium from aqueous solution in Nuclear power plant waste	[34]
4	Nanopowder of dysprosium hafnate changing instead of using boron carbide.	Control-rod modernization in nuclear reactors	[35]
5	Nanocrystalline uranium dioxide fuels	Grain boundaries absorb defects, lengthen life of nuclear fuel	[34]
6	Carbon nanotubes	Water-cooled reactor designs featuring enhanced safety	[36]

3.4 Oil –Fuel Based Energy: Nanotechnology has the potential to introduce revolutionary changes in several areas of the oil and gas industry, such as exploration, drilling, production, enhanced oil recovery, refining and distribution. Nano-sensors have been developed rapidly to enhance the resolution of the subsurface imaging leading to advanced field characterization techniques. Nanotechnology also strikes the stage of production enormously to enhance the oil recovery via molecular modification and manipulate the interfacial characteristics. Some of the nanomaterials which have potential advantage in such applications with more efficient, less expensive, and more environmentally sound, are listed in table 4.

Table 4: Review on Nanomaterial usage in crude oil purification research

S.No	Nanomaterial Used	Advantage	References
1	Magnetic shell cross-linked knedel-like nanoparticles (MSCKs) using iron oxide	Crude oil purification by successful removal of the hydrophobic contaminants	[37] & [38]
2	Nanocatalysts portray unique catalytic and sorption properties due to their exceptionally high surface area-to-volume ratio and active surface sites.	In-situ heavy oil upgrading and recovery enhancement.	[39]
3	Polydimethylsiloxane (PDMS)–graphene sponge	Exhibited high adsorption performance for the removal of petroleum products, organic solvents and emulsified oil–water mixtures.	[40]
4	Carbon nanotube sponges	Oil spill cleanup from sea water	[41]
5	Carbon nanomaterials such as mesoporous carbon (CMK-3), sulfur- or nitrogen-doped porous carbon and carbon black	Improved performances in detection, assessment as well as purification of oil and natural gas are studied and demonstrated.	[42]

3.5 Energy Storage: Materials store and deliver energy in the forms of batteries, super capacitors, or fuel cells. High performance nanomaterials for storing hydrogen would enable more energy efficient vehicles and off–grid operation. Nanotechnology improves battery technology by increasing the available power from a battery, decreasing the

time required to recharge a battery, reducing the possibility of catching fire, and increases the shelf life of a battery by separating liquids from the solid electrodes with the help of nanomaterials when there is no power draw on the battery. Some of the nonmaterial used in Battery and Fuel cell research are listed in table 5.

Table 5: Review on Nanomaterial usage in Battery and Fuel cell research

S.No	Nanomaterial Used	Advantage	References
1	Three-dimensional hierarchical Co_3O_4/CuOnanowire heterostructure arrays on nickel foam for high-performance lithium ion batteries.	The superior electrochemical performances of electrodes composed of hierarchical Co_3O_4/CuO NW arrays connected directly on nickel foam make them potential anode materials for high performance LIBs.	[43]
2	TiO_2 nanotubes.	Provide an open-circuit voltage of 3.39 V and a short-circuit current density of 1.01 mA/cm^2. Such an integrated power pack could serve as a power source for mobile electronics.	[44]
3	Activated carbon nanotubes.	Improved electrochemical properties of batteries.	[45]
4	Nanostructured $FePO_4$ for sodium-based batteries.	Improved capacity and power performance.	[46]
5	Nano-Sn electrode with high-quality nano-SEI formation for lithium ion battery.	Improved stability.	[47]

3.6. Artificial Photosynthesis: As an alternative to fossil fuels, technology can lead to some of the most efficient energy supply methods possible for future. By attempting to directly harness the power of the sun as bacteria, algae, and plants do through natural photosynthesis, scientists are seeking to produce viable renewable energy resources. Artificial photosynthesis is a chemical process that replicates the natural process of photosynthesis, a process that converts sunlight, water, and carbon dioxide into carbohydrates and oxygen. This leads to artificial food production. The recent breakthroughs in nanotechnology have led to a more bottom up approach more similar to natural photosynthesis, where engineered nanostructures are used for the capture and conversion of light into usable energy. In artificial photosynthesis, scientists are trying to mimic the core processes in natural photosynthesis like light gathering, charge separation, and recombination with the aim to create efficient synthetic nanostructures that can function as antennae and reaction centers. Table 6 contains a summery on review on nanomaterial used in artificial photosynthesis.

Table 6: Review on Nanomaterials usage in Artificial Photosynthesis.

S.No	Nanomaterial Used	Advantage	References
1	Artificial Photosynthesis systems contain a chromophore, such as a porphyrin, covalently linked to	This system uses sunlight to split water to oxygen and hydrogen fuel, but efficiencies are low and an external	[48]

	one or more electron acceptors, such as fullerenes or quinones, and secondary electron donors.	electrical potential is required.	
2	Nanoparticle made of four zinc tetraarylporphyrin molecules, $(P_{ZP})_3$-P_{ZC}, a free-baseporphyrin, and a fullerene molecule, P-C_{60}.	Efficient synthetic nanostructures that can function as antennae and reaction centers for artificial photosynthesis.	[49]
3	Highly efficient photosynthetic energy and electron transfers were realized at gold and indium–tin oxide (ITO) electrodes modified with self-assembled monolayers of porphyrin–fullerene-linked systems.	Porphyrin-modified gold nanoclusters were found to have potential as artificial photosynthetic materials and photonic molecular devices.	[50]
4	Rational Design and Engineering of Quantum-Dot-Sensitized TiO2 Nanotube Arrays for Artificial Photosynthesis.	Nanotubular morphology and hybridization of TiO_2 with CdS enables highly efficient photoregeneration of cofactors by ensuring better diffusion of reaction species and rapid charge separation.	[51]
5	Clusters of nano-sized cobalt-oxide molecules (CoO) acts as catalyst for artificial photosynthesis.	Found to be stable and highly efficient triggering agent in an artificial photosynthesis system.	[52]
6	A team of scientists at MIT, used a man-made virus to serve as a scaffold that attracts molecules of the catalyst iridium oxide and a biological pigment (zinc porphyrins).	The viruses then become "wire-like" and are able to split the water molecules into hydrogen and oxygen by having just the right spacing to induce the reaction.	[53]

3.7. Effective Energy Management: Renewable energy can be generated using nanotechnology materials and components in efficient manner at low cost by means of proper planning using nano-modified solar cells or by means of artificial photosynthesis and generated electrical energy has to be distributed by means of nanotechnology based transmission system and stored by means of nanotechnology batteries so that one can decrease the loss of energy during distribution as well as storage of energy. By means of properly planned energy management system, the loss of energy can be minimized. By means of properly arranged solar cells and battery system can provide continuous electrical energy for the concept of ubiquitous energy (any time, any amount and any amount of time).

4. Innovations and Business Opportunities for Nano-Modified Solar Cells:

Nano-modified solar cells and solar paints are potential products for future business both in developed countries and developing countries due to their enhanced conversion efficiency, low cost, and durability. The improved characteristics of such solar panels increase the demand in the market so that the business firms which involve

in nano-modified solar panel business have huge business opportunities for long period of time.

Business of Smart House: The planning and construction of smart house and smart office using nanotechnology is going to be major business in 21st century. In smart house and smart office, the green electricity is generated for keeping the night warm, running the electrical appliances including air conditioners and all other requirements using the nano modified solar paint pasted on both roof, walls, and windows. All houses and buildings are going to be independent and self sustainable in electrical energy usage.

Business of Solar Energy: Generating solar electricity in large volume either planning big solar parks or generating electricity near sun using space stations and transmitting the electrical energy to earth stations by wireless electricity transmission systems is a new challenge for 21st century.

Solar Automobiles: Improved battery storage and solar cell technology using nanotechnology, solar automobiles can bedeveloped which can use renewable energy without environmental pollution and improves the efficiency in terms of mileage. By developing efficient battery storage technology and manufacturing of automobile body by solar panels or solar paint, the automobile companies have huge business potential for long period.

Solar Industries: The heavy industries also have opportunity to make use of renewable energy either using nanotech solar park, or nanotech wind park or nano-modified nuclear reactors to improve the efficiency and to lower operational cost.

5. Innovations and Business Opportunities in Nano-Influenced Batteries &Fuel Storage Cells:

Fuel cells are electrochemical devices that convert chemical energy to electricity and thermal energy. Fuel cell systems are used for applications ranging from portable electronics, automobiles, computers, space vehicles, in Electronic entertainment Devices & Security Devices, and to utility power plants. Many types of fuel cells are already in market. Nanotechnology increases the efficiency and decreases the size and weight of the fuel cells so that they can last longer period with required energy output. Fuel cells can offer a higher energy storage density and more convenience than conventional battery systems. Fuel cells are also environmental friendly due to their low emission nature. Nanostructured fuel cells find business opportunities in many areas in the society which include:

Fuel Cell Automobiles: Fuel cell vehicles powered by hydrogen, or ethanol or gasoline with nano-material as catalyst lead higher efficiency and low cost and hence has potential business opportunities.

Fuel Cells in Computers: Business opportunity is also open for fuel cells with nanocomposites as catalyst to provide continuous electrical energy to maintain as server for providing undisturbed support to the entire world.

Fuel Cells in Space Vehicles: A fuel cell combines a fuel (hydrogen or hydrogen source) with an oxidizer (oxygen or air) to produce electrical power. Business opportunities are open to the organizations to develop fuel cells to provide auxiliary equipment power to commercial aircraft, for reusable launch vehicles, for Mars airplane, and for Space Shuttle upgrade, as well as for systems to produce electricity and store energy on the Moon, Mars or any other planet.

Fuel Cells in Electronic entertainment Devices & Security Devices: Nanotechnology offers business opportunity to develop micro fuel cells to use with devices such as digital cameras, portable radios, and notebook computers. A micro fuel cell is a power

source for electronic devices that converts chemical energy into electrical energy mostly uses methanol or solid oxides instead of hydrogen.

Fuel Cells for Electrical and Thermal Power to Buildings: Nanotechnology supported stationary fuel cells are ideal for power generation, either connected to the electricity grid to provide supplemental power and backup for critical areas, or installed as a grid independent generator for on-site services The advantages are operate virtually silently, reduce noise pollution as well as air pollution, the waste heat from a fuel cell can be used to provide hot water or room heating, and are highly efficient and have relatively low maintenance requirements.

Nanotech Batteries: Nanotechnology allows to increase the available power from a battery and decreasing the time required to recharge a battery. This is possible by coating the surface of an electrode with nanoparticles to increases the surface area of the electrode thereby allowing more current to flow between the electrode and the chemicals inside the battery. Nanotechnology also iincreases the shelf life of a battery and eliminates the possibility of batteries catching fire. As a result, huge business potential exist for organizations due to the advantages of nanotech batteries compared to presently using metal-acid or lithium-ion batteries.

6. ABCD Analysis of Nanotechnology Business Opportunities in Energy Sector:

ABCD listing and ABCD framework are two models of qualitative [54-60] and quantitative ABCD analysis [61-67] respectively. In this section, we have used ABCD analysis for qualitative listing of advantages, benefits, constraints and disadvantages from business service providers and customer's point of view.

Advantages:

- ✓ Nanotechnology solar cells are expected to be highly efficient in conversion of light into electricity, easy to large scale fabrication and maintenance for business service providers.
- ✓ Nano-solar cells and panels are efficient, durable and cost-effective for the customer point of view.
- ✓ Nano-solar cells are expected to solve the world energy problem by effective use of solar energy and contribute to the development of civilian society.
- ✓ Nanotech polymer matrix composites dominate the wind turbine blade market because of their low-cost, lower weight-to-power ratios, superior fatigue characteristics, high specific strength and modulus, and ability to make complex geometries.
- ✓ Nanomaterials and nanotechnologies have the advantage in nuclear fuel fabrication, spent nuclear fuel reprocessing, nuclear waste disposal and nuclear environmental remediation.
- ✓ Battery - Nanotechnology decreases the time required to recharge a battery, reducing the possibility of catching fire, and increases the shelf life of a battery by separating liquids from the solid electrodes with the help of nanomaterialswhen there is no power draw on the battery.
- ✓ Nanotechnology has advantage in crude oil exploration, oil well drilling,
- ✓ Oil production from the wells, enhanced oil recovery, improved refining and distribution. Nanotechnology is used in detection, assessment as well as purification of oil and natural gas.
- ✓ High performance nanomaterials for storing hydrogen in fuel cells enable more energy efficient vehicles and off–grid operation.
- ✓ Nanotechnology helps artificial Photosynthesis systems to use sunlight as the renewable energy source to produce carbohydrates and oxygen.

- ✓ In the case of solar cells, much higher output power can be expected from nanosized structures compared to their bulk forms.
- ✓ Opportunity for developing ubiquitous energy system.

Benefits:

- ✓ Due to higher absorption coefficient, nano-solar cells are highly efficient in conversion of light into electricity. The organic nano-solar cells are easy to fabricate and cost effective to both business service providers and the customers.
- ✓ Nano-metamaterial used in nano-solar cells harvest heat in the dark and turn it into electricity.
- ✓ Due to low-cost, lower weight-to-power ratios, superior fatigue characteristics, high specific strength and modulus, and ability to make complex geometries, nanotech polymer matrix composites, decreases the weight and strength of wind turbine blades.
- ✓ Environmental sustainability due to reduced.
- ✓ Nanotechnology improves battery technology by increasing the available power from a battery, increases the durability, and recharge cycles, and decreases the recharge time, size, and weight of the battery.
- ✓ Nanotechnology improves electrochemical properties of batteries.
- ✓ Increased efficiency in crude oil purification.
- ✓ Nanotechnology improves the performances in detection, assessment as well as purification of oil and natural gas.
- ✓ Nanotechnology-supported artificial photosynthesis system produces artificial food to the society.
- ✓ The benefit of using energy anytime, anywhere, and any amount of time through Ubiquitous energy system.

Constraints:

- ✓ Educating the people to shift from conventional energy sources to renewable energy sources.
- ✓ Higher initial cost for commercialization of new technology.
- ✓ Achieving higher efficiency in artificial photosynthesis using suitable nanostructures to convert sunlight, water, and carbon dioxide into carbohydrates and oxygen.
- ✓ The problem of complexity is the major constraints. The more advanced systems have huge numbers of parts, and their design and manufacturing involve a series of projects impressive in their complexity.

Disadvantages:

- ✓ Nanoparticles as though they are hazardous materials and take measures to ensure they are contained during manufacture and disposal.
- ✓ Presently artificial photosynthesis is costly process compared to natural food production.
- ✓ Deliberate abuse of the technology by hostile entities ranging from governments to terrorists, could be used for weapons of mass destruction.

7. Molecular Nanotechnology: A Futuristic Possibility to Solve Ever Demanding Energy Crisis:

Advanced research in nanotechnology is expected to produce some molecular machine systems which have the ability to self-replicateto make copies of themselves. Constructing an artificial self-replicating system at the molecular level will be difficult, but once made, it could make many copies of similar system and perhaps too many copies leads over replicated machines as virus do. A molecular machine can be defined

as an assembly of a discrete number of molecular components – that is, a supramolecular system – in which the component parts can display changes in their relative positions as a result of some external stimulus. Molecular machines and motors are of interest not only for basic research, but also for the growth of nanoscience and the subsequent development of nanotechnology to make further impact on solar energy, wind energy, nuclear energy, oil-fuel based energy, artificial photosynthesis, energy storage and effective energy management to promote nanotechnology based energy as ubiquitous energy system.

8. Conclusion:

The nanotechnology supported energy sources, distribution lines, energy storage systems, and energy utilising systems are becoming important and popular among the customers due to potential advantages of nanotechnology in electrical energy generation and storage. The clean energy without environmental degradation,at almost zero cost, is expected to solve energy problem of the world through the concept called ubiquitous energy. The impact of nanotechnology on seven energy sectors including solar energy, wind energy, nuclear energy, oil-fuel based energy, artificial photosynthesis, energy storage and effective energy management to promote nanotechnology based energy as ubiquitous energy system along with possible business opportunities are discussed and reviewed. Finally, the advantages, benefits, constraints and disadvantages of nanotechnology in the energy sector from business service providers and customers point of view are identified and listed.

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