Innovation Ecosystem of Nano Water Research in India: Step Towards Basic Research to Commercialization

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Abstract

In the last decade nanotechnology entered the policy arena as a technology that is promising solutions for most important issues for the world society in the XXI century such as ensuring a supply of safe drinking water for a growing population, as well as addressing issues in medicine, energy, and agriculture worldwide. This research paper is focused on exploring how nanotechnology applications could complement economic and social measures and contribute to addressing the range of global challenges presented by water (e.g. sustainable provision of clean drinking water) and how it is developing in country like India across the different sectors with special emphasis of water sectors.

This paper not only provide the overview of available prominent technologies in water sector in advanced as well as developing economies like India but also will draw insight how Nanotechnology interventions might be sought at specific junctures to alleviate the following challenges by integrating in water sector from the beginning (research) to end (commercialised product) of value chain.

Key words: Nanotechnology; water remediation; developing countries; value chain; India

1. Introduction

Nanotechnology using the bottom up approaches is the reverse of the classical top down approaches. It is the science of fabricating things smaller than 100 nanometers (a nanometer is one-billionth of a meter).That size is critical because classical gives way to quantum physics, creating new electrical, magnetic, and optical properties (Balzani, 2008). Nanotechnology, a knowledge intensive industry, is shaping the evolution of many economies. Nano technology is also cited as General Purpose Technology (GPTs) because of its pervasive potentiality of being generic, horizontal, enabling and/or disruptive, inherent potential for technical improvements and 'innovational complementaries' (youtie *et al*.,2008; Graham and Icopetta,2009; Breshnan,2010)

As an "enabling technology", nanotechnology is key in the value chains of different industrial sectors such as water, energy, medicine and environmental remediation, etc. It is already making an impact in manufacturing, energy solutions, medicine, automotive, ICT, etc by enhancing the functionality/development of novel processes and products there in (Freitas Jr, 2010; Kautt *et al.*, 20072007). This General Purpose Technologies (Gambardella *et al.*, 2010) is particularly appealing to developing economies such as India as along with the promise of improving the functionality of existing products/processes or creating new products, it can provide novel interventions in areas that are of pressing concerns i.e. water, energy, medical in developing and improvised economies. Nanotechnology if properly addressed can provide a 'window of opportunity' for developing economies like India that tends to address

developmental problems and forge economic growth through technological interventions.(Bhattacharya, *et al.*, 2012)

This paper will highlight the challenges in water sector and opportunity to get the blue gold from waste using nanotechnology. In first section we will discuss the water availably and quality problem in Indian context and potentiality of nanotechnology to reduce these problem across different industrial sector. Second section will highlight the nanotechnology market worldwide and prominent technologies available worldwide that can be used for developing and underdeveloped countries. Third section will provide the insight of R& D environment of nanotechnology in India

2. Challenges in Water Sector and Nanotechnology Opportunities: Indian Perspective

2.1 Challenges in Water Sector: An Indian context

Although water is seemingly abundant (over 70 % of our earths is covered by water), the real issue is the amount of fresh water available. Unfortunately 97.5% of all water on Earth is salt water, leaving only 2.5% as fresh water. Nearly 70% of that fresh water is frozen in the icecaps of Antarctica and Greenland; most of the remainder is present as soil moisture, or lies in deep underground aquifers as groundwater not accessible to human use. Less than 1% of the world's fresh water (~0.007% of all water on earth) is accessible for direct human uses. As the world's population rises to 9 billion by 2050, access to fresh water will become even more important in the near future. World Health Organization (WHO, 2010) has estimated that 80% of illnesses in the developing world are water related, resulting from poor water quality and a lack of sanitation. There are 3.3 million deaths each year from diarrheal diseases caused by E. coli, salmonella and cholera bacterial infections, and parasites and viral pathogens.

India with 4 % of world's total area and 16% of total population of the worlds has only 2.4 % of fresh water availability. Other side increasing population, growing urbanisation and industrialization growing a perception of sense of an impending water crisis in the country and a pressing need for the optimal use of water as well as technology development to increase the fresh water by various means like desalination process, water treatments, etc. Nanotechnology has the potential to contribute to long-term water quality, availability, and viability of water resources, such as through the use of advanced filtration materials that enable greater water reuse, recycling, and desalinization. Nanotechnology is the key to improve costs, efficiency and offer new functionality, products and systems as an emerging technology in water and waste water worldwide. Nanotechnologies will produce huge environmental benefits in terms of water management and treatment by improving filtering, decontamination, desalination, conservation, recycling, analysis and monitoring and sewerage systems.

2.2 Potential of Nanotechnology in Water Treatment

In- depth analysis of BCC research (2011) is projected the global value of nanotechnology products used in water treatment procedures was worth $1.4 billion in 2010 and is projected to reach $2.2 billion by 2015 showing 9.7 % increases at a compound annual growth rate

(CAGR) . The market is made up of two segments: established products and emerging products. Established products were valued at nearly $1.4 billion in 2010 and are expected to reach $2.1 billion by 2015, for a CAGR of 9.2%. Emerging products were valued at $45 million in 2010 and, with a CAGR of 20%, reach $112 million in 2015.. .
Well-established products make up most of the current market, and include reverse- osmosis, nanofiltration, and ultrafiltration membrane modules. The emerging products mostly are in precommercial phases, and include nanofiber filters, carbon nanotubes, and a range of nanoparticles.

Table1. Global Market For Nanotechnology Products Used In Water Treatment

Segment of Products	Products	Market in 2010	Market in 2015	CAGR %
Established Products	reverse- osmosis, nanofiltration, and ultrafiltration membrane modules	$1.4 billion	$2.2 billion	9.7%
Emerging Products	nanofiber filters, carbon nanotubes, and a range of nanoparticles.	$ 45 million	$112 million	20%

Sources: constructed by authors from various sources (BBC research, 2011)

3. Prominent Technologies available in water remediation worldwide

Some interesting membrane technologies are now emerging from Developed and Developing nations that are highly relevant to the needs of the developing as well as under developed countries.

Table 2. Prominent technologies used for the water treatment

Product	**How it works**	**Importance**	**Developer**
Nanosponge (building Blocks Cyclo Dextrin)	Cyclo dextrin exhibits a superior ability to absorb organic molecules in water. It provides a hydrophobic environment and creates a strong affinity for organic molecules at water solid surface. (size distribution 0.7-1.2nm)	It is natural extension of every drinking water faucet; Comparison with carbon and zeolites.and effective in cleaning up organic contaminants in industrial setting	Los Alamos National Laboratory in the United States by DeQuan Li and Min Ma
nanoparticles of magnetite (Building Block :iron oxide)	Iron can form bonds with arsenic and extract arsenic from drinking water by simply adding their rusty nanoparticles, and stripping toxic contaminants like arsenic from water more effectively than	Developing and under developed countries suffer thousands of cases of arsenic poisoning each year, linked to poisoned wells	Rice University, United States

	existing filters. e iron particles gather up the arsenic ions and then removing the particles with a magnet. (size of particle : <12 nm)		
Desalination membrane	A combination of polymers and nanoparticles that draws in water ions and repels dissolved salts	Already on the market, this membrane enables desalination with lower energy costs than reverse osmosis	University of California, Los Angeles and NanoH2O
Nano filtration membrane	Membrane made up of polymers with a pore size ranging from 0.1 to 10nm	Field tested to treat drinking water in China and desalinate water in Iran, using this membrane requires less energy than reverse osmosis	Saehan Industries, Korea
Nanomesh waterstick	A straw-like filtration device that incorporates carbon nanotubes	.The Nanomesh allows water to flow through quickly at a higher rate than an ultrafiltration membrane, but the carbon nanotubes attract contaminants. Microbes and chemicals adsorb (stick to the surface of) to the CNTs leaving the water chemical free	Seldon Laboratories, United States
World filter	Filter using a nanofibre layer, made up of polymers, resins, ceramic and other materials, that removes contaminants	Designed specifically for household or community-level use in developing countries. The filters are effective, easy to use and require no maintenance	KX Industries, United States
Pesticide filter	Filter using nanosilver to adsorb and then degrade three pesticides commonly found in Indian water supplies	Pesticides are often found in developing country water supplies. This pesticide filter could provide a typical Indian household with 6000 litres of clean water over one year	Indian Institute of Technology in Chennai, India, and Eureka Forbes Limited, India
Electrochemical Carbon Nanotube Filter	A carbon nanotube filter that takes advantage of the electrical conductivity of carbon nanotubes	By hooking upsmall power source to the filter, it is electrified and does electrochemistry as the water passes through. The electrical current	Harvard University (in research phase)

		kills or degrades the microbes or chemical contaminants, (Self cleaning filters)	
Lifesaver bottle	an ultra filtration membrane.	The holes in this membrane are only 15 nanometers in size, small enough to keep out the smallest viruses.	UK

Constructed by author from various sources (D. Li, 2000; A.S. Nair, *et al.*, 2003; Nair and Pradeep, 2007; Vectis, C.D., *et al*., 2011)

4. Research and Development (R & D) Environment: An Indian Context

4.1 R & D in Centre of Excellence

India has taken a major drive to create capacity and capability in Nanotechnology. It launched in 2001, the Nano Science and Technology Initiative (NSTI) (coordinated by Department of Science and Technology) with an allocation of Rs. 60 crore (15 million USD). In 2007, this programme was upgraded with another major initiative known as 'Nano Mission' with a budgetary allocation of Rs. 1000 crore (250 million USD) for five years.

This funding has been utilized to sponsor 90 research projects and create 19 Centres of Excellence. The CoE consist of eleven "Unit of Nanoscience (UN) that pursue the basics research in several broad areas of Nano science and Technology whereas seven "Centers of Nanotechnology " is mainly focus on R & D in niche areas or in specific dimensions such as nano electronics (IIT, Bombay)

Recently in 2011 Department of Science and technology approved the grant to Central of Excellence to open 6Thematic Unit of Excellence. It is important at this critical juncture to assess the status of research and innovation in nanotechnology in different industrial sectors in India.

Table 3 : Research and Development Environment of Nanotechnology in india

	Institutes/Universities/Laboratories As Centre of Excellence	Number of Unit of Nano Science (UN)/Centre of Nanotechnology (CN)/ thematic units of Nanotechnology (TUN)	Area of working
1.	Jawaharlal Nehru Centre for Advanced Scientific Research	UN-1	Basic Research

	(JNCASR), Bangalore	CN-	
		TUN-2	Nano Chemistry and Computational Material Science
2	Indian Institute of Science, Bangalore.	UN-0	Basic Research
		CN-1	Nano Devices,Nano composites and nanobiosensors
		TUN-1	Physics and Technology of nano assemblies
3	Indian Institute of Technology-Madras.	UN-1	Basic research
		CN	
		TUN-1	Water purification
4	Indian Institute of Technology-Kanpur	UN-1	
		CN-1	Printable electronics and nanopattering)
		TUN-1	Soft nanofabrication with application in energy, environment and bio platform
5	Indian Institute of Technology-Mumbai.	UN-0	
		CN-1	Nano electronics, polymer nanosensors, nanobiotechnology
		TUN-0	
6	Indian Institute of Technology-New Delhi.	UN-1	Basic researh
		CN-0	
		TUN-0	
7	S.N. Bose National Centre for Basic Sciences, Kolkata	UN-1	
		CN-1	NEMS/MEMS/ Nano Product
		TUN-1	Nano Device technology
8	Amrita Institute of Medical Sciences & Research Centre, Kochi	UN	
		CN-1	Implants, tissue engineering and Stem Cell Research
		TUN-1	Tissue engineering and medical bio-nanotechnology
9	Tata Institute of Fundamental Research	UN-0	
		CN-1	Nanoscale phenomena in biological systems and materials
		TUN-1	
10	Saha Institute of Nuclear Physics	UN-1	Basic research
		CN-0	
		TUN-0	

11	Indian Association for the cultivation of science	UN-1	
		CN-1	Photovoltaics and Sensor Devices
		TUN-0	
12	International Advanced Research Centre for Powder Metallurgy and New Materials (ARCI), Hyderabad	UN	
		CN	
		TUN-1	Nanotech based technology for automotive applications
13	CSIR-National Chemical laborator (NCL)y,PUNE	UN-1	
		CN- 0	
		TUN- 0	
14	Banarus hindu University	UN-1	
		CN-0	
		TUE-0	

Source: constructed by author from www.nanomission.gov.in

4.2 Key Players in Nano Water Research

Water treatment and remediation has already been cited as one of the critical area where nanotechnology applications might aid developing countries.

In India, research is mainly focus on developing decentralised or point of use system that do not requires electricity like Aqua sure from Eureka forbes Ltd; and Pureit from Hindustan Liver limited example. Some of companies are also looking community based treatment units like removal of specific contaminants like fluoride and arsenic.

Centre of Excellence and some other organization like Bhaba Atomic Reserch centre (BARC), International Advanced Research Centre for Powder Metallurgy and New Materials (ARCI), Hyderabad are actively involved in nanowater research. Tables 4 is summarizing the list of institutes having research in water purification sector targeting mainly creation point of use system.

Table 4: List of institutes and their nano water research

Institutes/University	Nano water research
Banaras Hindu University	BHU and Renssealer Polytechnic institute, USA have devised a method to produce carbon nanotube (CNT) filters that efficiently remove micro- to nano-scale contaminants from water and heavy hydrocarbons from petroleum. Made of carbon nanotubes, the filters are easily manufactured using a novel method for controlling the cylindrical geometry of the structure.

Bhaba Atomic Research Centre (BARC), Mumbai	Desalination Division, Bhabha Atomic Research Centre (BARC) has been engaged in R&D on various aspects of desalination and water purification technologies starting from basic research work to development and deployment efforts. More recently, CNT based water filters have also been developed and tested on the laboratory scale by Bhabha Atomic Research Centre (BARC), Mumbai.
Indian institute of Technology, Kharagpur	Indian Institute of Technology, Kharagpur. Developed finely divided iron oxide nanoparticles (IONPs) which can remove arsenic from contaminated water. IONPs are easy-to-produce and economically viable for mass use. IONPs have magnetic properties and arsenic-adsorbed were filtered out completely from the aqueous solution using magnetic separation.
Indian institute of chemical Technology (IICT)	IICT optimized the methods for preparing nano sized TiO2 predominately in anatase stage for removal of chlorophenol, bisphenol, metal ions, nitrobenzenes from water .
International Advanced Research Centre for Powder Metallurgy and New Materials (ARCI), Hyderabad.	Technology for nano silver coated ceramic drinking water filters has been successfully developed and commercialized. The amount of silver present in the filtered water is well below the EPA permissible level for safe drinking water.

Constructed by authors from various sources: (TERI, 2010; www.barc.gov.in www.indiawaterportal.org.,T. Pradeep and Anshup, 2009)

4.3 Commercialized Nanoproducts in Water Industry

Kenstar Appliance India launched 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 its 'Intelligent Water Purifier. 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. The technology has been transferred to SBP Aquatech Pvt. Ltd. Hyderabad

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.

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

5. Conclusion

India's present status of nanotechnology is still not in the league of countries such as US, Japan, South Korea, Germany, and China. However, it has developed a strong research ecosystem in this field with dedicated research groups in universities/research institutes. One of the key features that draw attention is its strong focus on creating nano-based applications in areas of pressing concerns namely effective drug delivery, safe drinking water, and energy. Emerging countries like India are demonstrating new pathways for addressing pressing problems of 'water', and are trying to create an'innovation climate' that would help India to move closer to frontier technologies and 'catch up' (defined in terms of production to innovation capabilities) with OECD economies.

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