

## Identifying Nanotechnology-Based Entrepreneurial Opportunities in Line Withwater-Related Problems

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**Abstract:** Water contamination is the most preventable of the major causes of death in the world and it causes over 2 million deaths yearly and things are getting worse. Water has a broad impact on health, food, energy and economy. Technology is one of important agent for the sustainability of mankind's development. Developing new technology options can help some of the world's most critical problems. Nanotechnology refers to every technology which operates on a nonmetric scale (1-100 nm). Nanotechnology, can change human's social life and solve many environmental problems in the world. Such as water purification and desalination, sustainable energy production and environmental monitoring and remediation. Water-related nanotechnology has the potential to make safe drinking water inexpensive and accessible to developing countries. This paper categorized some entrepreneurial opportunities in line with nanotechnology and water-related problems. Some of these opportunities arise from demand pull for detecting and removing pollutants from water and the others come from technology push. In each category there are several sub-categories of nanomaterials for solving water problems.

**Key words:** Water problems • Water-related nanotechnology • Entrepreneurial opportunities

### INTRODUCTION

Entrepreneurial opportunity is a situation in which a person can exploit or develop a new business idea that has the potential to generate a profit [1]. An entrepreneurial opportunity can be exploited the creation of a new product or services, the opening of a new market, the development of a new way of organizing, the use of a new material, or the introduction of a new production process. One of the most important sources of opportunities is change in external world that generate opportunities. Some examples of this change are technological change, political and regulatory change and social and demographic change [1, 2]. In a free enterprise system, changing circumstances, chaos, confusion, inconsistencies, lags or leads, knowledge and information gaps and a variety of other vacuums in an environment, industry or market spawn opportunities. Entrepreneurial opportunities are situational. High potential opportunities invariably solve an important problem, want, or need that someone is willing to pay for now. Many venture capitalists look for ideas will change the way people live and work or solve the world's problems [3-5].

Changing in technology is one of the most important sources of entrepreneurial opportunities in line with water problems. Technology is one of important agent for the sustainability of mankind's development [6-8]. Technology is, on the other hand, also a key factor of the innovation system and influences prosperity, consumption patterns, lifestyles, social relations and cultural developments. Some changing in technology such as developing new technology options can help some of the world's most critical development and therefore creates entrepreneurial opportunities. New technologies that are based on fundamental biological, physical or chemical mechanisms, such as gene modification or physical manipulations on the nano-scale (1-100 nm) which called nanotechnology, can shape social life [8-9]. Global development in this era is not sustainable over the long term. Every major ecosystem is under threat at different timescales, impacting water, food, energy, biodiversity and mineral resources—all exacerbated by the population growth and climate change. These changes also are sources of entrepreneurial opportunities. One of the remarkable solutions for these changes and threats is applying nanotechnology to solve some environmental problems such as water-related problems.

Ensuring the availability of clean, abundant fresh water for human use is among the most pressing issues facing the world. Clean water is a necessity of life, not just for humans, but for every ecosystem on earth. Unfortunately, it is not a readily accessible resource everywhere.

Worldwide, over one billion people lack reliable access to clean water and 2.3 billion people or 41 percent of the global population live in water-stressed areas, a number that will increase 52 percent by 2025 and things are getting worse.

Water bodies are threatened with alarming levels of contamination. The type of contaminants varies from industrial solvents (e.g., chlorophenol) to electronic waste (e.g., heavy metals) [12].

Nanotechnology is a key technology for the 21<sup>st</sup> century that will contribute to economic prosperity and sustainable development by a broad alliance of policy-makers, scientists and industry representatives. Nanotechnology is one of the newest and useful technologies which can change social life. In nanotechnology, new materials, products and services have developed in a wide range of applications, striving for high benefits [13].

Nanotechnology isn't a discreet industry sector – but a range of techniques used to manipulate matter at the nano-scale – where size is measured in billionths of meters. A nanometer (nm) equals one billionth of a meter. It takes ten atoms of hydrogen side-by-side to equal one nanometer. Nanotechnology is the study of the controlling of matter on an atomic and molecular scale. Generally nanotechnology deals with structures of the size 100 nanometers or smaller in at least one dimension and involves developing materials or devices within that size. Nanomaterials or nanoparticles have unusual properties not found in compounds made through traditional chemical processes. These unusual properties of nanomaterials make them useful for some applications such as environmental problems. Nanotechnology can be treatment and remediation tools of benefit for the long-term sustainability of air, water and soil resources. Nanotechnology has main role in sustainable development by some applications such as water purification and desalination, sustainable energy production and environmental monitoring and remediation. Nanotechnology could affect on food industries by different ways such as change packaging materials coated with nanoparticles that will allow food to be stored longer [12, 14, 15].

Nowadays many parts of the world will be facing water crisis. When the world population grows and climate change water crisis become increasingly worse. 30 percent of the available freshwater resources will decrease over the next 20 year [16-18]. Water covers 70 percent of the earth's surface but only 2.5 percent of it, is fresh water [16, 19]. Approximately 1.8 million people die each year from diarrheal diseases and millions more suffer from water-related illnesses due to lack of access to clean water and proper sanitation [20]. So access to clean water is a critical issue that governments are investing on it [19].

Nanotechnology has been used to solve water-related problems, to increase the sensitivity of detection of various water toxic contaminants and remediate contaminated water. Over the next 10-15 years the applications of nanotechnology for solving water-related is expected to become a significant industry [21]. This study gives an overview of the use of nanotechnology to solve water related problems. Based on the applications of nanotechnology for detection of water contaminants and also for removing them from water we have identified entrepreneurial opportunities of nanotechnology in line with water-related problems. We have highlighted recent advances on the development of novel nanoscale materials and processes for treatment of surface water, groundwater and industrial wastewater contaminated by toxic metal ions, radionuclides, organic and inorganic solutes, bacteria and viruses. Finally, we have categorized entrepreneurial opportunities for detection and removing pollutants from water.

## **MATERIALS AND METHODS**

Research method is qualitative; include documents content analysis. Data for this study were collected from two sources. The first source of data is water-related problems which can be solved by nanotechnology. These needs can be created some entrepreneurial opportunities. The driver of these opportunities is demand pull. These data was collected through many secondary sources such as water treatment literature and foresight studies. The second source of data is searching literature of nanotechnology to investigate nanotechnology applications for solving water-related problems. Some opportunities can be created from these applications. These entrepreneurial opportunities are technology push. Finally, collected data analyzed and identified entrepreneurial applications categorized into three main categories.

## RESULTS AND DISCUSSION

Entrepreneurial opportunity is a situation in which a person can exploit or develop a new business idea that has the potential to generate a profit. Entrepreneurs can actually develop business ideas to take advantage of emerging opportunities in five different ways: (1) they can develop new products and services; (2) they can develop or tap new markets; (3) formulate new methods of production; (4) identify new raw materials; and (5) develop new ways of organizing business processes [21]. These modes of developments are forms of the opportunities and they are independent of source of opportunity. Source of opportunities are the origins of new ventures and they generally arise from two major sources. The first view, initially proposed by Kirzner, is the information people have that helps them to recognize new business opportunities. In the second view, proposed by Schumpeter, changes in the external world generate opportunities. The changes are technological changes, political and regulatory changes and social and demographic changes. Technological change is a key source of opportunities and it is the most important source of valuable entrepreneurial opportunities. Nanotechnology development is a technological change. In line with water related problems, this technological change can generate valuable entrepreneurial opportunities for solving water problems in the world. These opportunities are technology push. The core of the science and technology-push argument is that advances in scientific understanding determine the rate and direction of innovation. Nanotechnology promises to dramatically enhance many water purification technologies such as adsorption, ion exchange, oxidation, reduction, filtration, membranes and disinfection processes [22]. These technologies create some opportunities which will be discussed in this paper.

Another important source of entrepreneurial opportunities is societal changes, such as those about environmental quality. In addressing these opportunities governments must choose from a formidable array of possible policy actions that have the potential to stimulate innovation. One principle guiding these decisions, sometimes referred to as “demand-pull,” is that policy can induce investment—and consequent improvements—in technologies by enlarging markets for them [23]. Changes in market conditions create opportunities for firms to invest in innovation to satisfy unmet needs. Demand “steers” firms to work on certain problems [24]. Environmental changes such as water

related problems alter demand for products and services to solve those problems. Also environmental changes make it possible to generate solutions to customer needs that are more productive than those currently available. Thus, environmental changes are a source of entrepreneurial opportunity [1].

There are different forms of nanotechnology-based entrepreneurial opportunities in line with water related problems. Some opportunities arise from nanotechnology development (technological change) and others are nanotechnology-based entrepreneurial opportunities for detection and removing pollutants from water. Figure 1 shows these opportunities in two main categories. In each category there are several sub-categories of nanomaterials for solving the water problems. Before discussing about these opportunities we discuss about applications of nanomaterials for detection of water pollutants and removing pollutants. After that we categorize nanotechnology-based opportunities in line with water problems.

### **Nanomaterials for Detection of Water Pollutants:**

Environmental monitoring of pollutants present in the atmosphere, in soils and in wastewater is necessary. For this purpose different categories of sensors are used such as biosensors, electrochemical sensors and optical sensors. The nano-detection sensors and devices will be the main instruments for trace heavy metals and permanent organic pollutants (POPs). The performance and sensitivity of biosensors can be improved by using nanomaterials for their construction [24]. There are some opportunities for commercialization of nanosensors. In this section we review some examples of the different developments of nano-sensing for water pollutants in which opportunities arise from nano-technological developments in sensing domain. Some categories of environmental nanosensors are (1) nanoparticle-based optical sensors, (2) nanoparticle-based electrochemical sensors and (3) magnetic-relaxation sensors [25].

**Nanoparticle-Based Optical Sensors:** Optical sensors have been developed for the detection of toxins, heavy metals and other environmental pollutants. Among the nanoparticles, gold nanoparticles and quantum dots are commonly used as optical sensors, because of their color and fluorescence properties. Other optical sensors are based on photoluminescence changes of quantum dots (QDs) or dyes. Optical sensors have an important role in detecting environmental pollutants due to typically high signal-to-noise ratios [25].

Environmental contamination by heavy metal ions is an ongoing concern throughout the world. Heavy metal pollutants can exert serious adverse effects on the environment and also on human health. Thus, monitoring of aqueous heavy metal ions in environment becomes more and more important. Gold nanoparticle-based sensor can be used for rapid, easy and reliable screening of  $Hg^{2+}$  ions and  $Cu^{2+}$  in aqueous solutions, with high sensitivity [26-28].

#### **Nanoparticle-Based Electrochemical Sensors:**

Electrochemical sensors have been widely investigated for use in environmental pollutants screens. Single-walled carbon nanotubes (SWNTs) impregnating porous fibrous materials such as fabrics and papers have been used to generate simple but high-performance biosensors. Zhang *et al.* generated a sensitive electrochemical immunosensor by functionalizing single-walled carbon nano horns with an analyte for detecting MC-LR in Tai lake water [24, 25].

**Magnetic-Relaxation Sensors:** MRS technology has been used to detect analytes in different matrices, including in environmental toxin monitoring. The magnetic sensors are expected to be able to identify and quantify bacteria in environmental samples. Ma *et al.* [30] developed stable and sensitive MC-LR-residue immune sensors based on the relaxation of magnetic nanoparticles [30].

Other methods for sensing contaminants in water are surface-enhanced Raman scattering technique for detecting analytes; surface plasmon resonance (SPR) technique for detection of permanent organic pollutants and heavy metals; and fluorescence detection method. The fluorescence detection method has been used in the detection of pollutants in water such as heavy metals by quantum dots. A novel nano-TiO<sub>2</sub> polymer modified based sensor can be used for major cations, such as  $Ca^{2+}$ ,  $Zn^{2+}$ ,  $Co^{2+}$ ,  $Pb^{2+}$ ,  $Mn^{2+}$  and  $Cd^{2+}$  [24].

Carbon nanotubes (CNTs) are useful for electronic detection of biomolecules. The surface of the CNTs can be functionalized with appropriate chemical groups for attaching desired biomolecules (nucleic acids, enzymes, carbohydrates) or enhancing the solubility or biocompatibility of the tubes. CNT-based sensors could find effective use in detection and control of viral diseases, in human and animal populations and in the environment (food, water and air).

Nanowires also allow real time detection of single virus particle with high selectivity. A single nanowire requires relatively high virus concentration to overcome the probability of the virus attaching to the sensor with

small surface area. The conductance change was proportional to the viral concentration and the system required no purification of the sample. Another advantage of these nanowire based devices is the detection of multiple analyte simultaneously in a single detection platform [31].

#### **Nanomaterials for Removing Water Pollutants**

**Sorbent Nanomaterials:** Large surface area to volume ratio properties causes nanomaterials act as sorbents. Superior sorbents with high, irreversible adsorption capacity (e.g., nano-magnetite to remove arsenic and other heavy metals) and reactants (NZVI) are some examples of these nanomaterials [22]. Sorbents are widely used as separation media in water purification to remove inorganic and organic pollutants from contaminated water. Nanoparticles have two key properties that make them particularly attractive as sorbents. On a mass basis, they have much larger surface areas than bulk particles. Nanoparticles can also be functionalized with various chemical groups to increase their affinity towards target compounds. Some nanomaterials and nanoparticle can play this role will be discussed as follow.

**Multiwall Carbon Nanotube:** Multiwall carbon nanotubes (MWCNTs) are applied to adsorb metal-ions such as  $Pb(II)$ ,  $Cu(II)$  and  $Cd(II)$  [32]. The metal-ion sorption capacities of the MWCNTs were 3–4 times larger than those of powder activated carbon and granular activated carbon, two commonly used sorbents in water purification.

**Chitosan Nanoparticles:** Chitosan nanoparticles (40–100 nm) prepared by ionic gelation of chitosan and tripolyphosphate are used to removing  $Pb(II)$  ion from water [31].

**Cerium Oxide Nanoparticles Supported on Carbon Nanotubes (CeO<sub>2</sub>-CNTs):** Cerium oxide nanoparticles supported on carbon nanotubes (CeO<sub>2</sub>-CNTs) have been shown are very good sorbents for arsenic [33].

**Akaganeite [b-FeO(OH)] Nanocrystals:** These nanocrystals are good sorbents for removing arsenic from water [34]. Nanocrystalline akaganeite is also an effective sorbent for Cr (VI) [35].

**Nano Zeolites:** nano-zeolites are effective sorbents and ion-exchange media for metal ions such as  $Cr(III)$ ,  $Ni(II)$ ,  $Zn(II)$ ,  $Cu(II)$  and  $Cd(II)$  from metal electroplating wastewaters [36].

**Nanoporous Ceramic Oxides:** Nanoporous ceramic oxides can be functionalized to increase their selectivity toward target pollutants such as toxic metal ions [37], anions [38] and radionuclides [39, 40].

**Nanoporous Activated Carbon Fibers (ACFs):** Nanoporous fibers can be used to absorb some pollutants such as benzene, toluene, pxyleneandethylbenzene [42].

**Fullerenes:** Polycyclic aromatic compounds (PAHs) such as naphthalene can be removed by fullerenes [43].

**Amphiphilic Polyurethane Nanoparticles:** These nanoparticles can remove aromatic compounds such as naphthalene and increase their bioavailability in aqueous solutions [44, 45].

**Catalytic Nanomaterials:** The nanostructured photocatalysts showed very fast photocatalytic degradation rates in organics, bacteria, spores and virus and thus have great potential in water disinfection and removal of organic contaminants in water [22].

**TiO<sub>2</sub> Based Photocatalyst:** Organic pollutants can be removed by TiO<sub>2</sub> based photocatalyst. Nowadays, nano-TiO<sub>2</sub> has emerged as promising photocatalysts for water purification. The removal of total organic carbon from waters contaminated with organic wastes was greatly enhanced by the addition of TiO<sub>2</sub> nanoparticles and nanostructures, such as mesoporous hollow spheres, nanowire arrays, dendric nanostructures, etc. in the presence of ultraviolet light. Nano-TiO<sub>2</sub> photocatalysts are promising for their application in the development of self-cleaning sensors and membranes. Mesoporous TiO<sub>2</sub> materials exhibit significantly enhanced organic adsorption capacity and photocatalytic activity. TiO<sub>2</sub> photocatalytic membranes have an additional function–separation of organic molecules [46-49].

**Ion Exchange Process for Water Purification by Nanomaterials:** Electrically switched ion exchange (ESIX) technology combines ion exchange and electrochemistry to provide a selective, reversible method for the removal of target species from wastewater. This technique is based on conducting polymer/carbon nanotube (CNT) nanocomposites as a new and cost-effective approach for the removal of radioactive cesium, chromate and perchlorate from contaminated groundwater.

It is a novel technique that combines both the principles of electrochemistry and ion exchange for the removal of toxic ions from waste effluents. This technology utilizes the redox reaction of electrically conductive material to regulate the uptake or elution of various ions to/from and into aqueous solution to maintain charge neutrality. By modulating the potential and time of the ESIX material, selective ion exchange of various cations or anions can be achieved.

The efficiency of these ESIX systems can be significantly improved through nanotechnology by providing better electrochemical stability and a larger contact area with wastewater. Therefore, the combination of novel electroactive ion exchange material with nanotechnology will lead to the development of more efficient and economic wastewater treatment systems based on ESIX technology [43, 52-55].

**Disinfection Nanomaterials:** Various oligodynamic metals exhibit microbicidal, bactericidal and viricidal properties; however, reducing the size of the metals to the nanoscale produces tremendous advantages in disinfection capacity due to the greater surface area, contact efficiency and often better elution properties. There are some nanomaterials for disinfection of water. These nanomaterials include silver nanoparticles, copper nanoparticles, zinc nanoparticles, titanium nanoparticles and cobalt nanoparticles. These metallic nanoparticles are expected to play an important role in the future of water purification because of their high reactivity resulting from their large surface-to-volume ratios. This new class of nanoparticles produces antimicrobial action referred to as oligodynamic disinfection for their ability to inactivate microorganisms at low concentrations.

Such materials as Ag deposited on titanium oxide and Ag-coated iron oxide had displayed faster kinetics and greater efficiency in eliminating bacteria [54-56].

**Pesticides Removing from Water by Nanomaterials:** Water derived from groundwater sources is contaminated with pesticides in many parts of the world. Many pesticides contain highly toxic recalcitrant groups and hence are extremely difficult to break through natural or synthetic degradation routes. Many of the organic pesticides are highly stable in the environment and highly insoluble in water. For most common pesticides such as chlorpyrifos, malathion and DDT, applied concentrations are very large and solubility fairly low. Nanotechnology will offer the most energy efficient and clean filtration

mechanism. Understanding molecular transport in cells and the roles of molecules and molecular materials can help us design energy efficient water filtration technologies. Contaminants such as pesticides can be removed through homogeneous or heterogeneous chemistry.

**Using Nanomaterials in Homogeneous Chemistry for Removing Pesticides:** In the homogeneous process, the molecules of relevance are degraded by the nanoparticles dispersed in the solution phase. This methodology is attractive because it utilizes all the available surface area offered by nanoparticles. However, a major issue of concern is the possible presence of nanoparticles and thereby the contaminants in the purified water. This is important as the dispersed nanoparticles cannot be easily separated [57].

**Using Nanomaterials in Heterogeneous Chemistry for Removing Pesticides:** Heterogeneous chemistry utilizes supported nanoparticles. Here, highly dispersed nanoparticles on supports such as oxides, polymers, fibers and so on are used and water is passed through such media. The binding between the particle and the support is strong enough to avoid leaching of the particles into water. Additionally with decrease in the particle size, metal particles gradually become unstable without protecting agents, due to increasing surface energy. Consequently, immobilization of metal nanoparticles on a suitable high-surface area solid helps in avoiding agglomeration, even though it leads to changes in the properties and behavior of the isolated particles [57]. Some methods for attaching nanoparticles on supports include impregnation, ion-exchange, Co-precipitation, deposition-Precipitation, vapor-Phase deposition and grafting [58, 59].

There are numerous variety of nanomaterials used for environmental detoxification such as nanometals, nanooxides and nanoclays.

**Nanometals:** The most important materials studied in this regard are zerovalent iron (ZVI), which is known to degrade a diverse variety of toxic molecules. Due to the low cost and easy production, ZVI is an industrially feasible remediation methodology. The attractiveness of nanometals arises from the dramatic increase in their specific surface area (owing to small particle size) and increase in the surface energies that helps in the generation of electrons and their consequent transfer to

organic species. The other category of nanomaterials is noble metals several other metals such as copper, zinc and tin have also been successfully tested for decomposition of chlorinated hydrocarbons [60].

**Nanooxides:** The common oxide materials of industrial relevance are nano-TiO<sub>2</sub> and nano-ZnO both of which are semiconducting oxides. These have been used to decompose a broad range of pesticides, organic dyes and industrial solvents by photo-catalysis. TiO<sub>2</sub>, in its bulk and nano forms, is one of the most researched materials for photo-catalytic activity because of its stability under harsh conditions, low solubility in water, possibility of investigation using both fixed-bed and suspension forms and commercial availability. Significant research attempts have been made to understand the factors affecting the photo-catalytic activity of TiO<sub>2</sub> [60].

**Nanoclays:** Clay is one of the naturally occurring materials that has been utilized by nature for maintaining flow of groundwater (due to a relatively high impermeability to water), removing toxic species present in the water (due to the presence of a surface charge on the clay structure) and imparting rigidity to natural structures (due to natural plasticity behavior). Clays are aluminosilicates with a planar silicate structure. There are three main categories of clay: kaolinite, montmorillonite-smectite and illite.

There are many approaches for increasing the adsorption of a specific molecule for example, to increase the adsorption of organic species, the inorganic cations are replaced by quaternary ammonium cationic surfactants (containing long chain alkyl group to make it more organophilic). Similarly, depending on the nature of charge on clay layer, metal cations (e.g., lead, arsenic, cadmium etc.) can be picked from the water [60].

**Dendrimers:** Dendrimers represent a novel category of polymeric molecules with multiple functionalities. They can be utilized in two ways: as a stabilizer to metal nanoparticles and as a contaminant-specific functionalized group on a nanoparticle surface. The two most commonly used dendrimers are polyamidoamine (PAMAM) dendrimers and poly propylene imine dendrimers. The terminal functional group of dendrimers can easily be utilized for engineering the interaction between molecules of interest with dendrimers, for example, long aliphatic chains can be activated on dendrimer surfaces so as to render the dendrimers

lipophilic, without affecting the binding properties of organic species with dendritic macromolecules. Similarly, the dielectric gradient between the core and the surface (owing to presence of different reacting species) can be tuned for the encapsulation of the incoming guest molecule. Similarly, the target molecules can be engulfed in the cavity of the dendrimer by providing appropriate molecular functionality within the cavity. These kinds of approaches have not been developed for pesticide molecules but interesting possibilities have been shown using metal ions and nanoparticles [60].

**Nanotechnology-based Membrane Technology for Purification of Water:** Membrane-based water purification processes are now among the most important technologies for conventional drinking water production, wastewater treatment, ultra-pure water production, desalination and water reuse. Commercially available membrane processes for water purification include electro dialysis (ED), electro-deionization (EDI), reverse osmosis (RO), nanofiltration, ultra filtration and microfiltration (MF). Intrinsic advantages of membrane processes include continuous, chemical-free operation, low energy consumption, easy scale-up and hybridization with other processes, high process-intensity (i.e., small land area per unit volume of water processed) and highly automated process control. General disadvantages of membrane processes are short membrane lifetime, limited chemical selectivity, concentration polarization and membrane fouling [61].

Three emerging nanotechnology-based membrane material concepts intended for use in water purification: (1) inorganic-organic nanocomposite membranes, (2) hybrid protein-polymer biomimetic membranes and (3) aligned-carbon nanotube membranes.

**Inorganic-Organic Nanocomposite Membranes:** nanocomposites such as hybrid protein-polymer biomimetic membranes and aligned-carbon nanotube membrane may produce membranes with advanced functionality to improve fouling resistance and pollutant removal.

The unique geometry and internal structure of carbon nanotubes (CNTs) give rise to newly discovered phenomena of the ultra-efficient transport of water through these ultra-narrow molecular pipes. Water transport in nanometer-size nanotube pores is orders of magnitude faster than transport in other pores of comparable size. Carbon nanotube (CNT) membranes are promising candidates for one such solution primarily

because of their transport characteristics. The inner cavity of a CNT forms a natural pore with very small diameter that can in some instances be smaller than 1 nm. Moreover, smooth hydrophobic surfaces of the nanotubes lead to nearly frictionless flow of water through them, enabling transport rates that are orders of magnitude higher than transport in conventional pores. Finally, the structure of CNTs permits targeted specific modifications of the pore entrance without destroying the unique properties of the inner nanotube surface. The combination of these three factors could enable a new generation of membranes whose transport efficiency, rejection properties and lifetimes drastically exceed those of the current membranes. Nearly frictionless graphitic walls of CNT composite membranes offer the unique combination of extremely fast flow and very small pore size, which potentially give them tremendous advantages over traditional membrane materials for energy-efficient, low-cost ultrafiltration and nanofiltration applications [62, 63]. There are two groups of carbon nanotube membrane: Polymeric/CNT Membranes [62] and silicon nitride CNT membranes [64, 65]. Some functions of CNT membranes in solving water-related problems are: Ion Exclusion in Carbon Nanotube Membranes [66-69] and altering transport selectivity by membrane functionalization [63, 70, 71].

#### **Nanotechnology-Based Entrepreneurial Opportunities**

**Analysis:** There are different forms of entrepreneurial opportunities that result from technological change and environmental change (two sources of opportunities) in line with water related problems. Tables 1 to 4 show examples of the different ways in which entrepreneurial opportunities arising from nanotechnology development as a technological change in line with water-related problems. Tables 1 to 4 also illustrate the fact that any given opportunity can be developed in one of several different ways: through development of a new product or services, tapping into a new market, a new method of production, new raw material and so on. Tables 1 to 3 show entrepreneurial opportunities in line with detection of pollutants and contaminants in water. Table 1 illustrates opportunities for production of nanoparticle-based optical sensors. Table 2 illustrates opportunities for production of nanoparticle-based electrochemical sensors. Table 3 illustrates opportunities for production of magnetic relaxation sensors.

Table 5 shows examples of different ways in which opportunities arising from societal changes such as environmental changes due to water pollution or creating threats for human health by entering pollutants into water.

Table 1: Examples of different forms of entrepreneurial opportunities that result from optical nanosensor development in line with detection of pollutants

Nanosensor development (source of the opportunity)	Water contaminant	Form of the opportunity
Nanoparticle- based optical sensors	Toxin	New product
	Heavy metals	New service
Gold nanoparticles-based sensor	Mercury ( $Hg^{2+}$ ion), $Cu^{2+}$	New product
Quantum dots-based sensor		New service
Photoluminescence sensor	$Hg^{2+}$ , $Cu^{2+}$	
Nanoparticle-based sensor(GNP)	$H_2$ , $CO_2$ , $NO$ , $O_2$ , Ammonium ions	
Cysteine-modified GNP-based label free enhanced Raman spectroscopy probe	Trinitrotoluene (TNT)	New product
Gold nanoparticle Optical sensors	Bacteria	New service
		New product
		New service

Table 2: Examples of different forms of entrepreneurial opportunities that result from electrochemical nanosensor development in line with detection of pollutants

Water contaminant (opportunity source)	Sensor (solution for problem)	Form of Opportunity
Copper Ion	Gold nano particle- based electrochemical sensor	New product
		New service
Microcystin-LR (MCLR)	Single wall carbon nanotube based sensor	New product
		New service
MC-LR	Functionalized single wall carbon nano-horns	New product
		New service
Toxin and hazard components	Nanoparticle-based electrochemical sensors	New product
		New service

Table 3: Examples of different forms of entrepreneurial opportunities that result from magnetic relaxation sensor development in line with detection of pollutants

Water pollutants (source of the opportunity)	Detection method (magnetic nanosensor)	Form of opportunity
bacteria	MRS Sensor:	New product
	Biocompatible magnetic nanoparticle act as magnetic relaxation switches (MRS)	New service
MC-LR	MNP sensor	New product
		New service

Table 4: Examples of different forms of entrepreneurial opportunities that result from nanotechnology development (technological change) in line with water related problems

Nanotechnology (nanomaterials) development (source of the opportunity)	Form of the opportunity (How it was developed)	Example of product/business idea in response to the opportunity
Chitosan nanoparticles	New product or services	Personal care products, microbicide in agriculture and biomedical products, Food wraps, biomedical, flocculants in water and waste water treatments
Chitosan nanoparticles	New methods or process	Biosorbents Immobilizer of bacteria, enzymes and other biological molecules
Silver nanopowder	New product or service	Portable water filters, clothing, medical devices,
Silver nanopowder	New methods of production	coating for washing machines, refrigerators and food containers
$TiO_2$ nanoparticles	New product or service	Air purifiers, water treatment systems for organic contaminant degradation Solar and UV disinfection of water and wastewater, reactive membranes, biofouling-resistant surfaces
Carbon nanotubes	New product or service	Biofouling-resistant membranes, carbon hollow fibers, packed bed fillers
ZnO nanomaterials	New product or service	Antibacterial ceramics, lotion and ointment, deodorant, self-cleaning glass and ceramics
Surface coating, mouthwash		



Table 5: Examples of different forms of nanotechnology-based entrepreneurial opportunities that result from entering pollutants into water

Entering pollutants into water (source of the opportunity)	Form of the opportunity (nanotechnology based)	Example of business idea in response to the opportunity
Pesticides: Chlorpyrifos, malathion, DDT	New product and service New method and	Nano-based TiO <sub>2</sub> as hypercatalyst Fullerene based photocatalyst Pd/Au catalyst for reduction processes process Zero valent iron nanoparticles Copper, zinc, tin nanoparticles
Organic dyes	New product	Nanooxides: nano-TiO <sub>2</sub> , nano-ZnO by
Industrial solvents	New method and process	photocatalysis
Arsenic, lead, cadmium	New product New method and process	Nanoclays, CeO <sub>2</sub> CNT, Akaganeite
Heavy metals	New product New method and process	Nanomagnetite Adsorption of heavy metals from water using self assembled ligands that form a nanocoating Nano zeolite
Microbial disinfections	New product New method and process	Enhanced solar and UV disinfection by TiO <sub>2</sub> derivatize fullerenes
Viruses	New service New method and process	Fouling-resistant (self-cleaning) multi-functional filtration membranes that inactive viruses
Organic contaminant	New product New method and process	Nano-based membranes
Benzene, toluene, pxylene, ethylbenzene	New product New method and process	Nanoporous activated carbon fibers
Polycyclic aromatic compounds (naphthalene)	New product New method and process	Fullerene Amphiphilic polyurethane nanoparticles

## CONCLUSION

In this paper, we identified some applications of nanotechnology in detection and removal of pollutants from water. We categorize Environmental Nano sensors for detection of pollutants in water, including nanoparticle-based optical sensors, nanoparticle-based electrochemical sensors and magnetic-relaxation sensors. Then we nominate Types of nanomaterial for removing water pollutants, including Sorbent nanomaterials, Catalytic nanomaterials, Ion exchange process for water purification by nanomaterials, Disinfection nanomaterials, Pesticides removing from water by nanomaterials, Nanotechnology-based membrane technology for purification of water.

Also we recognize two entrepreneurial opportunities according to these applications. The firstentrepreneurial opportunities come from nanotechnology development (technology push) and thesecondarise form detecting pollutants in waterand removing pollutant from water (demand pull).

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