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ENVIRONMENTAL SUSTAINIBILITY VIA EMERGING MOLECULAR NANOTECHNOLOGY

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ABSTRACT

With the state of the art technologies, human race as well as other species on earth is victimized by air and water pollution and threatened by hazardous nuclear wastes. Acid rain, global warming, ozone depletion have become part of daily household vocabulary. Environmental sustainability based on technology-to-date is pessimistic. Emerging molecular nanotechnology in all industrial fronts, such as nanoelectronics, nanobiotechnology, nanomaterial, nanoenergy etc., offer radical tools for human society for the first time to be on the upper hand in the struggle towards sustainable economic growth. Furthermore, it will have extra capacities for human civilization not only to remediate environmental liabilities accumulated since industrial revolution of 18th century, but also to produce unlimited material and energy with ultra green processes. This paper traces the causes of sustainability problems and diagnosis of the defects of current industrial manufacturing processes in the light of molecular nanotechnology. It also analyzes and extrapolates the prospect of additional capabilities that man may gain from the development of nanotechnology that has the potential to ascertain environmental sustainability, restore global environment while we still enjoy the abundance of material and energy.

WHAT IS MOLECULAR NANOTECHNOLOGY (MNT)?

Nanotechnology refers to the ability to put together nature's basic building blocks, atoms and molecules, into finished products. All products are made from atoms and molecules. The properties of the products are dependent upon how the atoms and molecules are arranged. By arranging basic building blocks in the molecular environment, we can create more precise and better products. Nanotechnology describes many types of research where the basic product is assembled from pieces with dimensions of about 1,000 nanometers. It involves studying and working with matter at an ultra small scale and a nanometer is just one millionth of a millimeter in length.

Manufactured products are made from atoms. The properties of those products depend on how those atoms are arranged. If we rearrange the atoms in coal we can make diamond. If we rearrange the atoms in sand (and add a few other trace elements) we can make computer chips. If we rearrange the atoms in dirt, water and air we can make potatoes. Today's manufacturing methods are very crude at the molecular level. Casting, grinding, milling and even lithography move atoms in great thundering statistical herds.

In the future, nanotechnology will let us take off the boxing gloves. It will be essential if we are to continue the revolution in computer hardware beyond the next decade, and will also let us fabricate an entire new generation of products that are cleaner, stron-

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ger, lighter, and more precise. If we are to continue these trends we will have to develop a new manufacturing technology which will let us build inexpensively computer systems with more quantities of logic elements that are molecular in both size and precision and are interconnected in complex and highly idiosyncratic patterns.

There are two more concepts commonly associated with nanotechnology:

i) Positional assembly
ii) Self replication

Clearly, we would be happy with any method that simultaneously achieved the first three objectives. However, this seems difficult without using some form of positional assembly (to get the right molecular parts in the right places) and some form of self replication (to keep the costs down).

The need for positional assembly implies an interest in molecular robotics, e.g., robotic devices that are molecular both in their size and precision. These molecular scale positional devices are likely to resemble very small versions of their everyday macroscopic counterparts. Positional assembly is frequently used in normal macroscopic manufacturing today, and provides tremendous advantages. Imagine trying to build a bicycle with both hands tied behind your back! The idea of manipulating and positioning individual atoms and molecules is still new and it needs some more time for us to get used to it. However, as Feynman said in a classic talk in 1959: “The principles of physics, as far as I can see, do not speak against the possibility of maneuvering things atom by atom.” We need to apply at the molecular scale the concept that has demonstrated its effectiveness at the macroscopic scale: making parts go where we want by putting them where we want!

Impact of human activities on environment sustainibility

All human activities are motivated by survival. For that human beings produce and consume energy, material and products. Before Molecular Nanotechnology (MNT), the technology employed for production is a Top-Down Bulk Technology(TDBT), whether it is traditional or high technology. Due to TDBT’s inherent shortcomings such as low efficiency, imprecision, crudeness etc., throughout the processes, energy and material are excessively wasted; pollutants and wastes are extensively generated. In addition, human consumption also consumes large quantity of energy and material and generates dramatic amount of pollutants and wastes. All this threatens the sustainability of our environment.

Human survival activities can be summarized into energy production, material production, product manufacturing and consumption (as shown in Fig.1). Because technology-to-date (TTD) is primitive in contrast with the emerging MNT; all human activities are exerting tremendous pressure on the environmental sustainability. In addition, current pollution abatement technologies are based on TDBT; secondary pollution generated essentially cancels the benefit. Available data indicate global environment is still worsening. Humanity is suffering from degrading environmental quality, diminishing natural resources and environmental related illness. If there is no fundamental technological or non-technological paradigm shift, a catastrophic destruction is predicted.

While MNT is still developing it is worthwhile to diagnose the causes and effects of current environmental sustainability predicament; the targets for MNT R&D specific for green production and products as well as restoring the environment can be identified.

This heading includes two aspects which we will discuss here.

Environmental impact from energy production

Major energy production processes adopted currently are hydroelectric, fossil fuels and nuclear. They are major pollution sources and destructive forces to the environment. Combined they produce more pollution and destroy more environment than any other single industry. Figure 2 summarizes the causes and effects of energy production to the environmental destruction.

Other minor power generation processes are solar, wind, geothermal, ocean thermal energy, tidal and other renewable sources. They are the adhoc energy production alternatives in response to the serious ecological impact of the major processes or depletion concern of non-renewable fossil fuels. Nevertheless, renewable energy facilities also affect wildlife, involve hazardous wastes or require cooling water and due to their lower production quantity and higher cost, the effect in enhancing environmental sustainability is limited.

Environmental impact from production and consumption

For ages human beings have been employing TDBT to obtain raw material and for manufacturing products. In the process, wastes and pollutants are generated and discharged to the environment; resulting in its undesirable encroachment Material consumption and waste generation rates are ever increasing. Pollution abatement and waste reduction technologies based on TDBT offer no radical solutions; they only transfer or distribute problems to less immediate impact areas, generating secondary pollution. Figure 1 summarizes the causes and effects of environmental destruction by human production and consumption processes.

Environmental protection & remediation by MNT

Molecular Nanotechnology (MNT) capability of to precisely manipulate atoms and molecule smakes it possible to revolutionize the Technology-to-date (TTD) for energy and material production and also our ways of living. Facing survival threat, it is vital for us to direct MNT innovations towards environmental protection and remediation through integration, so that a sustainable, pollution-free, resource-abundant, green-wealthy nanotechnology can be ascertained.

To that aim, we can adopt a double approaching method. The first is to control pollution at source. We should take full advantage of MNT so that pollution and waste generation can be minimized or even eliminated. The second is to remedy accumulated environmental problems via MNT. Following protection and remediation measures are taken:

1. Control of pollution at source by MNT

Source control is most effective for TTD and it remains so for MNT. TTD has been used to minimize human activity impact on the environment. It is mediocre effect is obliterated by attached secondary pollution and consumption rise. Net damage to the environment still exceeds nature's recovery capacity. Using TDBT to meet climbing material demand renders further environmental damage inevitable and sustainability impossible. MNT's revolutionary production processes promise eventual total elimination of all pollution sources, their consequent control, treatment or abatement.

Under this heading we will discuss three aspects that are as follows:

a. Control of pollution from energy production by MNT

Energy production processes are extremely destructive to the environment. To control pollution from energy production, the first approach is to minimize the energy consumption from demand side itself. Integrating nanoelectronics, nanoelectromechanical system (NEMS), nanomaterial, a series of novel devices will replace all those developed by TDBT. Lighter yet stronger material, more energy efficient and less friction enabled by MNT will automatically lead to less energy consumption.

The second approach is from the supply side to develop cleaner and more efficient energy production processes. There are 300 watts of raw solar energy irradiating each square meter of the earth daily. Harvesting solar energy using TDBT was proven to be not economically feasible during the last energy crisis. However results from frontier nanoelectronics and nanoenergy R&D indicate that the application of TDBT will soon be both technologically and economically feasible.

Nanoenergy developers currently are contemplating methods to reap this clean and abundant energy. Drexler proposed to resurface existing roads with a coating of high efficiency solar cells topped by a layer of tough diamond. Batelle researchers are developing a way of using solar energy to convert water into oxygen and hydrogen. AIST Japan has been successfully using an artificial photosynthesis system to split water into hydrogen and oxygen under visible light. Bennett's team has developed artificial photosynthesis membrane which can convert sunlight into energy. IMEC is conducting researches on thin film crystalline Si solar cells, GaAs solar cells and on new materials and technologies such as plastic solar cells to improve the efficiency and cost of solar cells. Japan's Matsushita Electric Works have teamed up to develop nanotechnology based solar cells to be incorporated into building materials for residential and commercial buildings in about four years.

From ongoing nanoenergy researchers, future energy production can be visualized. Using fossil fuels and even renewable fuels for energy will become obsolete. Dams and powerhouses will be demolished and rivers will return to their original meandering courses. Nuclear reactors will be mothballed and all radioactive substances wait to be safely retrieved, contained and properly stored or treated. Energy production processes that generate CO_2, SO_2, NO_X, radioactive wastes and other pollutants will be all banned. In the energy production arena they will be entirely replaced by solar based either photoelectrolysis hydrogen fuel energy or photovoltaic energy. Photoelectrolysis hydrogen fuel energy system uses self-replicating nanobots mimicking first half of photosynthesis to produce hydrogen gas. Fuel cells made of carbon nanotubes are used to interface with all energy consumption. The photoelectrolysis hydrogen fuel energy system is shown in Figure 3.

In this system quantum dots type of solar cell coating is applied to building external surface, road pavement and if necessary specially designed solar trees. Community's own small-scale nuclear fusion power plant is possible. Solar energy is ample; so far there is no need to tap into fusion energy source.

Another impact from energy production is power distribution system. High voltage transmission lines and towers not only destroy environment but their electromagnetic waves are also potentially harmful to mankind. Developments such as highly advanced solar cells, inexpensive hydrogen fuel cells and micro-generators of electricity will make many of our electronic products and appliances highly mobile. On-demand and on-location power generation will make decentralized power supplies extensive, affordable and environmentally clean.

A MNT photovoltaic solar energy system is shown in Figure 4.

b. Control of pollution from Material Production & Product manufacturing

Civilization based on TDBT tends to overexploit nature resources, generate pollution and waste during material processing and product manufacturing. MNT will render that obsolete. MNT processes will be pollution free, waste free and 100% recycled as raw material; thereby waste and pollution dilemma is controlled. In addition, environmental remediation can proceed by nature and MNT. MNT self-assemblers will manufacture most of the materials. Materials with high performance, unique properties and functions that traditional industrial processes are impossible to create will be produced. In addition, the serviceability of nanomaterial will exceed that of material from nature. Therefore except justifiable harvest for ecological balance, all nature exploitation activities will cease. Usage of petrochemical based material will terminate; environmentally destructive mining will also stop.

Nano photosynthesis can produce sugar, and starch for food; further there can be synthesis of cellulose for paper and wood to avoid clear cutting of forests. Nano biotechnology can yield protein and collagen to stop animal slaughtering. Carbon retrieved from atmosphere and recycled from existing wastes by MNT will be used to make carbon nanotubes, that are far superior than steel. Carbon will be the most common structural and functional element for a MNT based civilization. If there is specific need for metal, nanofactory with trillions of nanoassemblers can synthesize steel, copper and alloy to skip mining and refining. Thereby industrial wastewater, wastes and air pollution will all vanish.
A carbon based MNT material production model is shown in Figure 5.

Highly efficient MNT farming will use no pesticides and herbicides, occupy less land and generate no agricultural waste. Drexler suggested that nanorobots (nanobots) built and maintained high performance greenhouses covering approximately 10% of current farmland could feed the world's population and free-up millions of square miles of land to return to native habitat and thus the great extinction of species will be halted and sustainability assured.

One other essential material for human survival is drinking water. Global population is increasing while fresh water supplies are decreasing. United Nations predicts that by the year 2025, 48 countries will be short of fresh water accounting for 32% of world's population. Ecological recovery by dint of MNT will make raw water for cleaner water supply and in more abundance; however drinking water treatment is still necessary.

TDBT portable water treatment consumes large quantities of chemicals for coagulation, flocculation and disinfection. The process also needs to dam the river and produces chemical sludge that is harmful to the environment. The treated water contains disinfectant residual and in some cases Trihalomethanes (TMH's) that are detrimental to human health. The costly water distribution network not only encroaches on the environment but also provides chances for chemical and biological recontamination.

A series of nanodevices can be made to revolutionise water treatment process. Nanobots like nanoflocculants and nanocoagulants can be devised to neutralize the surface charge of suspended solids. They are non-chemical and 100% reusable. Smart nonfouling nanomembrane or nanoseparator can be developed to selectively separate dissolved solids while keeping beneficial minerals in the water or to desalinate brine water. Nano-disinfectants such as UV nanobots can accomplish germicidal task without leaving toxic residual and producing no THMs. Nanocondenser can be developed to extract water from air. Integrating these nanoprocesses and powered by abundant nano-solar energy, different water treatment systems can be designed to fit specific geographical conditions. Such development will make huge waterworks with messy piping system obsolete. On-demand and on-location generation of drinking water from liquid or vapor will make decentralized water supplies extensive, affordable and environmentally clean.

A MNT's future on-demand and on-location generation of drinking water system is conceptualized as shown in Figure 6.

c. Control of pollution from human consumption MNT

Distributed pollution sources from human consumption cumulatively have contributed significantly to destruction of the environment. Air pollution from living, municipal wastewater and solid wastes are the subjects to the reinvestigated under MNT for novel solutions.

Consumer products and their packaging will be 100% biodegradable or recyclable to terminate solid waste problem. Products that may create pollution during or after consumption will be replaced with environmental friendly nanomaterial. CFC propellants can be replaced by nano-halogen gas; VOC emitting solvents can use nanowater as alternative. TTD is making great strides on this issue, yet with MNT it will become a technological and economical surety. This eventually will stop air pollution originating from our consumption process.

MNT has no means to change the municipal waste water generation, unless lifestyle is altered. Nevertheless MNT can revolutionize waste water treatment. Waste water will be 100% human waste containing no heavy metals and toxic chemicals. Human waste contains organic substances that are resource to nature. Current treatment process uses electricity generated from fossil fuels, no wonder it can not solve the problem to the root. Future MNT waste water treatment will discard the large scale centralized waste water treatment plant philosophy. Decentralized on-site treatment will eliminate the environmental impact from odorous and costly sewage treatment and collection system. MNT can develop smart nanobots to separate water and solids at each household or small community. Separated water can be recycled and further treated as discussed above for drinking water. Extracted solids can be stabilized biologically, if needed with the assistance of nanobots and then consumed as fertilizer or animal feed.

2. Remediation of existing environmental problems

Since 18th century Industrial Revolution till 20th century Information Age we have accumulated a grave environmental liability that results in several potentially harmful problems. MNT now for the first time in human history, offers us capability to payoff accumulated debts and bring back nature to its pristine state. Some of the problems are discussed below:

a. Acid rain and smog

Sulphur dioxide (SO_2) and Nitrogen oxides (NO_X) are the primary causes of acid rain and smog. Acid rain causes acidification of lakes and streams and contributes to damage of forests and forest soils. In addition, it accelerates the decay of building materials and paints including irreplaceable buildings, statues and sculptures that are part of our world cultural heritage. The strength of the effects depends inversely on buffer capacity of the waters and soils involved. While in atmosphere SO_2 and NO_X gases and their derivatives, sulfates, nitrates and ozone contribute to visible degradation of public health.

In addition, future vehicles that will be constructed with nanomaterial, driven by nano electromechanical system and powered by Hydrogen fuel cell or solar cell will totally eliminate transportation related SO_2 and NO_X emission.

Nanobots such as nano-desulfurizer can be sent up to the atmosphere to capture SO_2 gas, reduce it to sulfur and precipitate it to earth's surface as dust; nano-sulfur precipitator contains calcium or magnesium ions and it can be sent up into the sky to oxidize SO_2 and then form $CaSO_4$ or $MgSO_4$ salts. Nanobots like nano-catalytic-converter can also be sent up into the atmosphere to convert NO_X into nitrogen and oxygen. If the agriculture technology still needs fertilizers, nanobots like nano-NO_X-reducer can be sent up to capture NO_X and transform it to ammonia and bring it down to the ground. For ground level treatment, of acidified water bodies and soil, we can disseminate a troop of nano-buffer to increase their buffer capacity in resisting acidity. We can also deploy an army of nano-neutralizers to dynamically adjust pH in water or soil to their original condition, either by capturing H^+ from the environment or giving off OH^- to the environment.

Global warming

The culprit of global warming is the excess greenhouse effect gas-CO_2 that our fuel burning civilization has dumped into the atmosphere. Before The advent of MNT, something like 300 billion tons of excess CO_2 have been added to the atmosphere. Climatologists project that climbing carbon dioxide levels, by trapping solar energy, will partially melt the polar caps, raising sea levels and flooding coasts sometimes in the middle of the next century. Application of MNT to energy production will enable solar power to be generated at an affordable cost. This will eliminate fossil fuel power generation as well as CO_2 emission and thereby relieve the worry of a flooding catastrophe.

MNT will also enable us to develop nanomachines or nanobots such as nano-photosynthesizer, nano-chlorophyll, nano-carbon-fixer etc. Powered by the cheap solar energy, these nanobots not only can be manipulated to extract all the 300 billion tons of excess CO_2 from atmosphere but they can also transform them into valuable materials. The carbon extracted by nanobots can be used in synthesizing functional and structural materials. It can also be extracted by other nanobots and further synthesized into sugar, starch and cellulose to supplement our demand for food, paper etc. (See Figure 5). This can relieve the pressure we exert on farmland and forest. Should there be excess of remaining carbon, we can place it back into the coal seams and oil fields from which it came.

b. Ozone layer depletion

The chief threats to the ozone layer are CFCs and halons. Of the 682 million kilograms of CFCs consumed globally during 1991 32% were for refrigerants, 28% for blowing agents, 20% for cleaning agents and 18% for propellants. Each molecule of chlorine in CFC is capable of degrading over 100000 molecules of ozone before it is removed from the stratosphere or becomes part of an inactive compound.

The relative potency of the different ODS depends on the stability of the reservoir compounds. Bromine reservoirs such as HBr and $BrONO_2$ are 10 to 100 times more effective than chlorine in destroying ozone. The non-reactivity of ODS, so desirable to industry, allows them to drift for years in the environment until they eventually reach the stratosphere. High in the stratosphere, intensive UV solar radiation severs halogens off the ODS and it is these unattached halogens that are able to catalytically convert ozone molecules into oxygen molecules. Different ODS require different time to remove from the stratosphere.

Future MNT mainly will sparingly use water as solvent and can recycle it 100%. Even at this pre-breakthrough stage, ODS refrigerants can be replaced at a higher cost. MNT will help lower that cost to negligible. Therefore the growth rate of ODP in ODS reservoir will become zero. As to the ODS remaining in the reservoir, Drexler proposed using sodium containing balloon type nanobots. The nanobots powered by nano-solar cells collect CFCs and separate out the chlorine in the stratosphere. Combining this with sodium makes sodium chloride. When the sodium is gone, the balloon collapses and falls. Eventually a grain of salt and a biodegradable speck fall to earth. The stratospheric CFC can be removed soon.

Nanobots containing other metals such as calcium and magnesium can also be devised to remove stratospheric CFC. Halogens other than chlorine such as bromine can be neutralized by using the same tactics, that is, by deploying an army of airborne solar energy powered metal containing nanobots into the stratospheric ODS reservoir. Figure 7 is a conceptual idea of how ODS reservoir in the stratosphere can be resolved by solar powered airborne metal nanobots to relieve ozone depletion problem.

c. Toxic wastes and water and soil contamination

Toxic wastes whether collected in piles or in contaminated surface water, ground water or soil concern us because they can harm living systems. Contaminants can be organic or inorganic. Organic contaminants such as PCB, Dioxin etc. actually consist of harmless atoms arranged into noxious molecules. Inorganic contaminants contain toxic elements such as lead, mercury, arsenic and cadmium.

After identifying the chemical properties of the organic contaminants specific nanobots for attacking specific contaminants at their weak points can be devised. An army of these nanobots can then be deployed into contaminated site whether it is in water or soil to render the contaminants harmless by rearranging their atoms. Nanobots can be designed decayable so that no retrieval is needed after mission is completed. They can also be designed reprogrammable so that after each task they can be retrieved and reprogrammed for other cleaning tasks. Inorganic contaminants can also be collected by specifically designed nanobots. Trillions of them can be sent into contaminated water bodies or soil to detect these toxic elements and store them inside. The nanobots are then retrieved from the site, instructed to release toxicants and then made ready for other tasks. Released concentrated metal ions can be rebuilt into rocks in the mines by nanobots or fused to stable form by nanomachine and returned to nature.

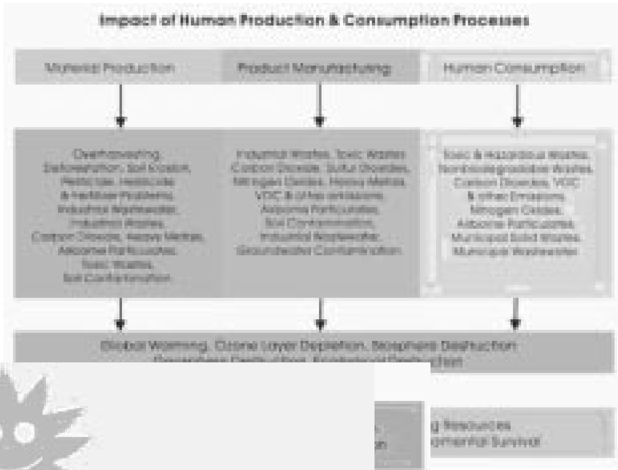
If there is any material additive demand for specific metal ion, they can be used as raw material.

d. Nuclear wastes

MNT cannot treat nuclear wastes and render them harmless directly becauseMNT only works with atoms and molecules and not nuclei. Yet indirectly, by lowering cost of energy and equipment, MNT can offer us means for a clean, permanent solution to untreatable nuclear wastes left over from nuclear era.

Nuclear wastes can be collected, concentrated by specific nanobots. Using Nanomachines we could seal them in self-sealing containers powered by cheap nano-solar energy. These would be more secure than any passive rock or cask. When MNT has developed cheap, reliable spacecraft then the concentrated nuclear wastes can be transported to the moon and bury them in dead, dry rock by nanobots or to other planets that are still radioactive or even shoot them directly into the sun.

Underground nano-atom smasher powered by cheap solar cells can also be devised to treat nuclear wastes. This is a reverse process of nuclear engineering. Instead of smashing non radioactive target and



environmental

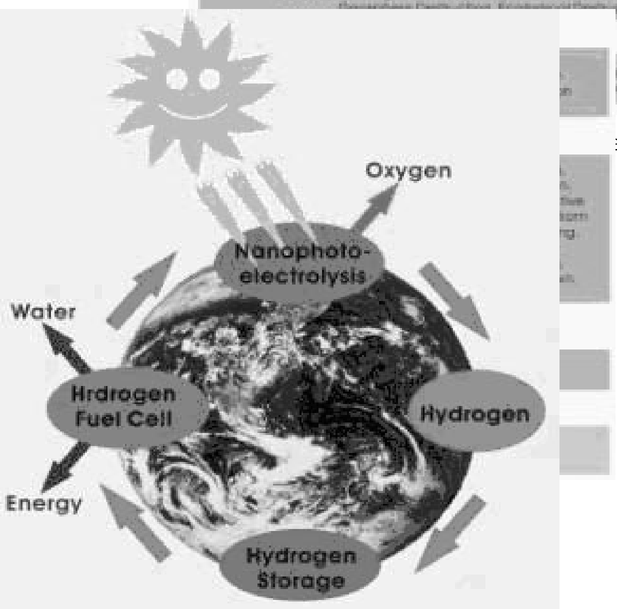


Fig. 2 Environmental impact from major energy production processes

Fig. 3 MNT photoelectrolysis hydrogen fuel energy system

Fig. 4 MNT photovoltaic solar energy system harvesting for radioactive substance, the nanomachine will smash radioactive target and harvest for non radioactive substance. The smashing and harvesting process will continue till stability is achieved. Figure 8 illustrates a few routes for resolving nuclear waste piles that are accumulated in environment and TDBT is at loss on dealing with them.

Other applications of molecular nanotechnology

a.) Enzymatic biocatalysis in reverse micelles.
b.) Multiple emulsion liquid membranes.
c.) Micellar chromatography for analysis of biological samples.
d.) Use of surfactants in soil remediation.
e.) Ocean oil spills containment.
f.) Micellar catalysis for chemical detoxification.
g.) Micro and nanotechnology for pathogen detection from environmental samples.
h.) To prevent, monitor and alleviate a wide range of environmental problems and prevent curb emissions from a wide range of sources while significantly reducing cost and improving performance.
i.) To develop new "green" processing technologies that minimize the generation of undesirable byproduct effluents.
j.) To detect and remove the finest contaminants from air, water and soil which would enhance the ability of governments to respond to terrorist threats and ensure the safety of water supplies.
k.) To attain sustainable development by reducing the use of raw materials.
l.) To design cars that are lighter and more resistant to denting and scratching resulting in fuel saving and increased longer life of vehicles.
m.) To extend the shelf life of food and beverages by creating barrier against water vapor and oxygen.
n.) To save energy through smart insulation and construction materials.
o.) MNT has potential to impart energy efficiency, storage & production.
p.) Nanometerized solar cells would be developed to provide much of energy needed around the world. Nanotechnology would cut cost of solar cells and make solar power economical. It would be cleaner and safer energy.
q.) To produce a nanoparticle reinforced polymeric material that can replace structural metallic components in the auto industry. Use of these nanocomposites could lead to reduction of 1.5 billion of gasoline consumption over the life of one year's fleet of vehicles and reduce CO_2 emission by more than 5 billion kgs annually.
r.) Replacement of carbon black in tires by a nanometer scale particle of organic clays and polymers gives wear resistant tyres.
s.) Developing improved chemical separations using nanoporous materials.
t.) Environment friendly shrink proofing treatment for wool with new keratin degrading enzyme

Fig. 5 MNT Carbon based material production system

Fig. 6 MNT On-demand and On-location generation of drinking water system

Fig. 7 MNT solution to stratospheric ozone depletion substance

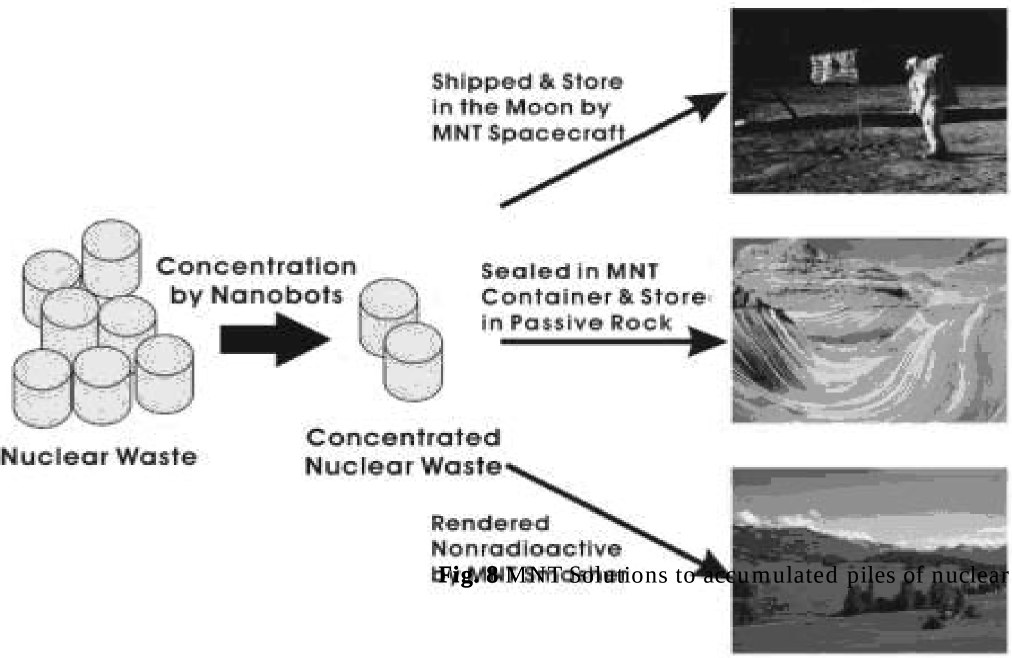


Fig. 8 MNT Solutions to accumulated piles of nuclear wastes on Earth

chemicals or synthetic resins.

u.) Nanosized Iron could help clean the environment. An ultrafine "nanoscale" powder from iron, one of the most abundant metals on earth, is turning out to be remarkably effective tool for cleaning up contaminated soil and ground water.

ogy is used to purify air using nano e-HEPA air purifier systems. e-HEPA is an electronic high efficiency particulate arrest filtration system. The system filters the air to filter particles, eliminate undesirable odours and kill airborne air threats. It uses a metal dust filter that has been coated with 8 nanometer silver particles.

w.) Electrospinning nanofibres can turn waste into new products.

x.) Carbon Nanotube Science and Technology

Carbon nanotubes are fullerene-related structures which consist of graphene cylinders closed at either end with caps containing pentagonal rings. They were discovered in 1991 by the Japanese electron microscopist Sumio Iijima who was studying the material deposited on the cathode during the arc-evaporation synthesis of fullerenes. He found that the central core of the cathodic deposit contained a variety of closed graphitic structures including nanoparticles and nanotubes, of a type which had never previously been observed.

Single-layer nanotubes and nanotube "ropes"

A major event in the development of carbon nanotubes was the synthesis in 1993 of single-layer nanotubes. The standard arc-evaporation method produces only multilayered tubes. It was found that addition of metals such as cobalt to the graphite electrodes resulted in extremely fine tube with single-layer walls. The availability of these structures should enable experimentalists to test some of the theoretical predictions, which have been made about nanotube properties.

An alternative method of preparing single-walled nanotubes was described by Smalley's group in 1996.Like the original method of preparing C60, this involved the laser-vaporization of graphite, and resulted in a high yield of single-walled tubes with unusually uniform diameters. These highly uniform tubes had a greater tendency to form aligned bundles than those prepared using arc-evaporation, and led Smalley to christen the bundles nanotube "ropes". Initial experiments indicated that the rope samples contained a very high proportion of nanotubes with a specific armchair structure.

Nanohorns

Single-walled carbon cones with morphologies similar to those of nanotube caps were prepared. They were produced by high temperature heat treatments of fullerene soot. They could also be produced by laser ablation of graphite, and were given the name "nanohorns". Nanohorns have remarkable adsorptive and catalytic properties and that they can be used as components of a new generation of fuel cells.

CONCLUSION

MNT is powerful and realizable within our lifetime yet it Is a tool. To survive with quality we need a real sustainable environment. MNT has great potential to restore the environment to its original pristine state and ascertain sustainability. However, the development of MNT now is sporadic; much is aimed at further economic growth and less is at environmental sustainability. System integration of MNT is vital for sooner realization of MNT's benefits. Redirecting of some MNT R&D to environmental remediation is essential for true environmental sustainability.

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