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Nano Optimization of Existing Energy System

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Abstract: Nanotechnology has continuously engaged itself in carrying out various research pursuits for fulfilling the societal needs of people at large. In context of the global scenario of increasing energy demand, threatening climatic changes and foreseeable scarcity of fossil fuels, the cost efficient production and storage of energy seems to be predominantly occupying the minds of most of the people today. The present paper is an attempt to highlight the role of nanotechnology in the optimization of the existing energy system. Nanotechnology has significant potential in efficient utilization of conventional energy resources like fossil and nuclear fuels as well as economic development of renewable energy resources such as solar, hydro, wind, tidal, biomass and geothermal. Nano-structuring helps in achieving the highest possible conversion efficiency in the generation of electric power from fossil fuels through turbines or fuel cells, in combustion and electric engines, in thermoelectric energy conversion and in the generation and conversion of chemical energy sources. Efficient conversion systems do not only save resources but also reduce CO_2 emissions thereby protecting the environment. Nano-structured semiconductors can lead to an increased efficiency and could provide scope for a broader application in the utilization of wasted heat emitted from automobiles, air-conditioners, electronic gadgets or human body. Another pertinent issue is the reduction of losses in power transfer by using extraordinarily conductive carbon nano-tubes, high temperature superconductive materials and even wireless electric transmission by lasers, microwaves etc. Reduction of fuel consumption in automobiles through light weight construction nano-materials, wear and corrosion resistant engine components, nano-porous thermal insulation materials for energetic rehabilitation of old buildings and controlled heat and light flow by nano-technological components are a few promising approaches in reducing energy consumption. Use of nano-technology in developing small sized storage systems for hydrogen fuel and increased utilization of bio fuels are also considered as solutions for the future energy needs.

Key Words: Nanotechnology, Optimization, Bio fuels, Energy system, Conversion efficiency

1. Introduction

Energy powers our life. It provides our living space and working environment with pleasant temperatures and brightness. It is the food of production plants, urban infrastructure as well as the multitudes of our electronic assistants in everyday life. As we are becoming more and more advanced with the budding of technological pursuits, the worldwide energy demand is continuously increasing and expected to increase by 50% until 2030. At present about 80% of our energy needs are covered by fossil fuels but they will not be able to meet the worldwide energy consumption in the long run. Fossil fuels are also affecting the environment by increasing the CO_2 content. To solve energy and climatic problems, it is not only necessary to utilize renewable alternatives to fossil fuels, but to optimize the whole chain of energy including development from primary sources, conversion, distribution, storage and consumers' utilization. Nanotechnologies as key and cross- sectional technologies exhibit the unique potential for decisive technological breakthroughs in the energy sector. These could be achieved by the incorporation of the promising nano-technological approaches into technical innovations for the development of a sustainable energy supply and realization of cost reduction in renewable energies to increase efficiency in generation and consumption. This review provides a number of examples for possible applications and developments of nano-technologies in the energy sector in which research facilities could be actively involved.

2. Strategies to Meet the Future Energy Needs through Nanotechnology

To secure global power supply in the long run, it is not only necessary to develop existing energy sources as efficiently and environmentally friendly as possible, but also to minimize energy losses arising during transport from source to end user, to provide and distribute energy for the respective application purposes as flexibly and efficiently as possible and to reduce energy demand in industries and households. Each sector of value added chain bears potential for optimization which could be tapped through the application of nanotechnologies. Following are a few strategies which could be implemented through nano-technological approaches to meet the world-wide power challenge.

1. Development of primary energy sources

2. Efficient energy conversion
3. Low loss energy distribution
4. Long term efficient energy storage
5. Minimizing consumption by efficient usage

2.1 Development of Primary Energy Sources: Nanotechnologies play a vital role for the development of both conventional (fossil fuels and nuclear) and renewable (solar, wind, hydro, tidal, geothermal, and biomass) energy sources. Development targets include achieving high efficiency and lifespan of several years. The potential for renewable energy sources is unequally higher but in the present scenario, the technically and economically usable part of it is insignificant due to low energy density and limited number of economically usable locations. Further constraints on the utilization of renewable energies are the inconsistent energy yields influenced by the environmental factors, low efficiency in energy conversion and cost- intensive production methods and materials. Nano-technology often enables the realization and economic breakthrough of new products and technologies in the first place, and thus providing optimized components and procedures which could be profitably applied. It will tap the greatest potential in the field of development of primary sources in the following fields of application.

2.1.1 Regenerative

Photovoltaic: A broad breakthrough in photovoltaic requires an increase in energy conversion efficiency, less expensive materials and production processes and economical equipment of large surfaces with solar cells, which could be enabled through nano-technologies. Nano solar cells embedded in flexible plastics will be able to adjust to the shape and terrain of the rooftops and could be put into the building materials like tiles and sidings making energy production possible at every rooftop. In the long run promising market potential will result from alternate cells such as thin layer solar cells, dye solar cells or polymer solar cells. Due to cheap material and production processes, self sustenance and flexible design, polymer solar cells have high potential for portable electronic devices, traffic control systems & safety and telecommunication systems. Conventional crystalline solar cells can also be improved by nano-structured anti-reflection layers which provide higher light yield[1, 2]. Anti-reflection layers for flat glass based on anno-porous coating of silicon-dioxide are commercially available. The porosity allows the adjustment of effective refractive index between glass and ambient air, which helps reduce reflection losses of glass panes. Quantum dots can be applied in solar cells because they can not only produce several electron-hole pairs per photon but can also optimally adjust absorption bands to the wavelength of the irradiating light. Nanoscience[3]also enables the production of solar cell glass that will not only generate energy but also act as window panes to reduce overheating of buildings thereby reducing the need for cooling.

Wind Energy: Development of wind energy will be confronted with the problem of choosing suitable sites which are increasingly relocated off-shore making maintenance more difficult. Nano-technologies through light-weight high-strength materials for rotor blades, tribological coatings and wear protection layers of bearings and gear boxes, conductive materials for improved lightning protection and optimized energy stores allow more economic feeding of wind power in the grid.

Geothermal: Geothermy is a long range energy source with deposits capable of meeting a multiple of the global energy demand. It provides the possibility of decentralized direct use of heat or its conversion into electric current. Economical utilizable geothermal energy deposits can be developed through depth drilling (more than 2 km) which could be improved through wear protection nano-structured hard layer systems for geothermal drill probes exposed to extreme stress.

Hydro/Tidal Power: Hydro and tidal power also have locational and mechanical limitations. Moreover the entire demand-supply chain in the energy sector is quite capital intensive, monopolistic and hence cumbersome. Nano coatings to protect wearing and corrosion offer immense potential to harness this energy resourcefully[2].

Biomass Energy: Biomass can not only serve the generation with energy and heat but also has provision of fuels. However, the production of bio-ethanol, the most important bio-fuel is not yet competitive. The energetic utilization of biomass requires great land resources and thus competes with food production. Thus in future alternative raw materials such as algae, domestic waste, paper, straw or hay are in demand to produce bio-fuels on an industrial scale[4]. Nano-technologies play a vital role in the development of new conversion methods using catalysts, process technology and sensorics and cultivation of bio-resources by efficiently utilizing fertilizers and pesticides through nano-encapsulation and nano-sensors[1].

2.1.2 Fossil Fuels

Nano-materials also play a role in the recovery of fossil fuels. Suspensions of natural nano-silicates are used in oil production. Nano-porous and nano-particulate materials help in the separations of contaminations in oil deposits and thus increase production yield[2].The optimization of mechanical wear resistance of drill probes for the development of oil and gas deposits in deep earth layers is also possible. In future, even unconventional source like oil shale will have to be increasingly utilized for the recovery of crude oil. However oil extraction from such sources requires improved technologies like sensorics for the exploration of storage sites, which could benefit from nano-technological innovations.

2.1.3 Nuclear

In nuclear energy, nanotechnology can help improve the radiation resistance of the materials. Nano composites which can prevent the leakage of hazardous radiation and can be used for shielding are the long term options of nuclear fusion reactor[2, 5]. This could make the conventional energy clean.

2.2 Efficient Energy Conversion: In the field of energy conversion, improvement of conversion efficiency is the main target. Apart from generation of electric current and heat through stationary large-scale power plants, decentralized and mobile energy converters like fuel cells or thermoelectric will play a growing role in future. Increase in power plant efficiency requires high operating temperature. Nano-materials with extreme heat resistance would provide the solution. Light-weight materials like titanium-aluminide with nano heat protection can be utilized for more efficient turbines in aircraft engines. Reduction of CO_2-emmision could be achieved by separation and sedimentation procedures in sub-surface storage sites[1, 2].

2.2.1 Gas Turbines

Thermal barrier layers are indispensible for heat protection of turbine blades in gas turbines since the temperature at turbine inlet is much higher than the melting point of the turbine material[2]. Thermal barrier layers should have low electrical conductivity and low thermal expansion to minimize tension and crack formation in the material. Complex heat barrier systems can be produced through multiple source plasma coating processes consisting of active, adhesive and barrier layers with nano-scale precision and various material combinations which reduces their heat conductivity and enables them to operate at high temperature thereby improving the efficiency of gas turbines with cost and CO_2 emission reductions.

2.2.2 Thermoelectrics

Thermo electrics may be used to convert thermal energy directly into electrical energy using See back effect. Thermo electrics should have low heat conductivity in addition to good electrical conductivity. Nano-structured thermo electrics are of great interest since the electrical and thermal properties of the materials are influenced by the structure size. The characterization of the relation of structure, composition and properties at the nano-level will enable the design of materials with desired properties. Nano-structured semiconductors with optimized boundary layer design could give a boost to thermo electrics through significantly improved efficiencies and might pave the way for waste heat utilization of automobiles, electronic devices and human body heat for personal electricity needs.

2.2.3 Fuel Cells

Fuel cells convert chemical energy of fuels such as pure hydrogen, natural gas, benzene, methanol or biogas, with a high efficiency in electric current. The application spectrum of fuel cells varies from power supply to mobile phones or laptops and vehicles and household with electricity and heat to small power stations. They are capable to provide uninterrupted power supply. Fuel cell usage has been limited due to material performance and high cost since it needs platinum which is scarcely available. Nanoscale material can replace platinum completely or partially with increased efficiency for specific applications[2]. Carbon nanotubes could enable a substantial improvement in the performance of fuel cell, together with a heavy cost reduction of catalyst material. Using nano-optimized membranes, catalysts and electrodes, higher electrical yield from efficient fuel cells which can be used in automobiles and mobile electronics can be achieved[1].

2.2.4 Hydrogen Generation

To pave the way for hydrogen as a future energy carrier, efficient processes for hydrogen production are required. Nano-structuring helps increase efficiency of metal catalysts in the electrolytic decomposition of water. Cells with nano-crystalline coatings of metal oxides enable production of hydrogen gas directly from sunlight[6]. In the photoelectric decomposition of water, the photo-electrodes should be stable in aqueous solutions and their conversion efficiency through band gap should be optimally adjusted to the redox potentials of water[1, 2]. Nano-structuring and nano-crystalline substances provide starting potential but further optimizations are far from economical applicability.

2.2.5 Combustion Engines

A significant part of global energy consumption is attributable to the motorized individual traffic. Thus an increase in efficiency of combustion engines could help save considerable amount of energy. Nanotechnologies provide solutions through heat, wear and corrosion protection layers for engine components and Diesel injectors which provide higher injection pressure and therefore improved energy yield. Nano-particles can be used as Diesel additives which optimize combustion in Diesel engines and hence save fuel.

2.2.6 Electric Engines

Electric engines could also benefit from nano-technologic developments. Nano-structured high temperature superconductors will allow higher power densities (100 times more than that of conventional copper windings) and thus highly efficient electric engines and generators. Fields of application include, for instance, ship engines and in the long run even aircraft engines are conceivable.

2.3 Low Loss Energy Distribution: The field of energy transfer will have to face great challenges in future regarding increase in efficiency and adaptation to changing basic conditions. Energy losses in power transfer should be reduced. Intelligent and flexible grid management capable of managing highly decentralized power feeds is the demand of the future.

2.3.1 Power Transmission

High Voltage Transmission: Efficiency of power transfer in high-voltage power lines increases with increasing amperage. The high-voltage power lines suffer from electrical and mechanical strains due to increased voltage and required current compaction arising because of decentralized power supply and huge supply in metropolitan areas. The material design on the nano-scale enables the optimization of electric insulation properties such as breakdown voltage. Multifunctional, non-linear and auto-adaptive insulation systems that's mechanical and electrical properties changes with field strength, temperature and mechanical stress and adjusts to the power demand, are in progress.

Superconductors: Superconductors will play a growing role in energy technology for low loss wired power supply, coil windings and bearings of electric engines as well as residual current circuit breakers in high-voltage power grids. Considerable progress was made in the development of high temperature superconductors in the last years[2]. The most important challenge is production of superconducting and buffer production layers by chemical means.

CNT Power Lines: For low loss power supply in high-voltage grids cables of carbon nano-tube composites could be an alternative. This would require further significant progresses with regard to more efficient production methods and technologies for production of long CNT fibers with uniform structure[1].

Wireless Power Transmission: In the long run options are given for the wireless energy transport through laser, microwaves or electromagnetic resonance, which could enhance security, safety and convenience. Power transmission via radio waves can be made more directional, allowing longer distance power beaming, with shorter wavelengths of electromagnetic radiation, typically in the microwave range. In the case of electromagnetic radiation closer to visible region of spectrum power can be transmitted by converting electricity into a laser beam that is then pointed at a solar cell receiver. This mechanism is generally known as "power-beaming" because the power is beamed at a receiver that can convert it to usable electrical energy[7, 8].

2.3.2 Smart Grids

The current power grids are not designed for a massive development of renewable energy sources. Future power distribution requires grid providing efficient energy distribution even over long distances, dynamic load and failure management, demand controlled energy supply with flexible price mechanism as well as feeding through multitude of decentralized renewable energy sources. Nano-technology could contribute decisively to the realization of this vision through nano-sensorics and power electronic components able to cope with the extremely complex control and monitoring of such grids.

2.3.3 Heat Transfer

Efficient in and out flow of heat can be achieved by nano optimized heat exchangers and conductors which could be based on CNT composites.

2.4 Long Term Efficient Energy Storage: Energy stores are indispensable at different points of the supply chain from energy conversion to the end user. In case of renewable energy production, it has to be considered that power generation occurs discontinuously and therefore energy must be stored as buffers to balance the fluctuating demand. Alternatives must be found for the long term storage of energy and its availability at short notice and in an efficient infrastructure. The utilization of nano-technologies for the enhancement of various (electrical, chemical, thermal etc) energy stores turns out to be downright promising[1].

2.4.1 Electrical Energy

The most important application field of electrical energy stores is the supply of mobile electronics. Electrochemical stores (batteries, rechargeable batteries, ultra-capacitors) with higher efficiency, energy and power densities in comparison to other power stores are advantageous in this field. Regarding the demand of electrical energy stores a number of criteria such as energy and power density, lifespan, reaction time, operating temperature range, safety and efficiency must be optimized. Nanotechnology could optimize some of these performance features.

Batteries: Due to high cell voltage and outstanding energy and power density, Li-ion technology is regarded as most promising variant of electrical energy storage. Nanotechnologies can improve the capacity and safety of Li-ion batteries decisively through high performance electrodes and new ceramic, heat-resistant and flexible separator foils. Application potentials are seen in electric vehicles and power stores in wind farms to bridge the gap between power demand and fluctuating power generation. In future nickel-hydride batteries could also serve as an alternative energy store[9, 10]. Currently, the large number of used batteries and accumulators represent an environmental problem. Nano materials could help develop batteries with higher energy capacities or rechargeable batteries and accumulators, which will help with the disposal issue of batteries. Also, nanotechnology can reduce the possibility of batteries catching fire by providing less flammable electrode materials[2].

Ultra Capacitors: Nanotechnology enabled super capacitors will help in local storage of energy. Super capacitors are electrochemical double layer capacitors characterized by high energy and power density. They consist of two electrodes surrounded by an electrolyte and separated by a separator. A high significant performance enhancement of super capacitors is achieved through nano structuring and associated surface extension[2, 11]. They are useful for mobile applications where high energy amounts are needed in a short interval of time.

2.4.2 Chemical Energy

Hydrogen: In future energy systems, safe and large scale storage of chemical energy, in particular hydrogen, will play an increasingly important role. Conventional energy stores such as high pressure stores being very heavy, liquefied gas stores being expensive due to costly insulation required to minimize losses through hydrogen evaporation and chemical H_2 stores of metal-hydride compounds being relatively costly and heavy bear some disadvantages which are prejudicial to broad economic application. Nanotechnology offers safe and practicable solutions like absorption onto high surface area solids and use of carbon nano tubes and nano structured graphite fibers for combining with metal hydride compounds, which may be practically realized[1, 2].

Fuel Reforming/Refining: Nano catalysts can be used for optimized fuel production through oil refining, desulphurization and coal liquefaction[1] .Research is undergoing to develop a system that produces transportable fuel through an inorganic, modified form of photosynthesis using nanotechnology called artificial photosynthesis. Nanocrystals are used to convert the sun's energy into electricity, then to take that electrical energy and convert it to chemical potential energy[12].

Fuel Tanks: The storage of fuels on hydrocarbon basis, like petrol, can also be optimized through nanotechnology. With nano-structured fillers in polymers the diffusion density of plastic tanks and pipes can be increased and undesired emissions and fuel losses can be reduced. Gas tight fuel tanks based on nano composites are used for reducing hydrocarbon emissions[1].

2.4.3 Thermal Energy

Heat stores play an important role in the heating of buildings through solar-thermal panels which make the solar heat stored in summers available in winters.

Phase Change Materials: New concepts of thermal energy storage are based on the application of phase change materials, which absorb heat through a reversible phase transition in the operating temperature range and emit it to the environment again. Nanotechnologies play a role in the development of micro-encapsulated phase-change stores which are used for thermo-statization of buildings.

Absorptive Storage: From economic point of view adsorption stores based on nano-porous materials such as zeolite, which dry up when heat is supplied and can be discharged when humid air passes through are used for reversible heat flow in buildings and heating nets. The adsorption of water in zeolite allows the reversible storage and release of heat.

2.5 Minimizing Consumption By Efficient Usage: To achieve sustainable energy supply, it is necessary to improve the efficiency of energy use and to avoid unnecessary energy consumption. Nano-technology provides a multitude of approaches to energy saving. The efficient usage of energy both in industries and private sector leads to greatest potential regarding the avoidance of green-house gas emissions. Toeholds for nano-technology arise first and foremost in heat insulation in buildings, thermo-stabilization in technical processes, light-weight construction material and energy saving lighting.

2.5.1 Thermal Insulation

The power demand for heating and cooling purposes in industrial fields and of private consumers has a considerable share in total energy consumption worldwide. Great savings could be done from energetic reconstruction of old buildings and insulation in technical processes. Intelligent management of light and heat flow in buildings could be done by electrochromic windows, micro mirror arrays or IR reflectors. Nano-porous materials have great potential as highly efficient insulation materials because of the pore size in the range of average free path length of the gas molecules. At this cell size the heat exchange due to collision of gas molecules would almost completely cease[13]. Examples for such materials are aerogels, polymer foams etc. The work on this concept is currently in the state of basic research.

2.5.2 Light Weight Construction

High stability light-weight construction materials can contribute to considerable energy savings particularly in the transport sector. Nano-materials offer various potentials such as extremely high strength-weight ratio, hardness, viscosity, wear-resistance, corrosion-resistance and thermal capacity[1]. Nano-scale structures of metal matrix composites (MMC) have a high application in aerospace industry due to their temperature stability, strength and low density. Nano-based protection coatings provide better abrasion and corrosion protection for magnesium alloys in car manufacture. Also polymer composites reinforced with CNT's have the potential for ultra-light high stability construction materials.

2.5.3 Industrial Processes

Technical processes in industries often involve high application of energy and contribute extensively to the operating cost. The energy saving potential through the application of nanotechnologies is mainly found in the substitution of energy-intensive reaction steps through nano-structured catalysts and thermal insulation materials. Due to increased active surface area, nano-structured catalysts enable higher reaction yields and energetically more favorable ways of synthesis. In the manufacture of ceramics, the nanopowders can reduce sintering temperatures and hence save energy. Micro-reaction technology i.e. the control of chemical processes in miniaturized reactors with optimized heat and matter exchange provides further approaches. Micro-reactors enable the production of chemicals requiring significantly lower energy inputs compared to large-scale industrial plants.

2.5.4 Lighting

Lighting systems consume a large amount of electricity all over the globe. Energy savings in this field first and foremost concern the development and efficient use of LED on the basis of inorganic and organic semiconductor materials. Due to compact design, variable colour scheme and high energy yield the LED technology has already tapped great market potentials in the illumination of displays, buildings and cars. Nanotechnology approaches for the further development of LED through quantum dots which help improve energy efficiency and light yield. Nano-scale light emitting particles contribute to the minimization of scattering effects of LED's and thus enhance light yield[1]. Development of OLED depends on the optimization of field carrier materials, succession and thickness of layers, application of dopants and purity of material used.

3. Environmental, Health and Safety Risks of Nanomaterials

Over the last years a debate has grown in intensity regarding the potential environmental, health, and safety (EHS) risks of nanomaterials. This is an issue that should carefully be addressed for us as society to take advantages of this new technology. Part of the problem with assessing risks for nanotechnology and nanomaterials is that the real risks of these cannot easily be evaluated due to a lack of data, the complexity of the materials, and the difficulty in measuring those risks. However, until now, the public's outlook on nanotechnology seem to be on the positive side despite a lack of knowledge.

4. Role of Energy Optimization for Conserving Environment

Nanotechnology applications can reduce the environmental problems substantially with their targeted and indirect interventions. Nano technology has the potential to change the way the things are produced and processed and to further reduce their hazardous side and after effects. From solar cell and fuel cell fabrication to energy management, transmission, conservation and savings the applications of nanoscience offer a range of opportunities. Low fuel consumption by using light weight strong materials would reduce the emission of greenhouse gases thereby protecting the environment[1]. Products with molecular level precision through the use of productive nano systems could result in virtually no chemical waste. Nano-enabled products like nanowire based paper can clean up oil and other organic pollutants. Nano-sized particles of iron are useful for cleaning up contaminants in groundwater, soil and sediments[2].

5. Conclusion

A solution to the global energy problem will require revolutionary new technology, as well as conservation and evolutionary improvements in existing technologies. Efficiencies in the use of energy will come from many advances, but that we believe nanoscience can bring the most immediate benefits. Nanotechnology could make essential contributions to inexpensive, sustainable energy supply and global climate protection. The most dramatic, real and concrete long term benefit in energy research would be to deliver a fuel system that could both allow society to avoid reliance on volatile Middle East oil supply while at the same time avoiding harmful emissions or other environmental impacts during the energy conversion process. With nanotubing and other nano-based materials new opportunities could be created to transport electricity efficiently and at lower cost over very long distances particularly from revolutionary new materials that are inexpensive, environmentally safe, and both stronger and lighter than steel. Transmission and storage of energy, particularly electrical power and hydrogen, is a major societal need, and holds the most promise in solutions with new nanotechnologies. Nanotechnologies can significantly reduce energy consumption thereby making the available sources last longer. Perhaps the greatest challenge, but most dynamic change toward these goals, would be if nanoscience could render the widespread collection, conversion and transmission of solar energy viable and affordable.

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