Access to Safe Water for the Bottom of Pyramid : Strategies for Disseminating Technology Research Benefits

Secondary Research Report

Submitted by

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Executive Summary

One in eight people in the world today lack access to clean drinking water. A child dies every 15 seconds from a lack of clean water. One in four children who die before age five worldwide, die of a water related disease. Most people without access to clean water live right above it. In many cases the only thing preventing access to clean water is money[1]. Access to clean water is the foundation of development. Food, health, hygiene, habitat, education, employability, productivity are all dependent upon access to water. Without clean water, none of these is possible and poverty is inevitable. Majority of these people are in the developing world.

Over the years, India has made improvements to both the availability and quality of municipal drinking water systems. However the exponentially growing population has stressed existing water systems and resources. The pressures of urbanization have stretched government solutions. Rural areas are still left out. Many water sources are contaminated with both bio and chemical pollutants, and over 21% of the country's diseases are water-related.

The Department for International Development (DFID) leads the UK Government's fight against global poverty. To take this agenda forward DFID is establishing a research programme to help engage with those new and emerging technologies with the potential to impact on poverty in a way that enables developing countries to take advantage of what they have to offer. Through this research, Technology and Action for Rural Advancement (TARA) seeks to identify key challenges and barriers that may reduce the impact of technologies such as Nanotechnologies for providing clean drinking water reaching the underprivileged in developing countries, its possible environmental implications and remedial measures.

Nanotechnology has introduced a new generation of water filters and purification systems. Research on Carbon nanofiltration membranes and nano catalysts like iron, silver and titanium dioxide for water treatment applications is a fast growing field. Universities like Stanford, Aberdeen, Rice, etc. as well as their Indian counterparts like the Indian Institutes of Technology, Benares Hindu University, Indian Institute of Science etc. are actively involved in nanotechnology research focused on the water technology. Some technologies have recently also been introduced in the market by companies like Eureka Forbes Limited, TATA Chemicals, etc. for point of use application.

1 The Water Project

This report is a secondary review of available technologies in the laboratory and the market. It is structured in three chapters. Chapter 1 offers a background to the study, focusing on current water issues globally and nationally. It also throws light on the reasons and approach for this study. Chapter 2 presents an overview on Nanotechnology, especially the role of nanotechnologies in the water sector. Prominent research from around the world is featured in the chapter. Specifically for India, it draws attention to research agencies that have initiated nano research. Also highlighted are nanotechnologies marketed in India in the water purification sector. The overview sheds light on the present market scene for nanotechnology. Policy issues and health and environmental impacts of nanotechnologies in the water sector, though little understood as of date, are mentioned. This is an area that requires further work.

Chapter 3 presents the way forward in the research study. This report is derived from scanning and mapping of the current scenario. Further the study involves consultations and primary surveys to identify potential technologies and partners.

The aim of this report is to develop and provide a basic understanding of the current research and market scenario with respect to nanotechnologies in the water sector.

We sincerely hope that this review has been able to place us on a sound footing from where to start the consultation process which will help us in achieving the aim of the project.

Background to the Study

Only 2.53 % of earth's water is fresh, and some two-thirds of that is locked up in glaciers and permanent snow cover. Nearly one billion people - one in eight persons in the world - lack access to safe water supply. Over 3.5 million people die each year from water-related disease; 84 % are children. 98 % occur in the developing world. Sixty five million people are at risk of arsenic poisoning in the Bangladesh, India and Nepal area. The water and sanitation crisis claims more lives through disease than any war claims through guns[2].

Indian government surveys reveal that only 30 % of the rural population had access to safe drinking (tap) water in the country. 55 % depend on tube well or hand pumps to meet their drinking water requirement. 15 % of rural populations were still looking for a dependable source of water. In urban areas, 74 % depend on tap water and 18 % on tube well/hand pump[3].

Despite the very real danger of future global water shortages, today's water crisis is not an issue of scarcity, but of access[4]. Poor people living in the slums often pay five to ten times more per liter of water than wealthy people living in the same city[5]. However investment in safe drinking water and sanitation can contribute to economic growth. For each $1 invested, the World Health Organization (WHO) estimates returns of $3 – $34, depending on the region and technology[6].

Altogether the cost of environmental damage is estimated to be $9.7 billion per year, of which the most vital is the health impacts of water pollution accounting for 59% of the total value of degradation[7]. Waterborne diseases (the consequence of a combination of lack of clean water supply and inadequate sanitation) cost the Indian economy 73 million working days a year[8]. Water quality is a major problem in both ground and surface water. Although in their upper reaches most rivers are of good quality, the middle and lower reaches of almost all rivers face major degradation. Some of the key pollutants and their sources are summarized below.[9]

- **Microbial contamination (faecal)** mainly arises from inadequately treated or untreated sewage. Lack of sanitation and sewage treatment facilities is the main cause for this.

2 2006 United Nations Human Development Report.

3 National Sample Survey Office (NSSO) study on Housing Condition and Amenities in India, 2008-09.

4 One Billion Affected, Water.Org

5 2006 United Nations Human Development Report.

6 United Nations World Water Development Report, "Water in a Changing World"

7 Brandon, Carter, and Homman K. 1996. The cost of Inaction. Valuing the Economy-wide Loss of environmental Degradation in India, Washington: World Bank.

8 WaterAid

9 The Energy and Resources Institute (TERI). 2009 , Nanotechnology developments in India – a status report

- **Heavy metal** contaminated waste water from industrial activities such as electroplating, textile dyeing; tanneries etc reach the surface or ground water sources if it's inadequately treated. In addition leaching from solid waste dumps (e.g. fly ash ponds, sludge from above industries) also contributes towards heavy metal accumulation.
- **High salinity** arises from decreasing groundwater levels and seawater intrusion. This is also aggravated by agricultural run offs, which are rich in salts.
- **Arsenic, fluoride, and nitrate** contaminants enter groundwater aquifers from their presence in the sediments of the region. This has been further aggravated by excessive groundwater withdrawals.
- **Micropollutants** include **pesticides, endocrine disrupting substances,** and **surfactants.** These arise from agricultural run offs and from sewage.

Water that does not meet drinking water standards should be treated to ensure that the health of the consumer or community is not compromised through exposure to toxic pollutants. Water supply systems in urban India are mainly centralized and managed by municipal bodies. Certain levels of treatment and purification occur at source before distribution via a piped network. Chlorination is the most common measure. Rural India depends on varied localized sources to meet its water needs. Traditionally households boil water before consumption. Urban markets today are flooded with household water purifiers catering to the middle and upper classes. The technologies used vary from reverse osmosis to UV purification to ionization, iodine filters, etc.

Polluted water is often treated by conventional or pressure-driven membrane processes to make it comply with drinking water standards. Conventional water treatment process consists of several stages. These include pre-treatment, coagulation, flocculation, sedimentation, disinfection, aeration, and filtration. The pre-treatment stage removes suspended solids. Coagulation and flocculation are carried out to precipitate dissolved impurities through sedimentation. The water is then filtered to remove any suspended particles. One of the disadvantages of the conventional water treatment method is that it cannot remove dissolved salts and some soluble inorganic and organic substances.

The DFID Research Strategy 2008 – 2013 recognises a key role for research to help anticipate and respond to future trends with respect to new and emerging cutting edge technologies that could have a real relevance to the needs of poor people. The Research Strategy also recognises that the challenge for DFID lies not in the development or commercial application of these technologies, but in translational research to support the longer term development agenda. Research is needed into the most effective, safe and affordable approaches to applying these new technologies in developing country situations and to ensuring the benefits are derived by the poorest. Purifying drinking water is one of the strategic areas for the research with a special focus on nanotechnology. TARA has undertaken this research to identify the key challenges and barriers that may be reducing the impact of these technologies on the lives of poor people and help to identify some of the key technologies that could form the basis of further work.

The research will focus on both; technologies under R&D stage with potential to bring great impact in developing countries as well as technologies that have penetrated limited markets but for some reasons are not able to penetrate mass markets for reasons that we are proposing to research. The key focus would be to scan the potential technologies where, if principles of design for environment are incorporated right in the development stage can address the needs of the bottom of the pyramid markets and are amenable to support of related institutional and financial systems.

This report is a secondary review of available technologies in labs and in the market. Based on this review, we will be short listing the technologies for further research and partners will be identified to take forward the research in phase 2.

Overview of Nanotechnology

Nanotechnology is defined as a technology where dimensions and tolerances are in the range of 0.1-100 nm. It is the application of these nano structures and principles behind them to make nano scale devices and to produce new materials.

Mihail Roco of the U.S. National Nanotechnology Initiative has described four generations of nanotechnology development. The current era is that of passive nanostructures, materials designed to perform one task. The second phase, which we are just entering, introduces active nanostructures for multitasking; for example, actuators, drug delivery devices, and sensors. The third generation is expected to begin emerging around 2010 and will feature nano-systems with thousands of interacting components. A few years after that, the first integrated nano-systems, functioning much like a mammalian cell with hierarchical systems within systems, are expected to be developed[10].

Although there has been much hype about the potential applications of nanotechnology, most current commercialized applications are limited to the use of "first generation" passive nano-materials. These include titanium dioxide nano-particles in sunscreen, cosmetics and some food products; silver nano-particles in food packaging, clothing, disinfectants and household appliances; zinc oxide nano-particles in sunscreens and cosmetics, surface coatings, paints and outdoor furniture varnishes; and cerium oxide nano-particles as a fuel catalyst. The principal way nanotechnologies might help alleviate water problems is by removing water contaminants including bacteria, viruses, arsenic, mercury, pesticides and salt pose.

Materials at the nano scale often have different optical or electrical properties from the same material at the micro or macroscale. E.g. nano titanium oxide is a more effective catalyst than microscale titanium oxide. It can be used in water treatment to degrade organic pollutants. But in other cases, manufactured nano particles small size may make the material more toxic than normal[11]. Many researchers and engineers claim that nanotechnologies offer more affordable, effective, efficient and durable ways of achieving this. Using nano particles for water treatment will allow manufacturing that is less polluting than traditional methods and requires less labour, capital, land and energy[12]. There is a need to develop new sustainable business models for nanotechnologies to solve real problems, identified in participation with local communities.

10 U.S. National Nanotechnology Initiative

11 Hillie Thembela, Munasinghe Mohan,; Hlope mbhuti,; Deraniyagala Yvani,; 2006, Nanotechnology, water Development, Global Dialogue on Nanotechnology and the poor: Opportunities and Risks, meridian Institute, Chennai, October 2006;

12 Nanotechnology, commodities and development. Meridian Institute background paper (2007)

Nanotechnologies in the Water Sector

A range of water treatment devices that incorporate nanotechnology are already on the market, with others either close to market launch or in the process of being developed. Various examples of nanotechnology in water treatment and purification and detoxification are:

- Nanofiltration membranes
- Attapulgite clays, nonporous Zeolites, and Nano porous Polymers
- Nano particles for catalytic degradation of water pollutants
- Magnetic nano particles
- Nano sensors

Nanofiltration (NF) membrane technology is widely applied for removal of dissolved salts (i.e., desalination) from salty (i.e., brackish) water, removal of micro pollutants (e.g., arsenic and cadmium), water softening (i.e., removal of calcium and magnesium ions), and wastewater treatment. The main advantages of the membrane process for water treatment is that it does not require chemicals, requires relatively low energy, and is easy to operate and maintain. NF membranes using carbon nano tubes and alumina fibres are already being used to remove dissolved salts and micro-pollutants, soften water and treat wastewater.

A team of Indian and US scientists have developed carbon nano tube filters that remove bacteria and viruses more effectively than conventional membrane filters[13]. A study in South Africa has shown than Nanofiltration membranes can produce safe drinking water from brackish groundwater[14]. Researchers at Stellenbosch University, South Africa have developed a sachet sucks up toxic contamination when fitted into the neck of a water bottle. The sachets are made from the same material used to produce the rooibos tea bags that are popular in South Africa. But inside are ultra-thin nanoscale fibres, which filter out contaminants, plus active carbon granules, which kill bacteria[15].

The membranes act as a physical barrier, capturing particles and micro-organisms bigger than their pores, and selectively rejecting substances. NF water treatment plants typically consist of two types of treatment stages in series. These are the pre-treatment and membrane systems. The pre-treatment system removes particulate matter; in particular, suspended solids. The membrane removes some soluble substances and minute

13 Efficient filters produced from carbon nano tubes through Rensselaer Polytechnic Institute-Banaras Hindu University collaborative research. Rensselaer (2004)

14 Hillie, T. and Hlophe,M. Nanotechnology and the challenge of clean water. Nature Nanotechnology 2 (2007)

15 Munyaradzi Makoni, 2010, Nano 'tea bag' purifies water, Science and Development Network

substances that were not rejected by the pre-treatment system. NF membranes selectively reject substances. The characteristic selectivity of NF has advantages because it enables the retention of nutrients present in water that are required for the normal functioning of the body. For example, calcium ions are necessary for the healthy development of bones[16].

Naturally occurring attapulgite clays are also used in nano filters. Attapulgite is a naturally mined clay. It is a needle-like clay mineral composed of magnesium-aluminium silicate. These are locally available in many places around the world and have innate nanometre-size pores[17]. A study using attapulgite clay membranes to filter wastewater from a milk factory in Algeria has shown they can economically and effectively reduce whey and other organic matter in wastewater, making it safe to drink[18].

Nano technology also utilizes the existence of nanoscopic pores in zeolite filtration membranes. Zeolites are microporous, aluminosilicate minerals commonly used as commercial adsorbents. These materials are also known as molecular sieve – they contain tiny pores of a precise and uniform size that are useful as adsorbent for gases and liquids. Zeolites can also be fabricated. Zeolites can be used to separate harmful organics from water and to remove heavy metal ions. Researchers at Australia's Commonwealth Scientific and Industrial Research Organization (CSIRO) have created a low-cost synthetic clay, hydrotalcite that attracts arsenic removing it from water. They have suggested a novel packaging for this product for low-income communities — a 'teabag' that can be dipped into household water supplies for about 15 minutes before drinking. And selling the used teabags back to the authorities might increase recycling and help with waste disposal of concentrated arsenic[19].

Nano catalysts could make heavily polluted water fit for drinking, sanitation and irrigation. Nano catalysts owe their better catalytic properties to their nanosize or to being modified at the nano scale. They can chemically degrade pollutants instead of simply moving them somewhere else, including pollutants for which existing technologies are inefficient or prohibitively expensive. Immobilisation is a good technique since it would keep water free of nano particles during and after water treatment. Researchers at the Indian Institute of Science, in Bangalore, are developing such a technique for degrading organic molecules using nano titanium dioxide[20]. A water filter under development at Stanford University uses a piece of cotton treated with nanomaterial (silver nanowires and carbon nano tubes) to

16 Hillie Thembela, Munasinghe Mohan,; Hlope mbhuti,; Deraniyagala Yvani,; 2006, Nanotechnology, water Development, Global Dialogue on Nanotechnology and the poor: Opportunities and Risks, meridian Institute, Chennai, October 2006;

17 David J. Grimshaw Nanotechnology for clean water, Science and Development Network

18 Khider, K., Akretche, D.E. and Larbot, A. Purification of water effluent from a milk factory by ultrafiltration using Algerian clay support. Desalination 167 (2004)

19 Gillman, G.P. A simple technology for arsenic removal from drinking water using hydrotalcite. Science of the Total Environment 336 (2006)

20 Nano scale water treatment needs innovative engineering. Ashok Raichur 2009

remove bacteria from water quickly by killing it with electrical fields using just 20 % of the power required by pressure-driven filters[21].

Researchers at the Nanotechnology and Integrated BioEngineering Centre (NIBEC), University of Ulster are working on are working on solar disinfection of water using photocatalytic nanoparticles (titanium dioxide) to remove chemical pollutants and pathogens from water, for developing countries.

Magnetic nano particles can be used to bind with contaminants like arsenic or oil. Magnetic nano particles have large surface areas relative to their volume and can easily bind with chemicals. Then they be removed using a magnet. Scientists at Rice University in the United States are using magnetic "nanorust" to remove arsenic from drinking water. Size 12 particles can remove upto 99.2% arsenic from solution[22]. They are developing a way of creating nanorust from inexpensive household items. This could significantly reduce production costs, making it a viable product for communities throughout the developing world[23]. Several companies are commercialising such technologies and researchers are frequently publishing new discoveries in this area.

Nano sensors for the detection of contaminants and pathogens can improve health, maintain a safe food and water supply, and allow for the use of otherwise unusable water sources. They can detect single cells or even atoms, making them far more sensitive than counterparts with larger components. Detection technology for water purification would allow people to more quickly find out what the contaminants are, without having to send samples to laboratories for testing. Nano sensors, such as those based on titanium oxide nano wires or palladium nano particles are used for analytical detection of contaminants in water samples.

A team at Pennsylvania State University in the United States has developed a way of detecting arsenic in water by using nano wires on a silicon chip[24]. Research is experimenting with single- and double-walled Carbon nano tube (CNT) that can detect chemicals in water[25]. The European Committee funded project BioFinger in developing a portable, versatile, and low-cost molecular detection tool. BioFinger is developing a handheld device that

21 Louis Bergeron, Stanford News Service, High-speed filter uses electrified nanostructures to purify water at low cost

22 Vicki Colvin , Using magnetic nanoparticles in water treatment, ACS Green Nano technology and the environment symposium 2006

23 Yavuz, C.T., Mayo, J.T., Yu, W.W. et al. Low-field magnetic separation of monodisperse Fe3O4 nano crystals. Science 10 (2006)

24 Patel, P. Nano sensors made easy. Technology Review (2009)

25 H.Verdala et al., "Surface Modification of Carbon Nanotubes Using Poly (Vinyl Alcohol) for Sensor Applications," International Latin American and Caribbean Conference for Engineering and Technology, Miami, June 2 – 4, 2004,

incorporates nano- and micro-cantilevers on a disposable microchip to analyze chemicals and bacteria in water[26].

A Binghamton University chemist has been awarded a three-year grant from the U.S. Environmental Protection Agency to develop advanced nano sensors for continuous monitoring of heavy metals in drinking water and industrial effluent[27]. In Brazil, The National Nanotechnology Laboratory Applied to Agribusiness, housed at Embrapa's agricultural instrumentation unit in São Paulo, has developed a cheap optical sensor incorporating nano-assembled films to evaluate the acidity of natural water supplies. And 'electronic tongues' — another kind of polymer sensor developed at Embrapa — can be used to distinguish between different mineral waters and between pure water and water contaminated by organic matter[28].

Table 1: Current Status of some prominent nanotechnologies

Technology	Description	Current Status
Hydrotalcite	Low-cost synthetic clay, hydrotalcite that attracts arsenic removing it from water packaged as a 'teabag' that can be dipped into household water supplies for about 15 minutes before drinking by CSIRO	Prototype developed
Silver Nanofiltration	High-speed, low-cost filter using plain cotton cloth dipped in a broth of silver nanowires and carbon nanotubes by Stanford researchers	Prototype being developed
Nanorust	Nano Iron binds with arsenic and is removed from water using a magnetic field. Technology developed by Rice University	Prototype being tested in Mexico
Nanofiber	Tea bags with ultra-thin nanoscale fibres, which filter out contaminants, and active carbon granules, which kill bacteria by Stellenbosch University	Under approval by SA Bureau of Standards
Nano Photocatalysts	Solar disinfection of water using photocatalytic nanoparticles (titanium dioxide) to remove chemical pollutants and pathogens from water being developed by NIBEC	Research
Carbon nano tubes	Simple method to produce carbon nanotube filters that efficiently remove micro- to nano-scale contaminants from water being developed by BHU	Research
Nano antimicrobials	Silver-based antimicrobial filter water bottle developed by IonArmour	Market by InnovaMaterials
Nano silver catalyst	UV disinfection with adsorption on nano silver based activated carbon blocks developed by IIT-C	Marketed by Eureka Forbes
Nano silver catalyst	Rice Husk Ash impregnated with Nano Silver particles, activated silica and carbon developed by TATA group	Marketed by TATA Chemicals
Nano silver catalyst	Coating technology for incorporation of nano silver in traditional candle filters for disinfection developed by ARCI	Field testing by SBP Aquatech Pvt. Ltd.

26 BioFinger, and Information Society Technologies, "Portable Molecular Detection Tool to Revolutionise Medical Diagnosis"

27 S. E. Barker, "A Featherweight Solution for a Weighty Problem: BU Chemist Wins $351K EPA Grant to Develop Nanoreactor to Detect,Trap Heavy Metals in Water," discover-e, 2003,

28 Developing world advances nanotech for clean water, Paulo Sergio de Paula Herrman Jr.

Nanotechnology Research in India

Department of Science and Technology (DST) is the chief agency engaged in the development of nano science and nanotechnology. It is at the helm of the principal program, the Nano science and Technology Mission (NSTM) between the years 2007-2012; established to develop India as a key player in nano science and technology.

Building upon the promotional activities carried out as part of the Nano Science and Technology Initiative (NSTI) in the highly promising and competitive area of Nano Science and Technology, the Government of India launched a Mission on Nano Science and Technology (Nano Mission) in May 2007. An allocation of Rs. 1000 crore for five years has been made. The Department of Science and Technology is the nodal agency for implementing the Nano Mission[29]. The IBSA (India-Brazil-South Africa) nanotechnology initiative, a collaborative research and development programme between the Departments of Science and Technology in India, Brazil and South Africa, shows how South-South collaboration can promote the use of nanotechnology for clean water and points to progress being made in these countries IBSA identifies three areas of research as high priority: Nanofiltration and ultrafiltration membranes; nano-based water purification systems for remote and rural areas; and carbon nano gels, nano tubes and nano fibres[30].

Beside DST, several other agencies with diverse mandates are also actively engaged in supporting nanotechnology in the national arena. This follows from the potential of nanotechnology to dovetail with diverse disciplines as well as serve multiple sectors. The Council for Scientific & Industrial Research (CSIR) has also commissioned R&D in nanotechnology in diverse areas. The Defence Research & Development Organisation (DRDO) is also contributing to the expansion of nanotechnology in India.

Public sector research and development (R & D) institutions play a predominant role in nanotechnology research. Research in nano science and nanotechnology is being carried out in various academic and scientific institutions. Foremost are the, 'Centres of Excellence (CoE) for Nano science and Technology' established under the NSTI by the DST. The "Centres" seeks to undertake R&D to develop specific applications in a fixed period of time. Nineteen CoEs have been spread across 14 distinct institutions. The S.N. Bose National Centre for Basic Sciences (SN Bose NCBS), Association for the Cultivation of Science (IACS), the Indian Institute of Science (IISc), Jawaharlal Nehru Centre for Advanced

29 Mission on Nano Science and Technology

30 http://www.ibsa-nano.igcar.gov.in/

Scientific Research ((JNCASR) and IIT Kanpur, each host a Unit of Nano science as well as Centre for Nanotechnology. These CoE's as well as the others at IIT Mumbai, Chennai and Delhi are considered amongst the leading institutes for nano science and technology research.

Aside these institutes, others involved in nano science and technology include CSIR labs like Centre for Cellular and Molecular Biology (CCMB), National Institute of Pharmaceutical Education and Research (NIPER), Chandigarh as well as universities like the University of Delhi31. Academic research in nanotechnology is also gaining momentum. Researchers at Banaras Hindu University (BHU) have developed a method to produce carbon nano tube filters that efficiently remove micro-to nano-scale contaminants from water and heavy hydrocarbons from petroleum. CNT filters have been prepared and tested successfully for bacteria removal. This was a joint research effort by BHU Varanasi and Rensselaer Polytechnic Institute USA. More recently, CNT based water filters have also been developed and tested on the laboratory scale by Bhabha Atomic Research Centre (BARC), Mumbai[32].

In a study by IIT Kharagpur iron oxide nano particles were synthesized for arsenic removal using chemical method with an average size of 45 nm. Under the experimental conditions studies, maximum adsorption of 96% was obtained[33.] In another study nano iron-titanium oxide was used. Sorption test using a fixed bed column gave water with arsenic content less than 0.01 mg/L[34]. In a research carried out by The Birla Institute of Technology & Science (BITS), Goa; International Advanced Research Centre for Powder Metallurgy and New Materials (ARCI), Hyderabad; Agharkar Research Institute (ARI), Pune, use of Fe-Ni nano catalyst was found effective for degradation of orange G dye in water. Nano TiO_2 photocatalyst has been studied for removal of chlorophenol, bisphenol, metal ions, nitrobenzenes[35]. Indian Institute of Chemical Technology(IICT)Indian Institute of Chemical Technology (IICT), Hyderabad, has developed nano silver coated alumina catalyst using electrochemical method. These catalysts were found to be efficient for microorganism control in water[36.]

31 Nidhi Srivastava, The energy and Resources institute (TERI), 2010. Nanotechnology development in India: the need for building capability and governing the technology

32 Kar S, Bindal R C, Prabhakar S, Tewari P K, Dasgupta K, Sathiyamoorthy D. 2008. Potential of carbon nanotubes in water purification: an approach towards the development of an integrated membrane system, International Journal of Nuclear Desalination, 3(2), 143–150.

33 De D, Mandal S M, Bhattacharya J, Ram S, Roy S K. 2009. Iron oxide nanoparticle-assisted arsenic removal from aqueous system, Journal of Environmental Science and Health, Part A, 44 (2), 155 – 162.

34 Gupta K and Ghosh U C. 2009. Arsenic removal using hydrous nanostructure iron(III)–titanium(IV) binary mixed oxide from aqueous solution, Journal of Hazardous Materials, 161(2-3), 884-892.

35 Project report No. 2006ST21: D5, Nanotechnology developments in India, April 2009, part of a project: Capability, Governance and Nanotechnology Developments: A focus on India,

36 Shashikala V, Siva Kumar V, Padmasri A H, David Raju B, Venkata Mohan S, Nageswara Sarma P and Rama Rao K S. 2007. Advantages of nano-silver-carbon covered alumina catalyst prepared by electro-chemical method for drinking water purification, Journal of Molecular Catalysis A: Chemical, 268, 1-2, 95-100.

Nanotechnologies Marketed In India

While a lot of this research is still at the laboratory stage, some systems incorporating nano materials have reached the market. Point-of-use (PoU) water treatment systems being developed in India are targeting both urban and rural markets. In this context, simple systems which do not require electricity for their operation have been developed for areas where electricity availability is a problem[37]. Kenstar Appliance India is marketing water purifiers that use nano silver antibacterial technology. Micro Polyvinyl acetate (PVA) and ceramic Pre-filters are combined with Nano Silver Ceramic Balls to ensure purity of the water. Philips Electronics India has launched drinking water filters based on Nanofiltration.

The International Advanced Research Centre for Powder Metallurgy and New Materials (ARCI), Hyderabad developed a coating technology for incorporation of nano silver in traditional candle filters for disinfection[38]. About 100 such Nano silver coated candles have been field tested in 40 villages over an 8 month period with both pond water and locally treated water. The technology has been transferred to SBP Aquatech Pvt. Ltd. Hyderabad which will mass produce and market the candle filters. There seems to be a clear emphasis on serving the needs of rural masses.

Nano-silver activated carbon block has been developed in collaboration with Indian Institute of Technology (IIT), Chennai and is being marketed by Eureka Forbes as part of its new water purifier, Aquaguard Total Gold Nova[39]. The treatment scheme includes UV disinfection, along with adsorption on nano silver based activated carbon blocks. This water purifier was launched in early 2008 and costs Rs 9,000-10,000. It appears to have been developed for urban populations.

Tata Chemicals has introduced a nanotech water purifier called Tata Swach, a result of years of collaboration between Tata Consultancy Services (TCS), Tata Chemicals and Titan Industries. The Swach does not require electricity or piped water to work. Tata Swach uses Rice Husk Ash (RHA)[40] impregnated with Nano Silver particles. RHA

TATA Swach® Bulb™ works on patented TSRF™ technology that removes harmful bacteria and viruses from water and makes it safe to drink. Its performance capabilities have been tested across reputed laboratories in India, United Kingdom and Netherlands. A household unit has a total capacity 18 litres and consists of an upper and a lower container of 9 litres each**.** Its purification system consists of 3 meshes. Mesh 1 and 2 remove the minutest visible impurities and make water clean & clear. Mesh 3 is a unique detachable component which ensures clear & pure water, even when subjected to very high levels of dirty water. It is being marketed by TATA Chemicals for ` 999 /- making it affordable for the common man

37 The Energy and Resources Institute (TERI). 2009 , Nanotechnology developments in India – a status report [Project Report No. 2006ST21: D5]

38 http://www.indiawaterportal.org/blog/wp-content/uploads/2008/10/nano.doc

39 http://www.thehindubusinessline.com/2008/02/27/stories/2008022751082300.htm

40 Rice Husk Ash (RHA) is the filtering medium for water and the nano-silver particles kills bacteria, germs and other organisms.

contains activated silica and carbon, where the activated silica reduces the turbidity or cloudiness of the water entering the filter and the Activated Carbon adsorbs most of the toxic organic impurities. The Tata Swach water filter took this year's top Gold award prize in The Wall Street Journal's Asian Innovation Awards[41].

41 Rural water purifier hits the market in India , WASH Technology, December, 2009

Market Scenario

Notwithstanding hopes or fears, nanotechnology is finally moving beyond the confines of the research laboratories to the marketplace. There is feverish activity as the nanotech-based products begin to enter the market in a big way. Industry majors such as TATA, Samsung, Reliance, Thermax and others have introduced a host of products such as nano-based water filters, washing machines, refrigerators, air conditioners, deodorants and cosmetics. Nano scale materials are also being used in electronic, magnetic and optoelectronic, biomedical, pharmaceutical, cosmetic, energy, catalytic and materials applications.

The global spending on nanotechnology grew by 29% in 2006 with government share standing at 52% followed by corporate and venture capitalist spending. Nanotechnology investments by the government were initially led by Europe, North America and Japan. However, countries such as Russia, China, Brazil, Turkey and India have joined the trend and are making significant investments into the sector. Asia-Pacific is anticipated to be the most important region for the sales of nanotechnology products in near future, followed by the US and Europe at similar level.[42].

According to the US National Science Foundation, the nanotech market would be approximately $1 trillion worldwide by 2015. "There is a potential for Indian companies to engage in $20 billion worth of products, services and technology during this period," feels Puneet Mehrotra, director of New Delhi-based industry body called Nano Science and Technology Consortium (NSTC)[43].

Total market for water purifiers in India is valued at INR 9 billion in 2009 and is expected to grow significantly in near future. Market comprises of three segments Ultra Violet (UV) based Purifiers, Reverse Osmosis (RO) purifiers and storage / resin based purifiers[44]**.** Nanotechnologies though introduced have not yet captured significant market share. However the potential for nanotechnology in this sector is large. Nanotechnology is expected to further improve membrane technology and drive down the prohibitively high costs of desalination and other water treatment.

New sensor technology combined with micro- and nanofabrication technology is expected to lead to small, portable, and highly accurate sensors to detect chemical and biochemical parameters. Several research consortia are field testing such devices and some expect to

42 Research Evaluates the Past, Current and Future Scenario of Global Nanotechnology Market , Nanobusiness

43 NANO MAGIC , Sudhir Chowdhary , financial express

44 Water Purifier Market in India 2010, Netscribes (India) Pvt. Ltd.

commercialise these soon. The nanosensor market in the United States is currently estimated at USD 190 million and is expected to grow at an average annual growth rate of 26% to reach USD 592 million by 2009. Several organizations are developing systems that provide real-time detection of waterborne viruses and particles. These systems may be commercialized soon.

Enabling access to safe drinking water

The need to provide safe drinking water to poor people in developing countries cannot be overemphasised. The close links between poverty and access to safe drinking water serve to highlight this need especially in the perspective of achieving the Millennium Development Goals. While nanotechnology has a huge potential in the commercial market, it can play a pivotal role in the development sector.

Research suggests that materials suitably treated or impregnated with nanotechnology-based methods can filter more effectively and thereby increase the health benefits. Several researchers are testing their nanotechnology based devices in developing countries. E.g. the tea bag arsenic removal device in South Africa, ARCI testing their silver nanofilters in villages in South India.

Though many technologies are still in the research phase, they are also looking at low cost material and manufacturing options to be able to cater to the needs of the developing world. E.g. Rice University researchers are looking at creating nanorust from household items. Researchers at Stanford used cotton from Wal-Mart to reduce costs of their nanofilters. Hydros bottles of InnovaMaterials have incorporated nanotechnology to filter tap water thus reducing the recurring spending on bottles water.

There is a need to develop sustainable and innovative business models for these technologies. Cross subsidizing costs between the rich and poor communities can offer a solution. Mass production will also lead to models becoming more affordable. Thus nanotechnology has a huge market potential that can be exploited to cater to the needs of the bottom of the pyramid populations.

Environmental and Health Impacts

There is anxiety over how used filters and media containing nano materials might affect the environment. The International Council on Nanotechnology maintains a database and Virtual Journal of scientific papers on environmental, health and safety research on nanoparticles. The database currently has over 2000 entries indexed by particle type, exposure pathway and other criteria.

In water purification applications, the nano material is typically coupled to, or embedded in, other materials like filters that keep it trapped. But this may not always be the case. For example, silver nano particles used as odour neutralisers in fabrics have been known to leach after soaking in water. If nano materials find their way into water bodies, they could affect population and food dynamics, harming aquatic life. Studies in the United States have shown that if nano particles end up in sewage sludge subsequently used as fertiliser, they could damage plant growth[45].

Research says that some nano scale materials can pass through the blood brain barrier and people can be exposed to nano particles through inhalation, ingestion, skin uptake and injection of nano scale material[46.] Another danger is the disposal of nano materials, when used in large numbers especially in household and community-level applications. Unsuspecting developing countries could suddenly face a completely new set of pollution problems. Extended producer / supplier responsibility might be an option for collecting and managing used nano-based products, else it will very likely end up in local dumpsites and landfills.

The UK Royal Society has recommended that existing regulation be modified on a precautionary basis because they expect that “the toxicity of chemicals in the form of free nano particles and nano tubes cannot be predicted from their toxicity in a larger form and… in some cases they will be more toxic than the same mass of the same chemical in aggregate form[47].

45 Kristen M. Kulinowski, November 2008. Environmental Impact of Nan silver

46 Hillie Thembela, Munasinghe Mohan,; Hlope mbhuti,; Deraniyagala Yvani,; 2006, Nanotechnology, water Development, Global Dialogue on Nanotechnology and the poor: Opportunities and Risks, meridian Institute, Chennai, October 2006;

47 Royal Society and Royal Academy of Engineering (2004). Nanoscience and nanotechnologies: opportunities and uncertainties.

Policy Concerns

Currently there is no international regulation on nanotechnology and nano products. Nor are there any internationally agreed definitions or terminology for nanotechnology, no internationally agreed protocols for toxicity testing of nano particles, and no standardized protocols for evaluating the environmental impacts of nano particles[48]. The Material Safety Data Sheet that must be issued for some materials often does not differentiate between bulk and nanoscale size of the material in question and even when it does these MSDS are advisory only[49].

Governments and regulatory bodies such as the United States Environmental Protection Agency and the Food and Drug Administration in the U.S. or the Health & Consumer Protection Directorate of the European Commission have started dealing with the potential risks posed by nano particles. Berkeley, CA is currently the only city in the United States to regulate nanotechnology. The regulation requires businesses to annually identify any materials they use or produce with at least one dimension of 100 nanometers or less, no matter how small the quantities. They must also share what they know about how toxic the particles might be and describe procedures for tracking, handling and disposing of them[50]. The European Union has formed a group to study the implications of nanotechnology called The Scientific Committee on Emerging and Newly Identified Health Risks (SCENIHR).

The Royal Society's 2004 report identified two distinct governance issues; that of the “role and behaviour of institutions” and their ability to “minimise unintended consequences” through adequate regulation and the extent to which the public can trust and play a role in determining the trajectories that nanotechnologies may follow as they develop[51].

Given the perceived risks to environment and human health, the Indian government has stepped in by deciding to put in place a regulatory body. As nanotechnology is also being used for medicine and health, policy makers in the government insist that the technology must be used safely and there should be greater awareness about nanotech products.

48 International Standardisation for Nanotechnologies. Institute for Food and Agricultural Standards.

49 Wikipedia

50 Teeny-Weeny Rules for Itty-Bitty Atom Clusters, By BARNABY J. FEDER Published: January 14, 2007

51 Royal Society and Royal Academy of Engineering (2004). Nanoscience and nanotechnologies: opportunities and uncertainties

Way Forward

This research study strives to explore the most effective, safe and affordable approaches of new cutting edge technology for water purification that might benefit poor people, and what research is needed to turn these benefits into reality. There is a need to explore successful service delivery models and absorptive capacities of the population.

From the literature survey carried out, a strong trend is observed with respect to the use of Nano silver for water purification. Various technologies using silver are being researched as well as marketed. The market potential of this among others, especially catering to the bottom of the pyramid market will be explored in the study.

The research will be undertaken in two phases. In phase 1, the key focus would be to scan and short list potential technologies that are eligible for further research based on set criteria keeping in mind the research objectives. This phase also will be used to frame and firm up the research methodology. Research partners will be identified as well as making those agreements to take forward the research in phase 2.

The current secondary research report scans the existing scenario and attempts to map the potential technologies that can be taken forward. Further in phase 1, pilot studies will be undertaken to firm up the research questions that require detailed action research in phase 2. Multi-stakeholder engagement and dialogue will be the key in this phase. Consultations, round table discussions and meetings with industry and academicians will be conducted across the country. Primary survey to determine community needs and aspirations will be undertaken. Inputs from these interactions and the literature review will help in identifying technologies with most potential for dissemination. A detailed market analysis for selected technologies depending on their potential will be conducted. TARA will engage and involve different stakeholders ranging from Government agencies, Policy makers, Technology providers distributors, NGO functionaries , scientific institutions like Indian Institutes of Technologies (IITs), CSIR Labs , Department of Science and Technology (DST) and finally with the beneficiaries in the study right from the inception. Since this is a multistakeholder platform, consensus of each stakeholder will be taken into consideration and decisions will made accordingly.

TARA through the various outreach channels of DA will disseminate the results of the current study in the public domain. It will use all the communication channels like DFID's Research portal RD4, and other prominent portals like India water Portal (IWP), Solution Exchange of UNDP, DST's Vigyan Prassar, etc.

Therefore, phase 1 will be broad based, providing key inputs for action research in phase 2. In phase 2 it will be action research involving key stakeholders to derive strategic responses for technology uptake by BOP and Governments. development agencies and other institutions

Annex 1: Technologies[52]

Technology	Description	Technical Details	Cost Constraints	Ease of Use	Additional Considerations
Carbon Nano tube Membranes	CNT can be uniformly aligned to form membranes with nano scale pores that are able to filter out contaminants. Their nano scale pores make these filters more selective than other filtration technologies. CNT also have high surface areas, high permeability, and good mechanical and thermal stability. Though several other methods have been used, CNT can be made by coating a silicon wafer with a metal nano particle catalyst that causes carbon nano tubes to grow vertically aligned and tightly packed. The spaces between the CNT can then be filled with a ceramic material to add stability to the membrane.	Laboratory studies report that CNT membranes can remove almost all kinds of water contaminants, including turbidity, bacteria, viruses, and organic contaminants. These membranes have also been identified as promising for desalination and as an alternative to reverse osmosis membranes.	The cost of producing CNT membranes continues to decrease as researchers develop new and more cost effective methods to mass produce them. CNT membranes are expected to be more durable and easier to clean and reuse than conventional membranes without a decrease in filtering efficiency.		CNT desalination membranes are expected to reach the market in 5 to 10 years. Researchers are currently working to overcome challenges associated with scaling up the technology.
Nanomesh	Seldon Laboratories, a small company in the U.S., has developed several device prototypes based on its nanomesh filter media. Nanomesh is composed of CNT that are bound together and placed on a flexible, porous substrate. CNT can be placed on a flat substrate to form a paper-like filter or on a rolled substrate that can be wrapped around any conventional	Nanomesh can be engineered to remove a wide range of biological, organic, and inorganic contaminants. The filter media can be constructed of several layers of CNT, with each layer functionalized to remove a different type of contaminant. the nanomesh currently used in the waterstick can be used to remove more than 99.99 % of bacteria, viruses, cysts, spores,	Seldon has reportedly developed a cost-effective mass production system for manufacturing nanomesh media.	The waterstick is designed for individual use and is used like a drinking straw, producing clean water as the user drinks. The waterstick is currently designed to be disposable, though in time, it may develop a unit	A water stick prototype is currently being used by doctors in Africa. Seldon is currently working to enhance this technology so that it can be used to desalinate seawater.

52Background paper for the international workshop on nanotechnology, water and Development, October 2006, Chennai

	cylindrical filter or other support structure. Flat nanomesh can also be pleated to maximize filter surface area. Seldon currently has several portable water purification device prototypes based on this technology, most prominently a pencil sized, straw-like filtration device known as the "waterstick."	moulds, coliform, parasites, and fungi and also significantly reduces lead and arsenic. Functionalized versions of nanomesh can remove organic contaminants such as pesticides and herbicides, as well as inorganic contaminants such as heavy metals, fertilizers, industrial effluents, and others. The filter media can also be coated with an antibacterial agent to prevent bio-film formation.		with replaceable filter cartridges. Additionally, the waterstick is designed to automatically stop flowing when its useful life is over. Loose nanomesh media can be incorporated into existing filtration devices.	
Nanofiltration Membranes and Devices	A number of NF membranes are available as alternatives to reverse osmosis and ultra- and microfiltration. For instance, Korean company Saehan Industries offers a line of NF membranes for use in a wide range of scales, including household POU. Additionally, Saehan has developed a device that incorporates NF with pre- and post-treatment filters for household water purification without the use of a storage tank. Storage water tanks can increase the risk of water recontamination if water is stored too long or with improper sanitation.	Saehan's NF device can be used to remove almost all water contaminants, including bacteria and heavy metals. It is also effective for desalination because it removes 90 % ion contaminants and salts.	NF may be significantly less expensive than reverse osmosis because of its lower energy input needs.	These membranes must be stored in dry, room temperature conditions. They should not be exposed to excessive cold or heat. The membranes are sold in air tight bags to prevent bacterial growth, After initially used; the membrane should be kept wet at all times.	Saehan's technology has been field tested in a variety of applications and locations, including drinking water treatment in China, desalination in Iran, and others.
Nanofibrous Alumina Filters	U.S.-based Argonide Corporation[53] offers nanofibrous adsorbent technology with its line of NanoCeram® filter media and cartridge filters, which are made	NanoCeram® filters remove and retain over 99.99 % of viruses, bacteria, parasites, natural organic matter, DNA, and turbidity. The filters have also	NanoCeram® filters are cheap to produce because they can be manufactured using papermaking technology. The filter	NanoCeram® filters do not require pre- or post-treatment, cleaning, frequent filter changes, or	Argonide indicates that coolants and ultra-fine metal powders removed by NanoCeram® filters

53 Argonide, http://www.argonide.com/

	with electropositive alumina nanofibers on a glass filter substrate. The alumina nanofibers have more available surface area than conventional filter fibers and exhibit a higher electropositive charge, which allows them to adsorb significantly more negatively charged contaminants such as viruses, bacteria, and organic and inorganic colloids at a faster rate.	been shown to adsorb 99.9 % of salt, radioactive metals, and heavy metals such as chromium, arsenic, and lead, even the particles are nanoscale or dissolved NanoCeram® filters function best between pH 5 and 9. A granular version reportedly removes over 99 % of salt, heavy metals, viruses, bacteria, and turbidity. NanoCeram® cartridge filters have a pleated design that increases surface area, which gives them greater holding capacity. The filter medium is also reported to be more clog resistant than ultraporous membranes.	media currently cost US$ 10 per square meter, but may cost US$ 3 per square meter once mass produced. Cartridge filters cost US$ 75 per 20 to 200 filters, depending on diameter. Filter media sheets can be wrapped around a metal tube, placed between two conventional filters, or held in a screened container, minimizing the cost of acquiring a filter device. Because NanoCeram® filters adsorb ultra-fine particles instead of collecting them on their surfaces; they have a relatively long useful life.	hazardous waste disposal. Most set ups have a pour-through design. The filters have been shown to simultaneously remove biological and chemical contaminants, even in salty of highly turbid water, without chemical disinfectants or coagulant flocculants.	can be recovered and recycled for industry applications.
Nanofiber Gravity-Flow Devices	U.S.-based KX Industries has developed World Filters, a line of gravity-flow filtration devices containing nanofibers specifically for use in developing countries. The filter medium consists of a prefiltration layer that removes dirt, an adsorption layer that removes chemical contaminants, and a nanofiber layer that removes colloidal-sized particles and contaminants. The nanofiber medium is made from a variety of hydrophilic polymers, resins, and ceramics, cellulose, alumina, and other materials. The technology is available in household and community-level scales.	World Filters reportedly remove over 99 % of bacteria, viruses, parasites, organic contaminants, and other chemical contaminants. The household scale World Filter device can produce 378 litres of water per filter at a rate of 4 to 6 litres per hour. The village-scale device produces more than 7,500 litres per day at a rate of 5.6 litres per minute. Each village scale filter is effective for up to 95,000 litres of water.	The household device is expected to retail for US$ 6.00 to US$ 11.00, with replacement filters costing US$ 0.80 to US$ 0.90 each, translating to US$ 0.002 per litre of water. The village-scale device is expected to cost US$ 100 to US$ 150, which is approximately US$ 0.0003 per litre.	World Filters are designed to be easy to use without training or extensive instructions. Both the household and village-level devices require no maintenance and have no moving parts.	KX Industries plans to establish local facilities in developing countries for the production of the device hardware, as well as local distribution systems similar to those used by the beverage bottling industry. KX is also contracting NGOs to distribute the devices in some regions.

Nanoporous Ceramic Bio-Media Filtration	Pourous Ceramic Shapes, LLC, recently acquired by MetaMateria Partners in the U.S., offers a line of lightweight ceramic products with controlled porosity called Cell-Pore™, which is currently commercially available for treating water in fish tanks. The ceramic material hosts aerobic bacteria within its porous structure. These bacteria convert different pollutants into nontoxic substances.	The aerobic bacteria hosted within the ceramic material reportedly convert organic pollutants and some harmful bacteria into non-toxic substances. The ceramic can also be combined with nano-engineered reactants to remove phosphates, biological contaminants, heavy metals such as lead and arsenic, and other contaminants. Pourous Ceramic Shapes indicates that Cell-Pore™ has 100 times more available surface area than other comparable bio-media products. The ceramic material can also be used to support inorganic membranes as an alternative to reverse osmosis, which uses organic membranes.	Ceramic filters are expected to become increasing cost-effective as rising oil prices drive up the cost of plastics used in organic and polymer membranes, filters, and substrates. Cell-Pore's™ porosity prevents clogs in prefiltration devices it might be combined with, reducing the costs associated with filter replacement.	Cell-Pore™ requires some maintenance, including allowing the aerobic bio-material to form within the material prior to use and, occasionally, scrubbing the filter's surface.	Cell-Pore's™ manufacturing process is flexible and a wide range of starting materials can be used for production. MetaMateria is planning to expand use of the material, as well as its manufacturing process, to drinking water treatment.
Nanoporous Ceramic Membrane Filter	Nanovation AG in Germany offers a line of nanoporous ceramic membrane filters under the name Nanopore® and membrane filtration systems with multiple filter modules. Nanopore® membrane filters are made from ceramic nano powders on a support material such as alumina, and they are available in a variety of sizes and in two basic shapes: a tube-shaped round filter and a disk-shaped flat filter. These products are made using the company's proprietary ceramic nano powders and continuous manufacturing process.	Nanopore® membrane filters effectively remove bacteria, viruses, and fungi from water. Additionally, water quality tests did not find coliforms, faecal coliforms, salmonella, or streptococci in treated water. The amount of water provided by a Nanopore® membrane filter depends on its size and shape, as well as the quality of the water being treated. A filtration unit with dimensions of 120 by 60 by 15 centimetres provides 11 square meters of filter area and can treat 8,000 litres of wastewater per day.	Nanopore®-based membrane filtration systems can be produced inexpensively through a continuous manufacturing process that simultaneously assembles and fires all the layers of the filter. Nanopore® membrane filters are indicated to be cost competitive with polymer membranes when all the filtration process costs, including maintenance, replacement filters, cleaning agents, and operating costs, are	Nanopore® membrane filters and filtration systems require infrequent cleaning because of their strong anti-fouling properties. The membranes can also be steam sterilized, instead of chemically cleaned. Nanopore® membranes are resistant to bacterial and fungal decay, friction, concentrated acids and bases, high temperatures,	

			combined, with these cost savings attributed to Nanopore® filters' longer life, greater durability, and less labour intensive cleaning process.	and oxidation.	
Self-Assembled Monolayers on Mesoporous Supports (SAMMS™)	The U.S. Pacific Northwest National Laboratory (PNNL) has developed SAMMS™, a technology made from glass or ceramic materials with nanoscale pores to which a monolayer of molecules can be attached. Both the monolayer and the mesoporous support can be functionalized to remove specific contaminants. SAMMS™ have exhibited faster adsorption, higher capacity, and superior selectivity than many other membrane and sorbent technologies. SAMMS™ are designed for removing metal contaminants from drinking water, groundwater, and industrial waste streams.	SAMMS™ remove 99.9 % of mercury, lead, chromium, arsenic, radionuclides, cadmium, and other metal toxins. SAMMS™ can also reportedly be functionalized to remove specific metals or metal groups or not remove specific metals, such as calcium, magnesium, and zinc. SAMMS™ are not effective for removing organic or biological contaminants. SAMMS™ can reportedly be scaled for POU water treatment to industrial waste stream treatment. They provide 600 to 1,000 square meters of surface area for each gram of material.	SAMMS™' reportedly costs US$ 150 per kilogram, compared to a typical ion exchange resin at US$ 42 per kilogram and activated carbon at US$ 1.78 per kilogram, and 13 kilograms of SAMMS™ are need to remove 1 kilogram of mercury, versus 154 kilograms of ion exchange resin and 40,000 kilograms of activated carbon.	SAMMS™ require occasional regeneration with an acid solution to remove the captured contaminants.	SAMMS™ are available as powders and extrudates that can be retrofitted for ion exchange devices. Spent waste from SAMMS™ regeneration is considered nontoxic according to U.S. Environmental Protection Agency standards and can be disposed of as conventional waste.
ArsenX	U.S. company SolmeteX[54], Inc. produces ArsenX™, an adsorbent resin made of hydrous iron oxide nanoparticles on a polymer substrate that is used for removing arsenic and other metal contaminants. The nanoparticles provide high surface area, large capacity, and rapid absorption kinetics. ArsenX™ can be scaled for small scale POU applications or large-scale industrial and	ArsenX™ has been shown to remove arsenic, vanadium, uranium, chromium, antimony, and molybdenum. It does not remove sulphates, carbonates, fluoride, chloride, sodium, magnesium, or biological contaminants. Flow rate depends mostly on the type of device in which ArsenX™ is being used. Regardless of system design, 2.5 to 3 minutes of contact time	As it does not lose capacity during regeneration, ArsenX™ may cost less than other adsorbents over its life cycle. The initial cost of the system depends on various different design considerations, but is reported to generally range from US$ 0.07 to $ 0.20 per thousand litres, including amortized capital	ArsenX™ does not require pre- or post-treatment treatment or backwashing. The material does require occasional regeneration with a mild caustic solution. Depending on contaminant levels, ArsenX™ will be exhausted after 3	ArsenX™'s polymer substrate is reportedly durable and can operate in temperatures ranging from 1 to 80 degrees Celsius. ArsenX™ can be scaled for industrial, community, or household use

54 Solmetex, http://www.solmetex.com/

	community use, and it can also be used in existing devices designed for ion exchange resins.	between ArsenX™ and the water is needed. Each gram of ArsenX™ holds about 38 milligrams of arsenic.	costs and operation and maintenance costs.	months to 1 year.	
Cyclodextrin Nanoporous Polymer	Cyclodextrin is a polymeric compound composed of particles with well-defined cylindrical cavities that can trap organic contaminants. Cyclodextrin polymer can be produced as a powder, granular beads, or thin film for use in different applications and devices. In addition to being used for POU water treatment, cyclodextrin polymer can also be used for in situ groundwater treatment or for cleaning oil and organic chemical spills.	Cyclodextrin has been shown to remove a range of organic contaminants, including benzene, polyaromatic hydrocarbons (PAHs), fluorines, nitrogen-containing contaminants, acetone, fertilizers, pesticides, explosives, and many others. Tests indicate that cyclodextrin polymer reduces these contaminants to parts-per-trillion, versus activated carbon and zeolites, which reduce contaminants to parts-per-million. The polymer has also exhibited 100,000 times greater bonding with organic contaminants than activated carbon. The polymer has shown the same removal efficiency for water with low contaminant concentrations. Cyclodextrin polymer has been shown to have a loading capacity of 22 milligrams of organic contaminant per gram of polymer, compared to 58 milligram per gram for activated carbon. It requires about 5 seconds of contact time with the contaminated water.	Cyclodextrin polymer is reportedly cheap to manufacture and can be produced directly from starch with 100 % conversion. Mass production is expected to bring the cost of cyclodextrin polymer below the price of activated carbon and zeolites. Scientific Polymer Products, Inc. indicates that it has developed a method to scale this process for mass production of the material. Manhattan Scientifics, Inc. is currently developing the technology for consumer applications and says that mass production will make the polymer less expensive than other organic contaminant removal methods.	Cyclodextrin polymer is not affected by air moisture and can be used in humid regions without becoming saturated and deactivated. Since the cyclodextrin polymer material is both hydrophilic and hydrophobic, it can be used to draw water through the pores without the addition of pressure. The polymer will need occasional regeneration using a simple alcohol such as ethanol or methanol. Cyclodextrin polymer may require more labour than activated carbon and other adsorbents because its loading capacity is lower.	Cyclodextrin polymer powder can be packed into column, cartridge, or bed filters through which water is passed, granular cyclodextrin can be placed directly in the water source or vessel, and thin film cyclodextrin can be placed on a glass substrate to form a membrane. All these different forms can be used in existing devices designed for filters, membranes, and adsorbents. The material reportedly does not lose capacity from regeneration and can be reused indefinitely. . It has also been shown to not leach the contaminants it has adsorbed. The contaminants absorbed by cyclodextrin polymer can be recycled after regeneration for

					fertilizers, pesticides, and various other industry products.
Polypyrrole-Carbon Nanotube Nanocomposite	The U.S. Pacific Northwest National Laboratory has developed a nanocomposite membrane made with a thin film of an adsorbent polymer called polypyrrole on a matrix of CNT, which add surface area and stability to the membrane. Unlike other adsorbent products that require chemical regenerants, these membranes can be regenerated electrically.	Polypyrrole- CNT membranes that are positively charged and can remove perchlorate, cesium, chromium, and other negatively charged contaminants. The nanocomposite membrane can also be designed to remove salt. The polypyrrole can also be negatively charged so that it removes positively charged particles such as calcium and magnesium. The polypyrrole-CNT nanocomposite membrane is reusable and tests have shown that the membranes lose very little effectiveness after 100 use cycles. These membranes have also exhibited rapid flow rates because of the fast mass transport properties of the CNT.	Polypyrrole-CNT membranes are expected to be relatively low-cost, especially with long-term use, because they can be regenerated and repeatedly used without significant loss in adsorptive capacity. These membranes may save on costs associated with purchasing and storing regenerative chemicals, disposal, and chemical handling training. Additionally, the cost of CNT is expected to decrease by a factor of 10 to 100 in the next 5 years.	Polypyrrole-CNT membranes are expected to be moderately easy to use because they do not require chemical regeneration or handling of hazardous secondary waste. The adsorbed contaminants are released from the membrane by applying an electrically current to neutralize the charge of the polymer. Once the contaminants are removed, the polymer can be recharged and reused.	Pacific Northwest National Laboratory's operating company, Battelle, has made this technology available for licensing and joint research projects.
Natural, Synthetic, Coal Fly Ash, and Compound Zeolites	Zeolites are adsorptive materials with lattice-structures that form pores. They can be acquired from natural sources or fabricated in laboratories. Synthetic zeolites are usually made from silicon-aluminium solutions or coal fly ash, and are used as sorbents or ion exchange media in cartridge or column filters. AgION Technologies, Inc. in the U.S. produces a compound made from zeolites and naturally-occurring	Zeolites are generally used for the removal of metal contaminants. Natural zeolites from Mexico and Hungary have been shown to reduce arsenic from drinking water sources to levels deemed acceptable by the World Health Organization. Zeolites made from coal fly ash can adsorb a variety of heavy metals including lead, copper, zinc, cadmium, nickel, and silver from wastewater. Under some	Zeolites can reportedly be produced cheaply because their source materials are naturally and abundantly available. For consumer products, it costs US$ 0.50 to $ 4.50 per kilogram.	The ease of use of zeolites depends mostly on the type of devices they are used in., which can include ion exchange resin, cartridge, and column devices, and others. Additionally, zeolites require occasional regeneration with an	AgION's silver antimicrobial protection may be preferable to chemical disinfection because the microbes are less likely to develop resistance to silver.

	silver ions that exhibits antibacterial properties.	conditions, fly ash zeolites can also adsorb chromium, arsenic, and mercury. The adsorptive capacity of zeolites is influenced by several factors including their composition, the water pH, and the concentrations and types of contaminants. Also, because lead and copper are more easily adsorbed by fly ash, high concentrations of these metals decreases the amount of cadmium and nickel removed. AgION's zeolite-silver compound has been proven effective against microorganisms, including bacteria and mould. Additionally, the silver in this compound provides residual protection against re-growth of these biological contaminants. Zeolites do not adequately remove organic contaminants. Also, air moisture contributes to zeolites' saturation and makes them less effective. The amount of water that zeolites can treat depends on the zeolites' source and the device in which they are used. In the case of fly ash zeolites, the carbon content of the fly ash significantly influences surface area and, consequently, the adsorptive capacity of the zeolites.		acid solution. Waste disposal handling and procedures are comparable to those for ion exchange resins. Disposal of fly ash zeolites may be problematic because studies have shown that trace amounts of lead, cadmium, chromium, copper, mercury, zinc, and other contaminants can be leached from the fly ash, causing water, groundwater, and soil contamination. Also, the levels of arsenic and manganese in fly ash leachate have previously been found to be higher than the levels recommended by the World Health Organization. AgION's zeolite-silver compound requires infrequent cleaning because the silver antimicrobial coating prevents the build-up of biological contaminants on the filter. This also	

				eliminates the need for storage, use, and disposal of chemical disinfectants.	
Nanoscale Zero-Valent Iron	Nanoscale zero-valent iron (NZVI) is used for both in situ and ex situ treatment of contaminated groundwater. It functions simultaneously as an adsorbent and a reducing agent, causing organic contaminants to breakdown into less toxic simple carbon compounds and heavy metals to agglomerate and stick to the soil surface. NZVI can be injected directly into the source of contaminated groundwater as slurry for in situ treatment, or it can be used in membranes for ex situ applications. Bimetallic NZVI, in which the iron nanoparticles are coated with a second metal such as palladium to further increase the reactivity of the iron, is also available. NZVI is more reactive and has a large surface area than granular ZVI.	NZVI can be used to treat a wide range of common environmental contaminants including chlorinated methanes, chlorinated benzenes, pesticides, organic dyes, trihalomethanes, PCBs, arsenic, nitrate, and heavy metals such as mercury, nickel, and silver. It may also be able to reduce radionuclides. Palladium coated NZVI has been shown to reduce all chlorinated compounds to below detection levels in 8 hours, while regular NZVI achieved greater than 99 % removal in 24 hours. The nanoparticles remain active towards the contaminants for a period of 6 to 8 weeks. NZVI has been shown to be effective across a broad range of soil pHs, temperatures, and nutrient levels. Competing anions, however, may reduce its effectiveness. Additionally, NZVI that is regenerated for reuse will corrode overtime and become less effective. The amount of groundwater that NZVI can treat may depend on the quality of the iron, including the number of times it has been reused, the type of substrate used (for ex situ use), and the quality of the water used to make the injectable	NZVI reportedly may still be more cost effective because small amounts are needed due to its significantly greater surface area and reactivity. NZVI has a reactive surface area of 33.5 square meters per gram, versus less than 1 square meter per gram for commercial ZVI powders, and allows for 10 to 100 times faster treatment rates.	NZVI is relatively easy to use both in situ and ex situ. For in situ remediation, NZVI powder is mixed with water in a tank to produce an iron slurry that is then injected with a pump and injection well directly into contaminated soil. No special well construction is necessary since the same equipment used for other injectable remediation is sufficient. NZVI is reportedly easier to inject than granular ZVI because of its smaller particles, and it can achieve deeper subsurface penetration. NZVI nanoparticles can also be secured to a solid matrix of activated carbon, zeolites, CNT, and others to produce membranes for ex situ remediation.	

		slurry, including the amount of oxygen and the amounts and types of particulates in contains (for in situ use).			
Nanoscale Titanium Dioxide Photocatalysts	Titanium dioxide functions as both a photocatalytic reducing agent and an adsorbent, and it is used for both in situ and ex situ water treatment. In the presence of water, oxygen, and UV radiation, titanium dioxide produces free radicals that decompose a variety of contaminants into less toxic carbon compounds. Nanoscale titanium dioxide provides larger surface area and faster photocatalysis than larger titanium dioxide particles. Titanium dioxide is available in nanopowder form for use in suspensions or granular media filters. It is also available in several other forms, including, but not limited to, coatings for fixed membranes, nanocrystalline microspheres, and composite membranes with silica.	Titanium dioxide breaks down almost all organic contaminants. It is also super-hydrophilic and, therefore, able to adsorb biological contaminants and heavy metals, including arsenic. Its effectiveness is influenced by the quality of the titanium dioxide, the UV intensity, the water's pH, the oxygen supply, and the concentration of contaminants. Different titanium dioxide systems provide different flow rates and speeds of removal, though all are generally reusable. Suspended titanium dioxide nanopowders provide the most efficient photocatalysis because their entire surface area is exposed for UV and contaminant contact. Titanium dioxide nanoparticles used as coating or fixed to glass, ceramic, or other substrates have been shown to exhibit 0.5 % of the photocatalytic efficiency of suspended nanoparticles. This is due to a combination of reduced contact area and passivation from interactions with the support material. The porosity of the base membrane or substrate will also influence the flow rate and useful life of these systems. Titanium dioxide nanocrystalline	Nanotechnologies, Inc. In the U.S., has recently patented a production system that they indicate can produce tonnage quantities of titanium dioxide nanopowder very inexpensively. Altair also plans to sell small-scale production units based on this technology. These production units will be available in two sizes, 40 kilograms per hour and 1 to 2 kilograms per hour. The units produce titanium dioxide from titanium tetrachloride, which can be bought for about US$ 1,100 per metric ton, or US$ 1.10 per kilogram.	Suspended titanium dioxide nanopowders can be complicated to use because recovering or separating out the particles after the treatment is difficult. Suspended particles are usually separated through ultra- or microfiltration, but a significant amount of the powder can be lost during this process. Nanocrystalline microspheres are easier to use. They are suspended in water by air bubbling and naturally sink to the bottom of the vessel or body of water for easy recovery. Membranes and granular media filters that are coated, filled, or made with titanium dioxide will have similar ease of use as the base technology.	

		microspheres have a surface area that is comparable to nanopowders, but slower photocatalysis.			
Titanium Oxide Nanoparticle Adsorbent	Adsorbsia™GTO™ is a granular adsorptive media from Dow Chemical Company that removes arsenic from water through the combined oxidative and adsorptive properties of titanium oxide. It is designed for small and mid-sized systems or POU applications.	Adsorbsia™ can be used to remove arsenic across a range of water pH and conditions. Under typical conditions, Adsorbsia™ has been shown to remove 12 to 15 grams of arsenic (V) and 3 to 4 grams of arsenic (III) per kilogram of media. In addition to pH, removal efficiency is also not affected by the presence of sulphate, phosphate, iron, chlorine, or other anions in the water. Since it is not affected by chlorine, Adsorbsia™ can be combined with disinfection to eliminate biological contaminants. Removal efficiency may be affected, however, by the amount of arsenic that is present in the water, the ionic form of the arsenic, competing impurities and ions, and the design of the equipment. Additionally, Adsorbsia™ has not demonstrated any contaminant leaching or reverse arsenic reaction. Adsorbsia™ is also said to remove viruses and bacteria. Adsorbsia™, because of its nanocrystalline form, exhibits ten times faster kinetics than iron media, allowing for faster flow rate. The media is designed to operate with flow rates of 40 to	Adsorbsia's™ base price is US$ 14 per cubic decimetre of media, with lower pricing for larger quantities. Because the costs of conventional technologies rise significantly as water systems become smaller, Adsorbsia™ is designed to be cost-effective for small and medium sized systems. Adsorbsia™ does not have costs associated with purchasing and storing chemicals because it does not require regeneration.	Adsorbsia™ is designed to be compatible with existing system designs. The media can be used in existing devices designed for other granular media, sand, activated carbon, activated alumina, and others. The media was also developed to be disposable in order to eliminate potentially difficult or labour intensive processes such as regeneration and hazardous waste disposal. When the media is past its useful life, it can be removed and replaced with fresh media, though the use of a dust mask and safety glasses is recommended for transferring the dry media. Unused media can be stored in dry conditions and is not affected by	Adsorbsia™ is safe for landfill disposal under current U.S. Environmental Protection Agency standards which eliminates hazardous waste disposal costs. Dow Chemical Company has distribution routes throughout North America, South America, Europe, Asia, and the Pacific. Adsorbsia™ has been field tested in Bangladesh.

		400 litres per minutes per square meter of media. The quantity of water that the media can filter in its useful life depends on the source water quality and the system design. Laboratory testing has found that Adsorbsia™ granule-filled column filters with a volume of 29 cubic centimetres and a flow rate of 1.3 litres per hour can produce between 25 and 38 litres of water per gram of dry granules before losing effectiveness.		extreme cold or heat. Backwashing may be needed periodically depending on feed water particulate levels and the system design.	
Nanostructured Iron Oxide Adsorbent	Adedge Technologies, Inc. in the U.S. offers AD33, a dry, granular nanostructured iron oxide media for removal of arsenic. AD33 combines the catalytic and adsorptive properties of iron oxide to breakdown arsenic into less toxic by-products and simultaneously filter it out of water. Adedge also offers a line of POU devices containing the AD33 media.	AD33 has been shown to remove over 99 % of arsenic. It can also reduce levels of lead, zinc, chrome, copper, and other heavy metals. AD33 has been shown to not leach adsorbed contaminants. AD33 media typically has a useful life of 2 to 4 years. Adedge's Medallion Series household treatment systems are available with three flow rates: 19, 26, and 38 litres per minute. Adedge also offers filter cartridges containing AD33 with an average flow rate of 2 litres per minute. These cartridges have a useful life of 3,800 to 11,400 litres, which is estimated to be 4 to 6 times longer than other commercially available adsorption products.	Medallion Series products are reportedly comparable to anion exchange products in cost. AD33 filter cartridges cost about US$ 50 each. The cost of loose media depends on the quantity purchased, but typically ranges between US$ 8 and $13 per litre.	AD33 media and products require infrequent replacement, and do not require the use of chemicals or regenerants. Because it is dry, AD33 media is reportedly easier to handle than wet iron-based filtration media and can also be used in a broader range of system types. The media can be used in any standard granular media device with a downflow configuration. Such devices will require twice monthly backwashing to maintain their flow	Spent AD33 media is not hazardous and can be land filled according to U.S. Environmental Protection Agency standards.

				rate. Medallion Series systems are pre-packaged and automatically conduct pre-programmed backwashing.	
MagnetoFerritin	Magnetic nanoparticles are generally studied as adsorbents and nanocatalysts for water treatment. NanoMagnetics, Ltd., a U.K. company, has developed a magnetic nanoparticle called MagnetoFerritin and is studying its ability to enable forward osmosis, a potentially energy efficient alternative to reverse osmosis. Magnetic nanoparticles would be used in such a system to produce the osmotic pressure needed to pull water through a filtration membrane, unlike reverse osmosis that requires energy-input to produce osmotic pressure.	MagnetoFerritin-enabled forward osmosis is intended for desalination, though other contaminants can also be removed, depending on the type of membrane that is used.	The long life and reusability of the material makes it more cost effective than reverse osmosis. Forward osmosis also eliminates energy-related costs, which account for 40 % of the cost of reverse osmosis.	A precise system for MagnetoFerritin has not yet been designed, but sources indicate that the magnetic nanoparticles would be added to some clean “draw” water on one side of a membrane to create a concentration imbalance with the source water. This difference in concentration would create the osmotic pressure needed to pull the source water through the filter. The nanoparticles could then be recovered from the purified water using a magnetic field.	MagnetoFerritin can be recovered from the purified water and reused without any specific limit.

Annex 2: Agencies in Nanotechnology in the Water Sector

Technology	Organization	Country	Type of technology	Link
Nanofiltration membranes:	Rensselaer [55]Polytechnic Institute	United States	Devised a simple method to produce carbon nano tube filters that efficiently remove micro-to-nano scale contaminants from water	http://www.rpi.edu/
	Banaras Hindu University[56]	India	Devised a simple method to produce carbon nano tube filters that efficiently remove micro-to-nano scale contaminants from water.	http://www.bhu.ac.in/
	Argonide	United States	Developed a filter comprising oxidised aluminium nano fibres on a glass fibre substrate	http://www.argonide.com/
	SolmeteX	United States	Develop and manufacture heavy metal binding resins that remove metals and metal complexes, including mercury, arsenic, cyanide, and cadmium from water.	http://www.solmetex.com/
	Filmtec Corporation	United States	Nano membrane filtration technologies	http://www.dowwaterandprocess.com/products/ronf.htm
	North West University, Potchefstroom	South Africa	Nano membrane filtration technologies	http://www.puk.ac.za/fakulteite/natuur/scb/index_e.html
	University of Stellenbosch, Institute for Polymer Science	South Africa	Nano membrane filtration technologies	http://academic.sun.ac.za/polymer/
	Brazilian Agricultural Research Co-operation, Embrapa[57]	Brazil	Develop a biodigestion system using nano filters to clean irrigation supplies and make water safe for drinking.	http://www.embrapa.br/english
	IIT Chennai, Eureka Forbes Limited[58]	India	Filter using Nan silver to adsorb and degrade three pesticides commonly found in Indian water supplies	http://www.mme.iitm.ac.in/
Attapulgite Clay, Nano porous Zeolites and Nano porous Polymers	Los Alamos National Laboratory	United States	Developed a new class of nano porous polymeric materials that can be used to reduce the concentration of common organic contaminants in water to parts per million level.	http://www.lanl.gov/
Desalination	The Stephen and Nancy Grand	Israel	Using reverse osmosis whereby pressure is applied	http://gwri.technion.ac.il/

55 Robert Pini, August 2004. Efficient Filters Produced from Carbon Nano tubes through Rensselaer polytechnic institute- Banaras Hindu University Collaborative Research

56 Paulo Sergio de Paula Herrmann Jr. And Jose Antonio Brum, may 2009. Developing World Advances nanotech for clean water [online];.

57 Paulo Sergio de Paula Herrmann Jr. And Jose Antonio Brum, may 2009. Developing World Advances nanotech for clean water

58 David Grimshaw, 6 may 2009. Nanotechnolog for clean water: Facts and Figures

	Water Research Institute		to salt water, forcing fluid through a very fine membrane resulting in virtually pure water.	
	Long Beach Water Department[59]	United States	Reduced overall energy requirement of seawater desalination using a relatively low pressure two staged nano filtration process.	http://www.waterindustry.org/New%20Projects/desal-20.htm
Catalytic Degradation	Stanford University, Department of Materials Science and Engineering	United States	Electrified Nanostructures using nano silver wires and carbon nano tubes for filtration	http://www.stanford.edu/group/cui_group/
	Rice University	United States	Exploring nano catalysts to remove trichloroethylene and organic aromatic contaminants from groundwater	http://cohesion.rice.edu/centersandinst/cben/research.cfm?doc_id=5099
	Inframat Corporation	United States	Developing a material composed of highly porous nanofibrous structure that can be used to remove arsenic from drinking water by combining a nanofibrous MnO2 oxidative process with a granular ferric hydroxide adsorptive process	http://www.inframat.com/
	EnvironmentalCare	Hong Kong	Developed a nano photocatalytic oxidation technology for the removal of bacteria and pollutants from water	http://www.environmentalcare.com.hk/
	University of Illinois, University of Pittsburgh, Yeshiva University	United States	Exploring the use of nano catalysts to reduce pollution of oxidized contaminants (e.g. nitrates)	http://www.uillinois.edu/, http://www.pitt.edu http://www.yu.edu/ http://pubweb.bnl.gov/users/frenke
	Indian Institute of Science, Bangalore[60]	India	Nano catalysts using nano Titanium Oxide which chemically degrade pollutants	www.iisc.ernet.in
	University of Ulster, Nanotechnology and Integrated BioEngineering Centre	United Kingdom	Solar disinfection of water using photocatalytic nanoparticles.	http://nibec.yellowdesign.tv/research
	University of Aberdeen	United Kingdom	photoelectrocatalytic fuel cell to treat dirty water and create electricity simultaneously.	http://www.cleanwaterproject.co.uk
Magneti	Rice University	United	Developing magnetite	http://cohesion.ri

59 April 2005. Long Beach water department wins $3 million California grant for innovative seawater desalination project

60 David Grimshaw, 6 may 2009. Nanotechnolog for clean water: Facts and Figures.

c Nano particles		States	nano crystals for arsenic removal from groundwater	ce.edu/centersandinst/cben/research.cfm?doc_id=5100
	Embrapa [61]	Brazil	developing magnetic nano particles to treat water contaminated with pesticides. This class of technology seems especially suitable for removing organic pollutants, salts and heavy metals from liquids.	http://www.embrapa.br/english
Nano sensors	BioFinger[62]	Europe	Developing a portable molecular detection tool	http://www.biofinger.org/
	University of Buffalo	United States	Developing a handheld sensor that can detect the presence of toxins potentially used as agents in biological warfare.	http://www.buffalo.edu/
	Pennsylvania State University[63]	United States	Developed a way of detecting arsenic in water by using nano wires on a silicon chip.	http://www.gonano.psu.edu/

61 Paulo Sergio de Paula Herrmann Jr. And Jose Antonio Brum, may 2009. Developing World Advances nanotech for clean water

62 Hillie Thembela, Munasinghe Mohan,; Hlope mbhuti,; Deraniyagala Yvani,; 2006, Nanotechnology, water Development, Global Dialogue on Nanotechnology and the poor: Opportunities and Risks, meridian Institute, Chennai, October 2006;

63 David Grimshaw, 6 may 2009. Nanotechnolog for clean water: Facts and Figures

Annex 3: Centre of Excellence (CoE) in India in the area of nano science and technology[64]

Unit of Nano Science	Programme Coordinator
IIT Madras, Chennai	Prof. T. Pradeep
IACS, Kolkata	Prof. D. Chakravorty
University of Pune	Prof.(Mrs.) S.K. Kulkarni
S.N. Bose National Centre for Basic Sciences, Kolkata	Prof. A.K. Raychaudhuri
NCL, Pune	Dr. Sivaram
JNCASR, Bangalore	Prof. G.U. Kulkarni
BHU, Varanasi	Prof. O.N. Srivastava
IIT Kanpur, Kanpur	Prof. Ashutosh Sharma
IISc, Bangalore	Prof. S. Chandrasekaran
IIT Delhi, New Delhi	Prof. B.R. Mehta
SINP, Kolkata	Prof. M.K. Sanyal
Centre for Nano Technology	**Programme Coordinator**
Amrita Institute of Medical Sciences, Kochi, Kerala (Implants, Tissue Engineering, Stem Cell Research)	Dr. Shantikumar V Nair, Biomedical Engineering Centre, Amrita Institute of Medical Sciences
S.N. Bose National Centre for Basic Sciences, Kolkata (NEMS & MEMS / Nano products)	Prof. A.K. Raychaudhuri, S.N.Bose National Centre for Basic Sciences
Tata Institute of Fundamental Research (Nano scale phenomena in biological systems & materials)	Dr. G.V. Shivshankar National Centre for Biological Sciences, TIFR
IIT-Bombay, Mumbai (Nanoelectronics, polymer nano sensors, nano biotechnology)	Prof. Ashok Misra Director, IIT-Bombay
Indian Institute of Science, Bangalore (Nano devices, Nano composites, Nano biosensors)	Prof. S. Chandrasekaran Division of Chemical Sciences, Indian Institute of Science
IIT, Kanpur (Printable Electronics, Nano patterning)	Prof. Y.N. Mohapatra Department of Physics, IIT-Kanpur
Indian Association for the Cultivation of Science (Photovoltaics & Sensor Devices)	Prof. D.D. Sarma Centre for Advanced Materials, Indian Association for the Cultivation of Science,
Centre for Computational Materials Science	**Programme Coordinator**
Centre for Computational Materials Science at Jawaharlal Nehru Centre for Advanced Scientific Research, Bangalore	Prof. Balasubramanian Sundaram, JNCASR,

64 Department of science and Technology, Nano mission