Fostering Nanotechnology to Address Global Challenges:

Water
ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT

The OECD is a unique forum where governments work together to address the economic, social and environmental challenges of globalisation. The OECD is also at the forefront of efforts to understand and to help governments respond to new developments and concerns, such as corporate governance, the information economy and the challenges of an ageing population. The Organisation provides a setting where governments can compare policy experiences, seek answers to common problems, identify good practice and work to co-ordinate domestic and international policies.

The OECD member countries are: Australia, Austria, Belgium, Canada, Chile, the Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Israel, Italy, Japan, Korea, Luxembourg, Mexico, the Netherlands, New Zealand, Norway, Poland, Portugal, the Slovak Republic, Slovenia, Spain, Sweden, Switzerland, Turkey, the United Kingdom and the United States. The European Commission takes part in the work of the OECD.

© OECD 2011

You can copy, download or print OECD content for your own use, and you can include excerpts from OECD publications, databases and multimedia products in your own documents, presentations, blogs, websites and teaching materials, provided that suitable acknowledgment of OECD as source and copyright owner is given. All requests for public or commercial use and translation rights should be submitted to rights@oecd.org.
# Table of Contents

**EXECUTIVE SUMMARY** ............................................................................................................................................ 5

**FOSTERING NANOTECHNOLOGY TO ADDRESS GLOBAL CHALLENGES: WATER** ......................... 9

  - The context ........................................................................................................................................................................... 9
  - Technologies for water treatment and resource management .......................................................................................... 15
  - Managing knowledge generation and sharing: infrastructures for nano-water technologies development ............................................................................................................................................ 26
  - Nanotechnology, water and industry ..................................................................................................................................................... 31
  - Key challenges identified from stakeholder discussions ........................................................................................................... 32
  - Goals and proposed actions to address the key challenges to the adoption of nanotechnology water solutions .................................................................................................................................................................. 41
  - Recommendations ........................................................................................................................................................................ 42

**ANNEX 1: OECD WORKING PARTY ON NANOTECHNOLOGY WORKSHOP ON NANOTECHNOLOGY AND THE GLOBAL CHALLENGE OF ACCESS TO CLEAN WATER** .......... 45

**ANNEX 2: OTHER POLICY ACTIVITIES RELATED TO WATER** ................................................................. 47

**ANNEX 3: NANOTECHNOLOGY IN WATER PROVISION AND MANAGEMENT – SOME EXAMPLES** .................................................................................................................................................... 55

**REFERENCES** ............................................................................................................................................................ 73
EXECUTIVE SUMMARY

Securing and managing access to clean water is a challenge both for developing and more economically developed countries. This document reports on the key issues of water access; some important technologies for water purification and resource management; nanotechnology, water and industry; and key challenges - findings from discussions with stakeholders. It is intended to address policy issues faced by both developed and developing countries. The document also identifies policy recommendations for consideration and adoption.

While potential ways for nanotechnology to address the global challenges are the focus of this work, it is essential that that proposition be placed in context. Critical issues for the provision and management of clean water are not technological alone. Economic and social aspects are of great importance and are the subject of many other studies, for example those completed and ongoing under the OECD Horizontal Programme on Water (OECD, 2010a). However, technologies such as nanotechnology may provide complementary solutions to the water problem in addition to the technological solutions already commercially available.

Nanotechnology has been in use as a conventional water treatment for many years – although until recently the term nanotechnology was not commonly used. Enhancements to existing treatments and novel approaches are both now leading to changes in water treatment systems, albeit some still at the experimental stages. Some technologies are also being adapted from other sectors such as healthcare.

The high surface areas and high throughputs of nanomaterials are being investigated as ways to improve membrane technologies, and the catalytic properties of some nanomaterials have the potential to neutralise chemicals and microorganisms. Sensor technologies based on nanotech are also being adapted for use in water resource management, for example in agriculture. The sensors being developed use nanotechnology to provide good accuracy and rapid response rates as well as robustness and small size. Nanotechnology also offers the possibility of combining sensing and feedback for example in measuring levels of contamination and treating them.

The industrial base using nanotechnology is expanding rapidly as the potential of this emerging technology is realised. The water sector is however fragmented in both industry and technology terms with a wide variety of water applications being developed by companies in many sectors, making it difficult to gain a clear picture in a short study such as this. Over time the picture should become clearer as the number of applications on the market and number of companies involved increases. In the interim, case studies were used here to gain insights into company and other stakeholder experiences and to identify some policy related issues.
In the course of this work, through discussions with water industry professionals\(^1\), a number of specific challenges were identified by stakeholders from industry, researchers, academics, regulators and users in the water and nanotechnology space. While the study was not exhaustive, the same challenges arose repeatedly amongst those experts, namely challenges in areas of:

- Environment, health and safety: clarifying the risks which may arise from the use of nanotechnology in the water industry and from the presence in water of nanoparticles released into the environment from industry or agriculture.
- Technology transfer challenges, in bringing nanotechnology from research to industrial use, in transferring the technology to the point of use and in making the appropriate choice of technology to meet local circumstances.
- Communication: knowledge sharing and capacity development between the communities of researchers, engineers, management and administrators and end users.
- System: the need for new or adapted business models to facilitate the integration of new technologies into the water industry and increase appropriate adoption of technology.
- Intellectual property rights in water-related nanotechnology and ensuring a sound strategy for intellectual property protection and use in the context of this emerging technology.
- Adoption challenges, which may include, in both developed and developing countries, cost, availability of supply, technical and local management, safe disposal and reluctance to adopt new technologies.
- Economic feasibility of using nanotechnology and other technologies to address the global water challenge and the impact of investments in water-related nano-infrastructures within the region of implementation.

Actions proposed by water and nanotechnology industry professionals, to be applied in the local context, to address these challenges include:

- Strengthening science, engineering and commercial linkages: Support activities in water and nanotechnology which have the potential to enhance communication, understanding and collaboration between stakeholders, drawing on the experiences of national good practice in the use of other technologies for the enhancement of water systems.
- Fostering international linkages: Identify good practice in managing international co-operation to address the issues of access to and management of water, and support the national development of and/or engagement in such co-operations for water and nanotechnology.

---

\(^1\) Discussions with over 30 practitioners in 2008-2009 through phone interviews and at the OECD workshop at NTNE 2008 (see Annex 1). The participants represented multi-national enterprises, utilities companies, start-up and spin-off companies, non-governmental organisations, consultancy companies, academic research, public research organisations, industrial research bodies, national research councils, aid agencies, government agencies, financiers, business representative organisations and networks of water practitioners. See also case studies in Annex 3 for further details.

• Developing supportive platforms: Increase coherence and co-ordination in supporting the development of nanotechnology for water research and development, including water resource management. Pricing water will not only improve its management, but will also strengthen incentives for innovation related to water.

• Fostering informed and balanced approaches: Determine, at national level, the best ways to support and engage in work on the risks and benefits of nanotechnology in providing clean water at both national and international levels.

• Developing strategic roadmaps: Consider at national and international levels the best financial means for water provision and good resource management and implement them in parallel with technology-based solutions.

A number of key challenges and the role that policy makers could play in supporting the development of nanotechnologies have also been identified from stakeholder discussions:

• Mechanisms which foster interaction between communities in the water industry (e.g. process engineers and nanotechnologists) can help to increase the impact of nanotechnology on the water industry as a tool and a process enhancement. Some governments and international funding bodies are facilitating this by supporting collaborative projects (industry/academic/public sector research) in the water sector, projects which incorporate research, technological development, testing, prototyping and pilot plants.

• A complete supporting system of research and industrial development (including research testing prototyping and pilot plants) can help the water industry to adopt and adapt to new technologies such as nanotechnology. Collaborative projects and a supportive environment are required.

• Work on the evaluation of the characteristics and likely impacts of nanoparticles in water, whether from water treatment or from external sources, is important in providing a basis for sound decisions relating to the operation of water monitoring and treatment systems.

• To aid in effective transfer of water-related nanotechnology, stakeholders should seek to enhance co-operative mechanisms, including i) the development of public-private partnerships in order to foster business development of water-related nanotechnologies; and ii) international co-operation between developed and developing economies.

• An appropriate intellectual property strategy is a core element in ensuring the wide availability of nano-enabled water technologies to all. The involvement of emerging and developing economies during all the key phases of development and delivery of nano-water technologies will assist in avoiding the development of a “nano-divide”.

• The cost of new nano-water technologies is likely to be a factor limiting its adoption in many countries. In developing countries, inability to pay for these technologies may require a change in aid and international funding strategies, for example redirection or increase of funds. However, the issue of reluctance to adopt a new behaviour and concern over health and safety would remain and may only be resolved over time. In developed countries, a reluctance to pay for
new developments in water treatment may be effectively addressed through education and communication.

- Economic impact assessment of the implementation of nano-water technologies through cost-effectiveness studies is of key importance. The environmental and social impacts of these technologies should also be measured. The relative impact of these issues will largely depend on the location of implementation of the technology.

Recommendations have been developed in light of the actions proposed by water and nanotechnology industry professionals and other stakeholders. These recommendations are put forward now for the purpose of stimulating debate within national governments and international contexts with the aim of moving towards appropriate measures to address the global water challenge. The recommendations are:

i. Governmental and intergovernmental bodies supporting collaborative research and development should consider ensuring that the potential of nanotechnology as a solution to global challenges such as water is reflected in their funding allocations.

ii. Stakeholders – government, non-government international bodies and industry – should support and engage with work on addressing fiscal, economic and social issues at national and international levels for different types of source waters in conjunction with national and international initiatives on nanotechnology and water.

iii. Countries should consider coming together in an international event on nanotechnology and water bringing together participants from the water industry, the nanotechnology industries including materials, and sensors, the science and public health communities, OECD governments and the OECD enhanced engagements countries\(^2\) to discuss the key issues raised in this paper, from needs to technological solutions; to exchange good practice examples in the use of nanotechnology and other technologies for the enhancement of water systems; and to identify steps to be taken by national and international governmental bodies to optimise the use of nanotechnology in the water sector.

By considering and debating the recommendations at national and international levels, it is anticipated that progress can be made towards taking appropriate measures to address the global water challenge.

\(^2\) OECD enhanced engagement countries are Brazil, China, India, Indonesia and South Africa.
FOSTERING NANOTECHNOLOGY TO ADDRESS GLOBAL CHALLENGES: WATER

This work was 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 good management of water including waste water) and to formulate related policy measures for discussion and consideration by national governments and international policy fora. This document reports on the key issues of water access; some important technologies for water purification and resource management; nanotechnology, water and industry; and key challenges – findings from discussions with stakeholders. It also identifies policy recommendations for consideration and adoption by national governments and other national stakeholders, as appropriate. It is intended to address the global water challenge in both developed and developing countries, where some of the same and some different issues arise.

The context

Managing and securing access to clean water is a major global challenge, in particular for public health in developing countries. Even in the developed world, water shortages can have a tremendous impact, not only on health, but on industries such as agriculture, manufacturing, and power production. Over three billion people were living in areas of water stress in 2005, more than half a billion of those in severe water stress areas and, without new action, the total is set to grow to 3.9 billion (47% of the global population) by 2030 (Figure 1).

Figure 1. People living in areas of water stress, by stress level (million), 2005 and estimates for 2030

Of the Earth’s water, 97.5% is saline and not readily available for consumption or use. While it can be desalinated, the energy required to desalinate it is often prohibitive in terms of cost and energy sources may not be readily available (see section on Technologies for Water Treatment and Resource Management). Of the remaining 2.5% of global water, almost 68.7% is frozen in ice caps and glaciers (UN, 2006). Other freshwater resources globally include ground sources (e.g. aquifers), surface water (e.g. rivers), water originating in other sources such as rain, snow and fog, as well as water contained in vegetation. Approximately 60% of global freshwater resources are contained in water basins which cross international boundaries (OECD, 2006a), leading to issues of contamination across borders and to possibilities of conflict and dispute. Per capita water availability ranges widely, for example with 697 cubic metres per capita per year [m³/cap/year] in the Netherlands and with 92 466 m³/cap/year in Canada (OECD, 2008a).

Many factors contribute to water scarcity: imbalances in water availability and demand, inadequate management of resources (minimal re-use of wastewater recycling and non-potable water), cost, the poor quality of some groundwater and surface water, competition between sectors such as industry, agriculture and the domestic water consumer, and interregional and international conflicts (FAO, 2010) and scarcity is compounded by declining freshwater quality. The OECD Environmental Outlook to 2030 (OECD, 2008a) highlights i) water scarcity, ii) poor groundwater quality and iii) agricultural use of water and pollution of water as three environmental issues which are either not well managed, or are in a bad or worsening state requiring urgent attention. In developed countries, increasing numbers of water sources are contaminated by industrial or agricultural activities or are being depleted, while demand for clean water rises. In addition, the global population is expected to increase by one third between 2010 and by 2030, leading to a requirement for crop production to increase by 50%, driving a significant additional demand for water. In developing countries, issues of sanitation, contamination and drought impact greatly.

Domestic consumption comprises ten percent of global usage but varies considerably by country and location (OECD, 2006a). In OECD countries, average daily domestic consumption is approximately 180 litres per capita. In certain cities of the United States, the daily consumption average can be higher than 400 litres, whereas in many African towns, it is less than 30 litres per household per day.

Worldwide, the World Health Organisation (WHO) estimates that around 6% of the global burden of disease is related to water, with infectious diarrhoea being the largest component (accounting for about 70%, or 1.7 million deaths per year). More than 4 500 children under five years of age die every day from diseases such as diarrhoea (WHO, 2007). Water, sanitation and health interventions typically reduce diarrheal diseases by 15-30%, and markedly reduce other diseases (WHO, 2010). Waterborne diseases can be caused by protozoa (e.g. cryptosporidiosis), viruses (e.g. hepatitis, parvovirus), bacteria (e.g. cholera, leptospirosis, typhoid and botulism) and intestinal parasites (e.g. schistosomiasis, enterobiasis) (OECD and WHO, 2003). One third of global urban dwellers, or a billion people, live in slums and settlements where they exist in cramped, congested living conditions, without access to safe water, sanitation, safe food, decent shelter or meaningful employment.
In addition to disease and problems of domestic hygiene, malnutrition and dehydration, lack of access to clean water has many impacts including (UN, 2006):

- Reducing the quantity and quality of food available, both livestock and crops.
- Diminishing farm incomes and undermining the credibility and reliability of agricultural exports, thereby impacting global food security.
- Resulting in environmental and climate change due to landscape erosion and loss of habitat, such as desertification and reduced bio-diversity.
- Necessitating temporary or permanent population displacement and emigration.
- Impacting industrial development, trade and tourism potential.
- Reducing the ability of countries to produce energy for national consumption, water being an essential element for energy production by most methods, with associated reciprocal impacts on water resources and impacts on the environment.
- Causing both local and cross-border conflicts.
- Affecting the educational opportunities of children and the employment potential of adults where it is necessary for them to travel long distances to gather water.
- Increasing social imbalance and gender inequity, reducing the social and economic capital of women in terms of leadership, earnings and networking opportunities.
- Impacting social cohesion and cultural need, for example through community tensions and impacts on language, rituals and ceremonies.

**Box 1. Water and agriculture**

Agriculture is by far the largest user of water. Agriculture is responsible for much of water pollution and it is projected to grow in its demand for water by nearly 50% by 2030 (OECD, 2008b). Agriculture uses a global average of 70% of all surface water supplies which, except for water lost through evapo-transpiration, is recycled back to surface water and/or groundwater. In OECD countries, agriculture accounts for 45% of water usage although it uses over 80% in Turkey, Mexico and Australia and less than 10% in Germany and Poland (OECD, 2008a).

Agriculture causes water pollution through its discharge of pollutants and sediment to surface and/or groundwater, through net loss of soil by poor agricultural practices, and through salination and water logging of irrigated land. Water pollution also impacts agriculture through the use of wastewater and polluted surface and groundwater, which can contaminate crops and transmit disease to consumers and farm workers.

It should be noted that water for agriculture typically comes from different networks from urban supplies and is of a different quality. Measures to conserve water use in agriculture include increased charges for irrigation water; direct support for enhanced on-farm irrigation technology; and the removal of input and output price support for agricultural production (OECD and WHO, 2003).
Water is in many ways a local matter and its scarcity is principally a governance issue. As well as the problems experienced in less developed countries highlighted above, many OECD countries face the challenge of replacing ageing water supply and sanitation systems and upgrading wastewater treatment systems in order to meet water quality standards and regulatory requirements and to reduce leakage and cross contamination between the water supply and sanitation systems. Many cities have ageing water infrastructures, up to 100 years old, with structures and materials which are reaching the end of, or exceeding, their life expectancy. Some such water systems still use asbestos-cement pipes and wooden storage tanks and suffer from problems of both water contamination and water leakage.

Data for EECCA\(^1\) countries in 1998 to 2003 showed leakages of 30 to 45% in Georgia and Moldova and 50 to 70% in Armenia and Kyrgyzstan (OECD, 2006b) and a number of OECD countries including the US do not perform better. Reliance on canal and river water in EECCA countries, as one alternative, leaves the population at risk from water contaminated with nitrates, oil, pesticides and bacteriological pollutants. In the US, much of the water infrastructure was built after 1945 and a US Environmental Protection Agency (EPA) survey published in 2007 found that, in systems providing water to over 100 000 people, about 30% of the pipes were between 40 and 80 years old and about 10% of the pipes were more than 80 years old (US EPA, 2007).

Replacing water infrastructure is expensive. The EPA identified that to upgrade US water systems would need an investment of an estimated USD 276.8 billion between 2003 and 2023 for drinking water and USD 205.5 billion for clean watersheds (including waste water treatment, sewers, storm water management and agricultural run-off) in the same time period (US EPA, 2010).

Water is typically cheap and is a commodity to which people, globally, feel entitled. It is seen as a basic human right although not legally designated as such. Figure 2 shows urban water cost per cubic metre in 2007. In developing countries, the cost of water through a domestic connection and via informal vendors varies greatly within some countries and is a business founded on the fact that users are not all connected to the water supply system. For example, in Delhi, water from a domestic supply costs USD 0.01 per cubic metre and from a vendor it costs up to USD 4.89 per cubic metre (UNESCO, 2010).

Challenges in water provision include cost (e.g. purification must be energy efficient), complexity (e.g. solutions suited to a large city with good technical infrastructure will not be appropriate to rural areas, even those in developed countries), technical challenges (including training of personnel), and lack of sustainable business models.\(^2\) Many international and national organisations are striving to meet these challenges (see Box 4 for more information).

---

1. Eastern Europe, Caucasus and Central Asia.
2. Current business models have partially failed to attract the level of finance required. Alternative approaches are emerging on a small scale, based on existing and innovative technologies (reuse, recycle) which may attract new and increased sources of finance.

© OECD 2011
The UN Millennium Development Goal of ensuring environmental sustainability commits governments to “reduce by half the proportion of people without sustainable access to safe drinking water” by 2015, a goal closely linked with the separate goal of access to sanitation and basic hygiene education. Access to safe water was projected to require a doubling of finance to this sector unless other solutions can be found.
Box 3. The OECD Horizontal Programme on Water

In 2007, the OECD Environment Policy Committee, together with the Investment, Agriculture and Development Assistance Committees, began a programme of work on sustainable financing of water and sanitation services and on the sustainable use of water in agriculture.

As regards water and sanitation, securing safe and reliable services for all is one of the leading challenges of sustainable development. All but a few OECD countries have connected 100% of their populations to safe water supplies, and the majority are connected to wastewater treatment. Progress has also been made in developing countries but there is still a long way to go.

A key challenge is to ensure the financing necessary to extend water services to those that are currently not connected, and to maintain and upgrade the existing infrastructure. This OECD project is examining:

- The financing needs for water infrastructure.
- The available sources of financing (including water pricing, public budgets, private investment, official development assistance).
- How the gap between the two can be bridged.

The OECD Horizontal Water Programme includes specific analysis of current water pricing practices and the challenges for improving their design and implementation; realistic water financing strategies for developing countries; private sector participation in water and sanitation infrastructure; sustainable water use in agriculture; and innovative approaches to water supply and sanitation.

The results of the OECD Horizontal Water Programme were reported internationally at the Fifth World Water Forum in Istanbul, Turkey, 16-22 March 2009, www.worldwaterforum5.org.


In March 2008, the UN Human Rights Council adopted a resolution establishing an Independent Expert on the human right to water and sanitation, a mechanism exclusively dedicated to issues related to the right to safe drinking water and sanitation. The resolution also confirms that governments have obligations to ensure access to safe drinking water and sanitation under international human rights law.

Standards for water quality are usually set by governments at both national (e.g. the US Clean Water Act of 1977 [US Office of Science and Technology, 2008]), the Japanese Water Pollution Control Law3) and international levels (e.g. the EU Drinking Water Directive [European Commission, 2009]). Further information is available from the website on Water Law and Standards (WHO and FAO, 2009), a joint project of the United Nations Food and Agriculture Organization (FAO) and the WHO.

This work on harnessing nanotechnology for clean water seeks to add to the policy debate by considering water in the context of nanotechnology and its applications. While acknowledging the importance of addressing economic and social aspects of the global water challenges, the report aims to highlight the potential for nanotechnology innovations to complement actions in those areas. The following section identifies technologies in use for water treatment and where nanotechnology can have a role.

---

Box 4. Organisations working on the global issue of water

Many organisations are working on water and there are conferences and meetings on a broad range of related topics on a weekly basis. These organisations include:

- UNESCO (UN-Water and its World Water Assessment Programme, WWAP)
- UN Food and Agriculture Organisation (UN FAO)
- The World Health Organisation (WHO)
- WaterAid
- The Global Water Partnership
- MEDRC – The Middle East Desalination Research Centre established in Muscat, Oman, within the context of the Middle East Peace Process
- The OECD
- The World Bank (Water Resources Management Strategy)
- The EU Seventh Framework Programme “Converging Technologies for Clean Water”
- The International Water Association (IWA Expert Group on Nano and Water – Application of Nanoparticles, Nanoengineered Materials and Nanotechnology)
- AquaFed: the International Federation of Private Water Organisations (www.aquafed.org)
- The EU Water supply and sanitation Technology Platform (WssTP)
- The US Strategic Water Initiative (USSWI)
- The European Membrane Institute

More details of organisations and their activities are given in Annex 2.

Technologies for water treatment and resource management

Water treatment technologies include filtration using membranes, chemical treatment, heat and ultraviolet treatment and distillation. They seek to remove solid and other contaminants, or to neutralise them, and many treatments have a long history of use in systems for producing water for domestic, industrial and agricultural use. Water resource management is an important element in the conservation of water and in optimising its use. Methods for identifying the amount of contamination in water and determining its suitability for use, as well as those for ascertaining how much water is needed and where, aid good water management.

Nanotechnology is gaining greater use in water systems. It is envisaged as being particularly efficient for three key purposes: treatment and remediation, sensing and detection, and pollution prevention. Established techniques for water treatment can have drawbacks which nanotechnology may help to address. Some methods use chemicals, are energetically costly, can be difficult to implement and manage, require substantial investments in term of funds, human capital and infrastructures, are not sufficiently adapted to local expertise and situations and may depend on having large infrastructures. New technologies, and especially nanotechnology, are expected to provide solutions which could help in the future in addressing this range of issues. However, while there is the potential for research and development to lead to improvements in water provision, the development of cost-effective nanotechnology-based commercial products is in the early stages, with a few notable exceptions in contaminant detection, treatment and filtration.
As with conventional technologies, both enhancements and entirely new materials and systems based on nanotechnology will advance to practical use only as cost, technical bottlenecks, fair access, risk and sustainability issues are addressed. Decisions by private and public stakeholders to pass on to users the up-front costs of developing, implementing and adopting new water-related technologies such as nanotechnology could be a crucial step in enabling nanotechnology bring the potential long-term benefits projected by some. The expected decrease in cost of purifying the world’s water supplies and the significant savings that could accompany reliable access to potable water in areas of the world which currently face a lack of drinking water and basic sanitation service would be just two potential benefits. The following section concerns itself with water treatment technologies and nanotechnology in order to illustrate some possible technology applications.

**Water treatment technologies (OECD and WHO 2003)**

Water purification can be used to remove inorganic (*e.g.* sand) and organic materials (including those in suspension); parasites; bacteria; algae; viruses; fungi; minerals (*e.g.* calcium, silica); toxic metals and semi-metals (*e.g.* arsenic, copper, chromium, lead and radium); and odours, tastes and colours. Table 1 provides a summary of conventional water treatments and some areas of water treatment in which nanotechnology is being applied, in research and development work.

<table>
<thead>
<tr>
<th>Conventional technology-based water treatment</th>
<th>Nanotechnology-based water treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Membrane filtration, including:</td>
<td>Membrane filtration, including:</td>
</tr>
<tr>
<td>Integrated systems</td>
<td>Integrated systems</td>
</tr>
<tr>
<td>Bioreactors</td>
<td>Nanobioreactors</td>
</tr>
<tr>
<td>Turbidity removal</td>
<td>Turbidity removal</td>
</tr>
<tr>
<td>Nanofiltration</td>
<td>Nanofiltration</td>
</tr>
<tr>
<td>Chemical treatment, including:</td>
<td>Chemical treatment, including:</td>
</tr>
<tr>
<td>Coagulation and flocculation</td>
<td>Disinfection <em>e.g.</em> using nano metallic particles</td>
</tr>
<tr>
<td>Disinfection</td>
<td>Catalysis enhanced heat and UV disinfection</td>
</tr>
<tr>
<td>Heat and UV disinfection</td>
<td>Dendrimer filtering</td>
</tr>
<tr>
<td>Dendrimer filtering</td>
<td>Integrated treatment and monitoring systems</td>
</tr>
</tbody>
</table>
Technologies which are in use for water filtration include: ceramics to filter out suspended matter (turbidity), coliforms, faecal contaminants, E. coli, asbestos and iron; biosand, composed of gravel and sand particles, to remove faecal coliform, protozoa, suspended sediments, zinc, copper and lead; charcoal and activated carbon for filtration of solids, organics and some metals which form organic complexes; granular media such as sand for the removal of turbidity, enteric bacteria and parasites; and fibres and fabrics to filter solid particles and large microorganisms (>20 µm).

Chemical treatments include coagulation and flocculation, independently and with chemical disinfection, for the purification of water containing turbidity, microbes, viruses, heavy metals and pathogens. These methods often require skill and can result in waste products, unpleasant tastes and odours.

Reverse osmosis is a separation process that uses pressure to force a solution through a membrane keeping the solute on one side with the pure solvent moving to the other. The membranes have a dense barrier layer in a polymer matrix and, for water applications, allow only water to pass through. Reverse osmosis is used for some industrial, medical and domestic applications and more than 50% of desalination technologies are based on reverse osmosis.

Distillation may be used to remove salts and heavy metals, basically by evaporating the water away from the contamination. They are therefore not suitable for organic contaminants which are soluble. Thermal distillation can be used for desalination but is more energy-intensive than reverse osmosis.

Heat and ultraviolet radiation (e.g. solar disinfection, UV lamps) can neutralise vegetative and coliform bacteria and enteric pathogens.

**Nanotechnologies**

The market for nanotechnology used in water and wastewater worldwide reached USD 1.6 billion in 2007 and is expected to reach USD 6.6 billion in 2015. Filtration was the dominant application in 2007 at about 43%, but desalination and irrigation are expected to deliver the most revolutionary results by 2015 and thereafter. Nanotechnologies help to reduce desalination process costs and reduce water use in irrigation. In 2015, filtration is expected to account for 30%, desalination for 23% and irrigation for 6% of the USD 6.6 billion total. One of the fastest growing of the smaller market segments is disinfection with broad applications and benefits (Kaiser, 2010).

Nanotechnology is generally used in areas where there is a need to address contaminants at the molecular level (see Box 5). In several cases (e.g. membrane technology), nanotechnology has been in use as a conventional water treatment technique for many years although the term “nanotechnology” was not in common use when the products and systems were introduced. Many nanotechnology developments for water purification are enhancements of conventional technologies, while others under development offer novel approaches (e.g. the adaptation of nanotechnology-based sensors, developed for healthcare (AzoNanotechnology, 2006), to water treatment and monitoring systems (AltairNano, 2010; Savage, 2005).
Box 5. Definition of nanotechnology

“Nanotechnology is a generic and evolving term that encompasses the development of a wide range of materials and products. Definitions vary, but the essential characteristic is the deliberate exploitation of particles or structures that are measured on the nanometre scale.

A nanometre is one billionth of a metre; by comparison, a human hair is 80 000 nm thick. There are three types of nanoparticles:

- Natural: such as tiny particles from volcanic eruptions.
- Incidental: such as emissions from engine combustion.
- Engineered: purposely manufactured.

Nanoparticles may be divided into soluble and insoluble, the latter being of the greater potential toxicological concern when released.

Engineered nanoparticles are usually developed by scaling down commonly used materials (e.g. carbon, metal oxide and precious metal) from large particles to small. Others are built atom by atom to create completely new compounds that have no large size counterpart. Some are fixed (embedded material); others are free and could be released into the environment.”

Investment and interest in nanotechnology from the private and public sectors is increasing because of, amongst other things, its potential to transform sectors such as medicine, energy or water. Nanotechnology is expected to rapidly become a major element of the global economy. Currently most of the research is being done in OECD countries; however emerging economies such as Brazil are increasingly putting nanotechnology in their programme priorities.

Source: UNEP (2007), Emerging Challenges – Nanotechnology and the Environment; Global Environmental Yearbook, Membranes: the dominant technology

Membrane technology is a major actor amongst water treatment technologies. From the literature, nanotechnologies have an important role to play in the development of more efficient, cheaper and easier to use membrane technologies for water treatment. Nanotechnologies – nanosciences which can act at the scale of membrane pores – are being developed (e.g. nano-filtration membranes with pores enabling the selection of particles at the nanoscale) but nanotechnologies can also be used in the engineering of novel materials for improving membrane efficiency. Membranes can also be coupled to other technologies to perform more complex tasks for water treatment (e.g. membrane bioreactors). Nanotechnology can also be used to reduce fouling of membranes and filters.

Membranes: microfiltration, reverse osmosis and nano-particle enabled membranes

Contaminated or salty water is most often treated using two techniques. The more common method involves 7 stages: pre-treatment, coagulation, flocculation, sedimentation, disinfection, aeration, and filtration. By this method, all suspended solids, impurities and particles are removed; but it may not be effective for dissolved salts or for some soluble inorganic and organic substances. The second technology commonly used is pressure-driven membrane technology. This technology is based on a membrane which separates two homogenous phases (see Figure 3). It allows
some solutes to pass through but rejects the permeate. It achieves the separation of solutes of a fluid mixture when a force is applied (the force can be a pressure difference, a concentration gradient, a temperature difference or an electrical potential difference) (Hillie, 2006).

Four types of pressure-driven membranes technology exist. They vary essentially in the size of the pores of the membrane, the type of transport and/or the type of pressure applied. These technologies are: microfiltration (pore size 0.05-10 micron), ultra-filtration (pore size 1-100nm), nano-filtration (pore size <2nm) and reverse osmosis (pore size <2nm). Nano-filtration and reverse osmosis are the technologies most frequently used for desalination, remediation of water pollution, water softening and waste water treatment.

Nano-filtration using membranes is inexpensive compared to reverse osmosis due to the lower operating pressure and higher flow rates. It is especially well-suited to the treatment of municipal water which has been contaminated, well water or water from surface sources like rivers and lakes. Nano-filtration systems are capable of removing water hardness (calcium and magnesium). They are also used to remove pesticides and other organic contaminants from surface and groundwater.

Figure 3. Pressure-driven separation processes


Membranes have the advantage of requiring minimal use of chemicals and they are relatively easy to install and maintain. The energy required for these technologies to work varies but is relatively low in comparison with other technologies, e.g. reverse osmosis (RO). Increasingly, research is oriented toward the design of nanoparticle-enabled membranes which offer more energy-efficient water cleaning and reduced maintenance of RO systems. The development of novel nanomaterials is expected to have a major impact on the synthesis of novel polymer and ceramics enabling the design of higher quality membranes with, for example, better permeability, selectivity or resistance to fouling.
The main examples of membrane nanotechnologies under development today are inorganic-organic nano-composite membranes (for the moment mainly used for gas separation, pervaporation, and fuel cell applications); hybrid protein-polymer biomimetic membranes designed to mimic the highly selective transport of water and solutes across biological membranes; carbon nanotube membranes; and membranes enhanced through the immobilization of titanium oxide in the form of films. The choice between uses of these technologies will depend on the planned use of the water once cleaned. For example, nanofiltration using membranes does not affect water alkalinity, unlike reverse osmosis.

Increasingly, research is oriented toward the development of nanoparticles that will significantly improve the performance of membranes, for example, nanoparticles designed to limit the fouling of reverse osmosis (RO) membranes. Membranes for reverse osmosis are primarily for purification. Salty or contaminated water is pumped at extremely high pressure through the pores of the membrane, letting the water pass through but blocking the transit of salt ions and other impurities. Traditional RO membranes become unclean as bacteria and other particles build up on the surface. As a result more energy is needed to pump the water, and this eventually necessitates costly cleaning and replacement of the membranes. In membranes currently being developed, nanoparticles are designed to attract water, soaking it up like a sponge, while repelling nearly all the contaminants that might ordinarily stick to the surface. This creates a water purification process that is as effective as current methods but may have lower energy requirements (Science and Development Network, 2006). Although RO membranes, first designed in the 1960s, are already made on a nanoscale, this may be the first time that a material made of nanoparticles has been developed commercially for the purpose.

Membranes: Membrane bioreactors

A membrane bioreactor consists of the combination of a biological reactor (Go Green, 2005) and an ultra- or nano-filtration membrane. They can replace conventional treatments and combine clarification, aeration and filtration capabilities. In the bioreactor, the organic material of wastewater is digested by a biomass of filamentous bacteria. These bacteria live in colonial structures called floc and are kept in suspension by the mechanical action used to introduce oxygen into the wastewater. This mechanical action exposes the aerobic floc, also called activated sludge, to the organic material while treatment takes place. The membrane separates the water permeate (which goes for disinfection or is discharged) from the activated sludge (which is returned to the bioreactor). The suspended solid concentrations in the system are considerably higher than those achievable through sedimentation.

Compared to a septic tank, which takes several days to reduce the organic material, an activated sludge tank can reduce the same amount of organic material in approximately 4-6 hours. This allows a much higher degree of overall process efficiency. In most cases, treatment efficiencies and removal levels are so much improved that additional downstream treatment components are dramatically reduced or totally eliminated.

The Singapore National Water Agency (PUB) has developed a membrane bioreactor. The osmotic membrane bioreactor (OMBR) is an enhanced version of membrane technology and can produce water with better water quality at lower
energy cost. This is possible because it uses nanotechnology and a “natural osmotic pump”, mimicking osmosis in nature. This is also known as forward osmosis (FO), where water naturally flows through a membrane from the side of lower concentration to side of higher concentration (for example, of a salt). Water which has been used and is contaminated is purified by being put in contact (via a membrane) with a draw solution, which is of a higher concentration. In desalination, for example, ammonia and carbon dioxide gases can be dissolved in water to form a highly concentrated solution of ammonium salts (Menachem, 2007). This solution can be used as the draw solution to remove salt from water. After use, the draw solution can be heated to decompose the salts into ammonia and carbon dioxide again enabling them to be reused.

Box 6. Membranes in the water industry

Membranes are a dominant water purification technology, estimated at 20% of the market for water treatment and with a growth rate of 11% expected to approach USD 363 million in 2010. Membranes have relied on nanotechnology for decades but, as in other sectors, the term “nanotechnology” has only come into common use in recent times. Filters and membranes with nanoscale features operate under the principles of reverse osmosis (i.e. when pressure is used to force a solution through a membrane, keeping the solute on one side and allowing the pure solvent to pass to the other side).

Currently, up to a third of the cost of desalination plant is due to the energy required by high pressure pumps to force water through membranes. While further development is still required, research indicates that some nano-based water treatment methods require less energy than conventional treatment methods, can be delivered at a small scale, and may potentially offer wider applications at a lower cost than existing methods, which can be particularly important for their application in developing countries. For example, one proven way to reduce the energy cost of using membranes is to reduce the osmotic pressure and researchers have experimentally demonstrated fast transport of water and gases through membranes containing carbon nanotube pores.

The high surface areas and high throughput displayed by nanoscale filters and membranes make them attractive, together with the potential to engineer specific properties into them, e.g. electropositive surfaces to reduce fouling.

The number and size of membrane based plants for the production of potable water and for the treatment of wastewater are increasing rapidly, the market for membrane based systems being set to double in Europe alone between 2006 and 2011. Membranes have been in use for many years, their industrial scale use beginning with reverse osmosis membranes in the US in the 1960s. These plants produce clean water typically within one of the following scenarios: i) feed source seawater, supply unlimited, product potable water; ii) feed source brackish or human-contaminated well water, supply limited, product potable water; iii) feed source polluted water from rivers or lakes, supply often almost unlimited, product potable water; and iv) feed source waste water, product high quality clean water for farming/gardening or for discharge into rivers/lakes.

The integration of nano and membrane technologies can lead to greater contaminant absorption and increased efficiency, resulting in reduced cost of clean water production, e.g. using immersed membrane bioreactors.

Integrated membrane systems (IMS) combine pressure driven membranes (e.g. reverse osmosis), membrane bioreactors (MBRs) and membrane concentrators (for brine disposal). One area in which integrated membrane systems would be of use is to counter fouling (which results in reduced flux over time and which is generally irreversible). Nature deals with this by sloughing and nanotechnology is being used which mimics nature. There are many IMS under development but they are not yet ready for technology transfer for industrial testing. Some use rare metals (Pd, Pt) and are too expensive to scale up so cheaper alternative metals (e.g. Fe) are being sought.
Metals and semiconductor materials: an efficient biocide

Metals and semiconductor materials on the nanoscale are more effective than their larger scale counterparts in neutralising chemicals and microorganisms. Nanoparticles have two specific properties that make them particularly attractive sorbents: their mass (they have a much larger surface area than bulk particles) and their capacity to be functionalised with various chemical groups (increasing their affinity to the targeted compounds). They can also be doped with antibacterial metals to counter bacterial pathogens. Magnetic nanoparticles may also be used to remove salts (also achievable by nano electrocatalysis) and metals and to encourage the decomposition of organic materials (Roh, 2006).

For example, magnesia (MgO) and magnesium (Mg) nanoparticles are very effective biocides against bacteria and bacterial spores (Stoimenov, 2002). Silver and silver compounds have been used as antimicrobial compounds for coliform in waste water (Jain, 2007). Zinc oxide nanoparticles have been used to remove arsenic from water (Kalaugher, 2004).

Dendrimers: enhancing filtration membranes

Dendritic materials are attracting increasing attention as research and development in nanotechnology progresses. Dendrimers are spheroid or globular nanostructures that are precisely engineered to hold molecules encapsulated in their interior voids or attached to the surface (see Box 7). Size, shape, and reactivity are determined by the generation and chemical composition of the core, interior branching and surface functionalities (Dendritic Nanotechnologies Inc., 2005). It is relatively easy to control very precisely the size, composition and chemical reactivity of a dendrimer. Because of these characteristics, dendrimers have the potential for use as nanometre-sized building blocks.

Dendrimers show some potential to selectively attract contaminants and retain them in their branched structures and, due to their large size, to prevent them passing through membranes (Balogh, 2001). The presence of numerous chain-ends is responsible for the high solubility and miscibility and for the high reactivity of these structures.

There are more than a hundred families of dendrimers – they vary in the functions of surface, interior and core – meaning this technology presents a large spectrum of possible applications (Klajnert, 2001). Currently, dendrimers are principally used in the biomedical context as in-vitro diagnostics, for targeted drug delivery or as vectors in gene therapy. However, dendrimers can also be used for environmental purposes such as in environment friendly industrial processes or for water treatment.

In the case of water treatment, dendrimers could be used to enhance water filtration techniques. For example, dendrimers can be used in a first step of a water treatment in order to bind contaminants, and then a second step of filtration would produce water from which contaminants have been removed or modified. Examples of dendrimers that may be used in this type of process include cation-binding dendrimers, anion-binding dendrimers, organic compound-binding dendrimers, biological compound-binding dendrimers, viral-binding dendrimers and combinations of these.
Dendrons are dendritic wedges that comprise one type of functionality (such as chemical bonding) at their core and another at the periphery.

Dendrimers are dendrons coupled together to a core moiety with only one type of functionality at the periphery. Typically bis-MPA dendrimers are tridendrons that comprise a multitude of functional groups.

Bifunctional dendrimers are two dendrons with different peripheral functionalities joined together. These novel dendritic scaffolds are expected to find use in cutting-edge applications where a high degree of control over the dendritic polymer is of importance.

Hyperbranched materials are less perfect molecules than dendrimers, but still possess the highly branched architecture with a multitude of end-groups. The number of functional groups coupled with lower purchasing costs make these materials extremely promising in future applications.

In the case of ultra-filtration, for example, ultra-filtration membranes require less energy than nano-filtration or reverse osmosis, but the membranes are not effective in removing certain dissolved organic and inorganic solutes due to their small size. Coupling dendrimers with ultrafiltration membranes could enable the efficient removal from water of toxic metal ions, radionuclide, organic and inorganic solutes, bacteria and viruses.

Zeolites are micro-porous crystalline solids with well-defined structures. Generally they contain silicon, aluminium and oxygen in their framework and cations, water and/or other molecules within their pores. Many occur naturally as minerals and they are extensively mined in many parts of the world. Others are synthetic and are made commercially for specific uses.
Because of their unique porous properties, zeolites are used in a variety of applications with a global market of several million tons per annum. In the western world, major uses are in petrochemical cracking, ion-exchange (water softening and purification) and in the separation and removal of gases and solvents (British Zeolite Association, 2001).

Zeolites are widely used as ion-exchange beds for domestic and commercial water purification, softening and other applications. Zeolites are effective sorbents and ion-exchange media for metal ions. Their capacity for ion-exchange is exploited in a major way in water softening, where alkali metals such as sodium or potassium prefer to exchange out of the zeolite, being replaced by the "hard" calcium and magnesium ions from the water. Many commercial washing powders contain substantial amounts of zeolite for this reason. Commercial waste water containing heavy metals and nuclear effluents containing radioactive isotopes can also be cleaned up using such zeolites.

Zeolites contribute to a cleaner, safer environment in a great number of ways. Many applications of zeolites have been driven by environmental concerns, or have a significant role in reducing toxic waste and energy consumption.

**Zero-valent iron particles and derivatives**

The reducing capabilities of metallic substances have been used for water decontamination since the early 1990s. This is especially the case for zero-valent iron particles which are being investigated because of their ability to treat a large range of contaminants in waste water. Water pollution treatment using zero-valent iron nanoparticles (Tratnyek, 2006) is showing promise in neutralising organic solvents, fertilisers, pesticides and metal contaminants without dangerous by-products being formed when they are added directly into the polluted water source.

**Nanomaterial-based biosensors: monitoring water quality**

Sensors in water, and more particularly biosensors, are essentially used for recognising, measuring and monitoring the presence of contaminant. Nanotechnology is expected to enable the development of sensors that would be less expensive and more sensitive – by up to thousands or millions of times in the magnitude of their sensitivity – than the existing ones. Many nano-base sensor platforms operate on site, in real-time and they are able to measure simultaneously a broad range of pollutants and toxic agents.

The developments in sensor technologies based on nanotechnologies, for example in the food, medical devices and point of care health industries, could lead to useful tools that can be adapted for monitoring the effectiveness of the water purification process and for water management systems (see Box 8). Typically, sensors based on nanotechnology are more sensitive than those using other methods and enable users to measure rapidly with minimum sample size. Classical measurements of contaminant detection include polymerase chain reaction (PCR) and other DNA related methods (Science Daily, 2007) that operate at the nanoscale.
Nanomaterials are very attractive for the development of biosensors because of their capability to provide strong electrocatalytic activity, stability and minimize surface fouling of the sensors. Different nanomaterials can be used to manufacture highly sensitive and robust biosensors including carbon nanotubes, gold nanoparticles, magnetic nanoparticles, quantum dots and other materials such as metals, metal-oxides and polymers. These particles are increasingly being used in biosensors because of their particular physical, chemical, mechanical, magnetic and optical properties which enable significant enhancements in the sensitivity and specificity of sensor detection.

A biosensor is a device incorporating a biological sensing element either intimately connected to or integrated with a transducer. Specific molecular recognition is a fundamental prerequisite, based on the affinity between two or more complementary entities – such as enzyme-substrate, antibody-antigen and receptor-hormone. This property of the biosensor is used for the production of concentration-proportional signals. The selectivity of the biosensor and its specificity are highly dependent on the biological recognition systems connected to the transducer (Zhang, 2009). Advances in environmental research will increasingly take advantage of new nanomaterials-based sensing technologies for portable, ultra-sensitive systems for real-time and direct analysis. The extremely high surface-to-volume ratio of nanowires and their synthesis in a myriad of chemical forms (ceramic and polymeric) lend themselves to detection of chemical agents (e.g. pesticides), microorganisms (e.g. E.coli, giardia), and mineral compounds; the key for applications lies in modifying interfacial chemistries to achieve selectivity for a specific application (National Science Foundation (Experimental Program to Stimulate Competitive Research (EPSCoR) in Idaho, 2009).

One example of biosensor use is the Nanostructured Enzyme Biosensor designed by the Nanotechnology Centre at Victoria and Monash University’s School of Applied Sciences and Engineering in Australia, for the detection and monitoring of phosphate and nitrate in water and sediment samples (as well as sulphites in wine, beverage and food samples).

The sophisticated biosensors of today enable better measurement, analysis and monitoring of water quality in different ecosystems. Networks of sophisticated sensors are being put in place to collect and analyse the tremendous amount of data generated in water systems. IBM, together with the Beacon Institute for Rivers and Estuaries and Clarkson University, is for example, creating a data platform to support instrumentation of the entire length of the Hudson River (IBM, 2009).
Managing knowledge generation and sharing: infrastructures for nano-water technologies development

Examples of research bodies involved in water and nanotechnology include: the MESA+ Institute for Nanotechnology and the European Membrane Institute, both at the University of Twente in the Netherlands; Eawag, the Swiss Federal Institute of Aquatic Science and Technology (Switzerland); WaterCAMPWS (US); the Grand Water Institute (Israel); Beijing, Tsinghua and Peking Universities (China) and the Middle East Desalination Research Centre MEDRC (Oman) (See Annex 2 for information on some of these and also Boxes 9, 10 and 12 on China, Israel and India).

Box 8. Potential of nanotechnology for improved water management in agriculture

Nanotechnology: “the understanding and control of matter and processes at the nanoscale, typically, but not exclusively, below 100 nanometres in one or more dimensions where the onset of size-dependent phenomena usually enables novel applications. Utilising the properties of nanoscale materials that differ from the properties of individual atoms, molecules, and bulk matter, to create improved materials, devices, and systems that exploit these new properties.” (ISO TCC, 229)

Precision farming is increasingly using satellite-positioning systems (GPS), geographic information systems, automated machine guidance and remote sensing devices. Researchers are working to improve these systems – their accuracy and response rates as well as their size and robustness – through the use of nanotechnology (NanoForum.org, 2006). Water management in agriculture can be significantly improved in the future through the effective application of such emerging technologies.

Currently, wireless nanosensors are facilitating intensive sensing of environmental conditions to control the automated application of water, as well as fertilisers and pesticides (US Department of Agriculture, 2003) (Rickman, 2003). Sensing drought, levels of irrigation are automatically adjusted in the field in real time, making for more effective and efficient water use for better crops and lower costs. Likewise, sensors using nanotechnology can be fitted to combine harvesters to measure the amount and moisture levels of grains being harvested on different parts of a field, generating computer models which guide decisions about the application or timing of water inputs.

Industry is already applying wireless sensor networks in agriculture. Intel is combining electronic chips with nano-scale features into wireless networks of ‘motes’ (i.e. miniature, self-contained, battery-powered computers with radio links: motes can self-organize into networks, communicate with each other and exchange data). Motes can be used on the farm for irrigation management (Galcon, 2009), frost detection and warning, pesticide application, harvest timing, bio-remediation and containment, and water quality measurement and control (Crossbow Technology, 2009). Installed in vineyards in Oregon and California, United States, sensors measure the soil temperature once every minute but can equally be applied to measuring moisture levels and determining the need for irrigation (Intel, 2009; Millennium.net, 2009) (Dataweek, 2005). Networked sensors scattered on fields can also provide detailed data on crop and soil water content and relay that information to the farmer. As nanotechnology developments lead to better and cheaper sensors, this technology may be more widely applied.

The nanotechnologies being used in agriculture involve carbon nanotubes4, nano-cantilevers5, nanoparticles, nanosurfaces and nanosensors. They can also be applied in diagnostics; in detecting parasites and bacteria; encapsulation and controlled release of herbicides, pesticides and drugs; for grass growth regulation (Syngenta, 2009).

---

4. Rolled graphite sheets, hollow and a few nanometres in width but micrometres in length.
5. Micro-scaled structures which bind to specific chemicals causing the structure to bend like a cantilever, the motion being optically or electronically detected.
Emerging countries are investing heavily in research, initiatives and programmes for nano-water technology development and implementation

The involvement of emerging countries in finding solutions to tackle the issues of water availability and pollution, including the possible use of nanotechnologies, is increasing rapidly. In particular, Brazil, India, Israel, Russia, Singapore and South Africa are heavily involved in developing nanotechnology programmes. The involvement of scientists from emerging or developing countries may help to ensure a balance between the demand global for up-market products and services and the needs of developing and emerging countries.

An important question linked to the development of nano-water technologies by developed countries is whether research in this field will include a focus on providing products or services to serve the needs of emerging or developing countries (Chunli, 2008). The direct involvement of emerging and developing countries in water research and collaboration with research institutes and industries in developed countries can help to facilitate an equitable and efficient sharing of knowledge and competencies and will in the longer term assist developing countries to more easily adopt new technologies.

Box 9. China and water-related nanotechnologies

China is a country with a vast territory, varied landscape, complicated climate and frequent flood and drought problems. Water management has always been a crucial issue for China. China's total quantity of water resources is 2800 billion m³, which accounts for 6% of the world total and ranks the 6th in the world (after Brazil, Russia, Canada, United States and Indonesia). However, the average amount of water available per capita is 2100 m³ which ranks it 121st in the world. This places China as one of the 13 countries with the lowest average amount of water resource per capita. At the end of the 20th century, the estimate of annual water scarcity in China was approximately 30 to 40 billion m³. Between 1979 and 2007, China invested over RMB 851 billion in its water sector. In 2008, water infrastructure was massively developed and during this year provincial governments invested RMB 166.7 billion in water projects (Ministry of Water Resources of China, 2009).

A large number of projects linked to water have been launched in China including strengthening endangered reservoirs; undertaking urban water supply projects; addressing irrigation issues; introducing water conservation projects; and promoting rural safe drinking projects. Policies have been increasingly oriented towards the water crisis through, for example, the enhancement and adaption of the legal system and policy framework for water resources management and changes in the allocation of water resources.

China continues to increase its investment and promotion of scientific and technical innovation for water treatment, including nanotechnology solutions. China's investment in the nanotechnology research and development has increased by 20% each year since 1999 (Mackenzie, 2009). In 2015, it is expected by China that it will catch up with leading countries like United States, Germany and Japan in terms of its participation in the world market (Helmut Kaiser Consultancy, 2006). In 2008, for example, researchers at the Research Centre for Eco-Environmental Sciences of the State Key Laboratory of Environmental Chemistry and Ecotoxicology, Chinese Academy of Sciences, have developed novel low-cost magnetic sorbent material for the removal of heavy metal ions from water by coating iron oxide magnetic nanoparticles (magnetite) with humic acid (HA). The coating has greatly enhanced the stability of the material and the heavy metal removal efficiency of the nanoparticles.
Partnerships are being developed to increase the collaboration between emerging and developed countries but also between emerging countries themselves in the fields of science and technology. Many of these initiatives include nanotechnology as a priority in their agenda and some have developed specific programmes linked to new technologies and water:

- The German–Israeli Water Technology Co-operation Programme is one example of such initiatives. The co-operation in water technology stimulates research focussed on contributing to solving water problems in Israel and its surroundings and/or in Germany. The research is multidisciplinary and potentially applicable to the needs of the water sector. In addition to scientific partners, the programme aims to include industrial partners and related stakeholders (The Ministry of Science and Technology of Israel, 2009).

- The Singapore-Netherlands project on technology for water: the project of implementing an osmotic membrane bioreactor (OMBR) technology (see previously: membrane bioreactor) is a collaborative partnership between PUB and KIWA Water Research of the Netherlands. Studies on the technology are being carried out at the same time in Singapore and Netherlands under different climatic conditions. The findings are shared between the partners, which speeds up the research progress. If successful, the OMBR technology may be applied in various countries and could contribute to the quest for cost-effective ways to produce high quality water (Singapore’s National Water Agency, 2009).

**Box 10. Israel and water-related nanotechnologies**

Israel is one of the world’s most arid regions and provides water for over 7 million citizens. Population growth, from 1 million at independence to approximately 7 million in 2008, together with an increase in the standard of living has greatly increased Israel’s demand for water. Israel has developed efficient and integrated water planning and management projects as well as introducing innovative irrigation techniques for farming. Israel is the amongst the largest water recyclers in the world with a recycling rate of 75%. However, these projects alone would not have been sufficient to meet the significant rise in per capita water consumption and the below average rainfall. Israel has also had to search for and adopt new technologies to desalinate seawater and to recycle and purify waste water, and as a result had added 56% to Israel’s natural water resources (State of Israel, 2008).

Israel continues to invest greatly in cutting edge technologies for water treatment. The *Israel Export and International Co-operation Institute* reports that water technology exports totaled USD 1.4 billion in 2008 – double the value of exports in 2005. The global water market was expected to reach a value of USD 537 billion in 2009. Israel is also becoming an important source of research and development into nanotechnologies, with 81 companies participating within Israel (www.nanoisrael.org). In addition to initiatives such as the Israel National Nanotechnology Initiative (INNI), the Israeli government in investing over to USD 8 million for nanotech related equipment purchases and for advanced research projects in water treatment using nanotechnology (Ben-Artzi, 2007).

Note: The statistical data for Israel are supplied by and under the responsibility of the relevant Israeli authorities. The use of such data by the OECD is without prejudice to the status of the Golan Heights, East Jerusalem and Israeli settlements in the West Bank under the terms of international law.
Within the countries particularly affected by scarcity of exploitable water, programmes are also being launched to assist implementation of new technologies, such as nanotechnologies, within already existing water infrastructures (see Box 11).

The implementation of a simple water filtration method for cholera prevention in Bangladesh is an illustration of the range of issues that must be considered when developing projects for improving access to clean water. In this case, simple sari cloths were employed as filters for removing cholera bacteria from water. This system was introduced in underprivileged populations of Bangladesh and the evidence is that four months after the system was implemented 90% of the population had accepted the sari filtration system into their daily lives and the cases of cholera in this group was diminished by about 48% (in comparison to a group control). Sari filtration in this type of population satisfies economic efficiency, social equity and environmental protection (Hillie, 2006)

Box 11. Case study of a nanofiltration method in South Africa

“The South African Nanofiltration Case Study describes a project using nanofiltration membranes to provide clean drinking water to rural communities. It demonstrates that developing countries are applying nanofiltration technology to meet their citizen’s needs.

This is a project initiated by the South African government and implemented by researchers from a South African university. The case study is set in North West Province, a semi-arid region of South Africa. The majority of people in the rural area depend on groundwater or borehole water for their livelihood. Some groundwater sources are contaminated with inorganic nitrogenous pollutants, chloride, fluoride, calcium, and magnesium ions, which are a health risk to people in these rural communities.

North West University (NWU) obtained a research grant from South Africa’s Water Research Commission to conduct a research project to test a nanofiltration membrane technology unit for the removal of nitrate, chloride, phosphate, and sulphate ions pollutants from groundwater and to monitor rural consumer knowledge of and attitudes toward water purification.

Four flat-sheet nanofiltration (NF) membranes and a reverse osmosis (RO) membrane were selected for the water treatment study. The membranes were tested in a laboratory to enable the selection of the membrane most appropriate for contaminated groundwater in the village where the water treatment device would be deployed. Following the laboratory characterization, on-site water treatment studies were carried out with the water treatment plant.

The plant, which is compact and easily transportable, is also easy to operate and maintain, and has built-in safety features. In conjunction with the technical project, NWU conducted a study to determine consumer understanding of the implementation of a water treatment project, identify aspects that needed to be addressed in an educational program on water treatment, and develop, implement, and evaluate a water treatment education program. The involvement of the community from the outset and providing the community with the necessary information regarding basic water services resulted in the acceptance of the water treatment project and in community ownership of the service. Community members have shown a preference for the filtered water.

In addition to the direct humanitarian benefits of improving access to clean water, the technology highlighted in this case study can also promote economic viability in rural communities. A research student who has been working for the pilot project plans to acquire an identical system to install in her village.”

Infrastructures and networks

Infrastructures and networks are being put in place to increase research effectiveness and co-operation between public and private sectors with the aim of providing tools and knowledge for more efficient management of the development, transfer and implementation of water-related nanotechnology.

Infrastructures such as public-private partnerships or networks are seen as a key step to assist water-related nanotechnologies efficiently reach the market and the populations which need it. The use of these types of initiatives is increasing around the world. These types of infrastructures aim to improve knowledge exchange, establish and reinforce contacts between the private and public sector, support access to new projects and equipment, raise the awareness of young scientists regarding water issues and foster business development of water-related nanotechnology.

For example, in 2008, Yissum, the Technology Transfer Company of the Hebrew University of Jerusalem, launched a programme valued at USD 1 million to support the development of “cleantech” inventions coming out from the Hebrew University of Jerusalem. Amongst these inventions are novel technologies to combat water shortages. This initiative aims to reduce the gap between cutting edge research of the university and product-based industry, stimulating the commercialisation of novel technologies for water treatment.

Box 12. India and water-related nanotechnologies

India has the world’s second largest population with more than one billion people. Its population is more than three and a half times that of the United States; however India is only one-third of the size of the US in land area. Thus, India’s enormous and growing population is putting great stress on the country’s natural resources and particularly on water resources. Moreover, many water sources are contaminated by sewage and agricultural runoff. Although access to drinking water has improved, the World Bank estimates that 21% of communicable diseases in India are related to unsafe water. In India, diarrhea alone causes more than 1 600 deaths daily. (www.water.org/waterpartners.aspx?pgID=887).

Regarding the water issue, finding solutions to improve citizen’s access to safe water has become a major concern for policy makers in India. The Indian Water Portal (www.indiawaterportal.org/) shows the wide range of initiatives that have been taken to address this problem. Much is also being done to share water management knowledge amongst practitioners and the general public.

In addition to other projects, India has invested significantly in novel technology research for water treatment. Many initiatives have been launched to significantly enhance nanotechnology research in India. In 2007, the Indian government started a five year national project to make the country a global hub for nanoscience and nanotechnology with an investment of around USD 254 million. In this plan a particular emphasis have been given to research in novel water-related nanotechnology for water purifying, to eliminate bacteria and viruses, etc.

Nanotechnology, water and industry

The use of nanotechnology by global industry is expanding rapidly, along with increasing awareness of the potential of nanotechnology, and large companies are acquiring both nanotechnology companies and the technology. Small companies are being established in countries such as the US and China and are being bought out by large companies. The nanotechnology ‘sector’ is currently very fragmented across different industries. Further, sub-areas such as membranes are also fragmented both according to the business area and the technology employed. Much of the industry’s work on water tracks the health agenda (e.g. sensors as mentioned above). Industries which have particularly high water usage include chemicals production, paper and textiles.

Small and medium sized enterprises in nanotechnology typically hold one unique technology on which their whole portfolio is based (AltairNano, 2009). Large enterprises engaged in nanotechnology research (e.g. General Electric, Siemens, Dow Corning) are diversifying their research into the area of water and developing a broad portfolio of activities and a wide potential client base. Increasingly, they are forging collaborative relationships, encouraged by the vast scale of the global water challenge.

One area in which nanotechnology research is approaching commercial application is in point-of-use (POU) and point-of-entry (POE) water systems. POE systems are those in which the water is treated as it arrives at the building or complex while POU systems are closer to the user, e.g. under sink, on tap or jug filtration systems. For example, silver nanoparticles are being incorporated into activated carbon and ceramic based water filters to enhance anti-bacterial and microbiocidal effects (Diallo, 2008).

Testing and verification of nanotechnology based-systems is a necessary part of the development and commercialisation process, and the results can be a valuable tool for companies in diffusing information about their technologies and products to government and water supply decision makers, water financiers and businesses. However, the cost of testing and verification can also act as a barrier to companies bringing new products to market.

In addition to the technical challenges in bringing new nanotechnologies to market, the uncertain regulatory environment for nanotechnologies in many countries, the water industry is concerned about the legal risks presented both by the uses of nanotechnologies and of the potential presence of nanoparticles from waste water from industry and agriculture in its source water. For example, if industry is using a nanotechnology process or product and a problem subsequently arises, there may be an issue of accountability regarding the lack of preventive action. The industry is therefore keen to identify, assess and negate the potential risks. In addition, the water industry wants to be sure processes are available so that nanomaterials in industrial wastes and processes are able to be effectively extracted and that, if hazardous, can be isolated in a well-contained repository.

The water industry is undertaking projects to specifically address two aspects of the use of nanotechnology in water processing:
The first is the use of nanotechnology as an enabling technology to reduce costs, improve water quality and enhance public health. Industry is willing to adopt new technologies (with varying degrees of enthusiasm depending on their openness to being an early adopter) provided there are identifiable, minimal and acceptable levels of risk to the public and industry employees. But in the field of nanotechnology, health and safety risks remain unclear and is the subject of ongoing exploratory work (e.g. work of the OECD Working Party on Manufactured Nanomaterials, www.oecd.org/env/nanosafety). For example, where there is inclusion of nanoparticles in a water treatment system, it is important to be able to ensure that the particles are retained. Even where the nanoparticles are immobilised, disposal of obsolete and used components and materials also has to be considered.

The second issue is the presence of nanomaterials in water being treated. "Natural" nanoparticles have been in the environment for decades and more without known negative effects, however there are uncertainties around the presence of engineered nanoparticles in water. These nanomaterials may come from a variety of sources, for example industry, healthcare or agriculture. The involvement of the water industry in research into the potential health risks and environmental impacts which could be associated with manufactured nanomaterials indicates their strong interest in this issue.

The general level of awareness of potential nanotechnology solutions to water problems is currently low e.g. governments are unaware of the potential solutions which are being developed in research laboratories. Furthermore, the importance of water in solving the global challenges of energy or the environment is seldom recognised or mentioned.

However, it is also important to remember that the challenges in the provision and management of clean water are not only technological. Economic and social aspects are also of great importance and are the subject of many other studies, for example some completed and ongoing under the OECD Horizontal Programme on Water (OECD, 2009a). However, new technologies, including nanotechnology may make significant contributions to the arsenal of technological solutions already commercially available to address water problems.

In order to explore the issues for the business and research sectors in bringing nanotechnology based products to the water market place, discussions were held with business organisations and companies involved in water treatment, management and distribution; researchers engaged in work on water and nanotechnology with an industrial or social focus; non-governmental and governmental agencies working on the issue of water; including people in the field; experts in regulatory aspects of the water industry and health.

Key challenges identified from stakeholder discussions

For policy makers, the main challenge in providing access to safe water lies in balancing objectives which are often in conflict: economic, environmental, social and fiscal. Policy measures integrated across a number of government responsibilities are required. These in turn require cross-ministerial and inter-governmental agreement. This same approach also applies to the development and adoption of nanotechnologies to address the global challenge of access to safe water.
To explore some areas of policy challenge in relation to water, discussions were held with a variety of stakeholders, including industry professionals, researchers, academics, regulators and users from both the water and nanotechnology sectors. Whilst the study was not exhaustive, the same challenges were raised repeatedly by experts and have been synthesised into a number of specific challenges, outlined in the following sections under the headings of:

- Communication: knowledge sharing and capacity development
- System: the need for new or adapted business models
- Environmental, health and safety: clarifying potential risks
- Technology Transfer challenges
- Intellectual property rights in water-related nanotechnology
- Adoption challenges
- Economic feasibility

Annex 3 presents a number of case studies of technologies and related issues arising in the course of these discussions.

Each section below discusses a specific challenge and concludes with a boxed statement regarding the role of policy makers in supporting the development of nanotechnologies aimed at addressing the global water challenge.

**Communication: knowledge sharing and capacity development**

Water treatment using nanotechnology involves many different professional groups and communities. These include researchers, in both academia and industry; engineers, who operate and optimise the water plant; management and administrators; regulators and end users (domestic, industrial and agricultural). To illustrate the challenges of communication, two of the communities will be considered now.

The research community is successfully producing laboratory scale quantities of nanomaterials – particles, coatings and agglomerates. These materials can be applied at the laboratory scale, for example micro-litres of water per minute, to test the effects and effectiveness of nanotechnology-based materials in experiments which mimic water treatment systems. For researchers, the cost of producing clean safe water through these systems is not a consideration. Their focus is on the generation of new knowledge and, in some cases, its application.

Water industry process engineers are responsible for optimising water treatment and supply systems. They deal with hundreds of thousands of cubic metres of water with very high flow rates per second. The cost of processing water is of paramount importance to this group.

6. Discussions with over 30 water and nanotechnology professionals in 2008-2009 through phone interviews and at the OECD workshop at Nanotech Northern Europe Conference 2008 (see Annex 1). The participants represented multi-national enterprises, utilities companies, start-up and spin-off companies, non-governmental organisations, consultancy companies, academic research, public research organisations, industrial research bodies, national research councils, aid agencies, government agencies, financiers, business representative organisations and networks of water practitioners. Summaries of the discussion are presented in Annex 3.
Thus, for the outputs of the nanotechnology research sector to be relevant to the water industry, the materials they produce must be robust and be transferable at large scale and a competitive price to industrial water processes. However, the experiences reported by these two groups highlight the challenge of effective communication and reflect the more general challenge in the application of new technologies to traditional industries. Industrial systems continue to move away from the old style “black box” plants, which ran with little technical input, to highly sophisticated plants requiring increased technical expertise. More effective communication is needed between researchers and industry as the complexity of industrial production increases and increasing numbers of technically skilled people are employed in operational roles. Whilst this is a general trend across industry, it creates particular difficulties in more traditional industries where, until recently, the need for technological understanding has been fairly low.

In the water industry, better communication between the research and water sectors is necessary for new technologies such as nanotechnology to be adopted. Currently the gap in technological understanding between process engineers and nanotechnologists is often very wide. There are also similar gaps in understanding between each of the professional communities, for example researchers and management, engineering and management, etc. One possible mechanism to enhance communication between these groups would be the use of so-called “gatekeepers”, who combine specialist and general knowledge and can bring an understanding of different sectors into the communication process (OECD, 2010b).

### The role for policy makers

Mechanisms which foster interaction between communities in the water industry (e.g. process engineers and nanotechnologists) can help to increase the impact of nanotechnology on the water industry as a tool and a process enhancement. Some governments and international funding bodies are facilitating this by supporting collaborative projects (industry/academic/public sector research) in the water sector, projects which incorporate research, technological development, testing, prototyping and pilot plants.

### System: the need for new or adapted business models

Related to the challenge of communication is the challenge of establishing a system which facilitates the integration of new technologies into the established water industry and enhances the willingness of the marketplace to adopt the newly proved technologies.

The water industry, even multinational companies, cannot undertake the breadth of research required to remain at the forefront of industrial and technological development. Nor can they identify and adapt all the available useful technologies. These companies are faced with a number of options: to rely on the current technology base, possibly diminishing competitiveness in the market; or to develop partnerships and collaborations to enable it to utilise the latest developments. Many of the largest water companies and groups of companies are actively forming partnerships with researchers in universities and the public sector; with start-up companies; with service providers and with their clients. These partnerships assist the companies to access the expertise necessary to develop complete
and competitive systems. Partnerships are also being formed to assist companies
deal with regulatory, legal and social issues.

Discussions with industry indicated that start-up companies also welcome this
approach. In addition to finance, start-ups require the expertise of the water
industry to bring their technology and the resulting new or improved products to
the market place. The public sector water companies were identified as valued
clients whenever relationships could be established and where they are willing to be
early adopters of new technology.

In addition, the need was identified for a system of financing to support
companies to grow (e.g. through the stages of testing, prototyping and pilot plant
operations) as part of the overall development system of water industry. As the
industry develops further along a technological path, systems and policies to
facilitate technology procurement, intellectual property management and regulation
may be required as part of the overall policy environment for the industry.

Some national research and industrial development policies foster innovation
from the laboratory to the marketplace and take a long-term and risk-accepting
view. Annex 2 sets out the approaches to water policy of a range of international
organisations.

### The role for policy makers

A complete supporting system of research and industrial development (including research
testing prototyping and pilot plants) can help the water industry to adopt and adapt to
new technologies such as nanotechnology. Collaborative projects and a supportive
environment are required.

### Environmental, health and safety: clarifying potential risks

Nanoparticles can behave quite differently from macro-particles. Whilst there is
strong interest in the different functionalities of nano-particles compared to macro-
particles, there is only limited knowledge of their toxic and eco-toxic characteristics.
The unknown impacts of these properties lies at the core of the ongoing health and
safety concerns regarding the use of nanoparticles, including in water processing
and treatment. Some specific characteristics result from properties which are
specific to nanoparticles such as solubility, reactivity, selectivity, and catalysis, as
well as propagation and mobility in the environment and in organisms (e.g. permeability
of cell membranes and penetration of the brain via the nose and olfactory nerve)
(Steinfeldt, 2007). The key challenge lies in determining and clarifying which specific
safety and environmental risks can arise when manufactured nanomaterials enter
the environment, as well as when using these particles in controlled conditions.

Risk assessment mechanisms within countries are yet to be fully adapted to
cover nanotechnologies. Facilities for the manufacture of nanoparticles are still
approved based upon previously existing regulations and on the worker safety and
environmental risk assessment procedures for macro particles, although regulations
are increasingly being amended and adapted. The demand for methodologies enabling
the assessment of the entire life cycle of a nanoparticle is growing. In 2005, more than
USD 10 billion was spent on nanotechnology research globally, while the United
States and the European Union were estimated to be spending USD 39 million per
year on research on the effects of nanoparticles on human health and the environment (United Nations Environment Programme, 2007).

Many groups are currently working on these issues. For example, the OECD Working Party on Manufactured Nanomaterials (WPMN) has the key task of strengthening international co-operation on safety research related to manufactured nanomaterials (see www.oecd.org/env/nanosafety). For a national example, see the Nanoscale Science, Engineering and Technology Subcommittee of the US National Nanotechnology Initiative (NNI), whose Nanotechnology Environmental and Health Implications (NEHI) Working Group provides a forum for US agencies to co-ordinate their individual activities related to understanding any potential risks of nanotechnology (National Nanotechnology Initiatives, 2009). As mentioned previously, the water industry is also engaged in projects looking at life cycle issues related to both nanotechnology as an enabler in water processing and as a potential agricultural or industrial pollutant in water supplies.

Companies developing nanotechnologies are thus faced with changing and potentially expensive national and international regulatory environments as they bring products to market. Nevertheless, the nanotechnology sector is committed to the exploration of potential health effects in the use of any technology or methodology for water treatment.

Also life cycle perspectives are important to take in account when considering the potential risks and benefits of nanomaterials/nanotechnologies throughout their lifetimes. Starting from the premise that all scientific work is inherently incomplete, decisions – in particular regulatory ones – need to be made in the face of uncertainty. The potential hazard arising from and/or exposure to a nanoparticle will need to be weighed against the criticality of and/or need for the nanoparticle. In this debate, it is important to continually question whether the use of nanotechnology is necessary to yield a significant advantage over other, more traditional technologies. Lifecycle perspectives are critical as nanotechnology moves forward, and life cycle analysis (or components therein) may be a useful tool. Innovation should incorporate guiding principles like green design and lifecycle perspectives. Early and ongoing analyses of potential exposures and/or hazards can also benefit nano-related innovation.

The role for policy makers

Work on the evaluation of the characteristics and likely impacts of nanoparticles in water, whether from water treatment or from external sources, is important in providing a basis for sound decisions relating to the operation of water monitoring and treatment systems.

Technology transfer challenges

Technology transfer: from research to industry

An important technical challenge in using nanotechnology for water treatment relates to the use of laboratory developed materials for industrial purposes. Materials for research do not generally have the robustness required for industry. For example, for nanoparticle production, industry may require a strictly limited size profile while research uses may not. In addition, the products of laboratory research may not be tested and validated to the standards and with the stringency required by industry
i.e. that needed to provide a robust characterisation data sheet. Particles may also exhibit essential active characteristics in the laboratory (e.g. photo activity) which may be lost on an industrial scale. Finally the cost of the materials for industrial scale use must be competitive with existing technologies, whereas this requirement is rarely a factor for laboratory quantities of nano-materials.

In addition, other important elements of this challenge relate to a lack of effective communication between researchers and industry, discussed above, and to the management of intellectual property, discussed below.

**Technology transfer to the point of use**

Solving the technical issues linked to the development of nano-water technologies is not an end in itself. To deliver useful outcomes, the technologies and relevant skill sets need to be transferred to the industries, countries and regions where they will be used. Effective wide-spread implementation of new technologies is a complex business, likely to meet frequent obstacles. Indeed, successful transfer cannot be guaranteed.

Delivering new technologies to address global challenges requires large scale transfer to both developed and developing countries.

Transfer to developing countries presents additional challenges. The application of new technologies needs to be adapted to local conditions, and to be adopted by the local population. If possible, these solutions should be developed in conjunction with the countries involved. And to be successfully implemented in developing countries, the technology solutions should be relatively simple and inexpensive to install, operate, and maintain; this applies equally to nano-water technologies.

Local characteristics to be considered to assist successful implementation include the capacity of the local and regional market, current available infrastructure, the development of local capability and capacity to deliver sustainable adoption, efficient operation and ongoing maintenance of the nano-water technologies, and the capacity for future upgrade of the plant and technologies. These issues are crucial to successful implementation, and must be adapted to local conditions, knowledge and capacity.

The public sector, in particular public utilities, can play a significant role in bringing new water process technologies to the marketplace. Some countries choose to use public procurement to enable the introduction of systems into the market and to support the growth and stability of nascent industries. Public procurement of nanotechnology-based water treatment could also assist new and small companies to prove the effectiveness and efficiency of their innovations in nanotechnology and water.

**Choosing between water technologies**

Successful operation of water facilities requires the selection of appropriate technologies from a range of possibilities. In order to fully exploit the potential of nano-water technologies, it will be crucial to choose the most appropriate technologies from amongst numerous existing technologies or those under development, taking into account the local conditions where the technologies will be applied. Indeed, different countries and regions face different environmental, social, and economic conditions and have different needs with regard to water use and water
quality. Suitable, sustainable technologies must also be chosen with the local operational and maintenance requirements in mind.

At least three major criteria have to be taken into account when a water solution is implemented in a particular area: economic efficiency, social equity, and environmental protection. There are a wide variety of technologies – from basic to highly sophisticated – that could be adopted to address particular water issues. Equity of access to novel and cutting edge technologies for developing countries should be considered; however, simple solutions are often efficient and can be more easily adopted. In making choices amongst the technologies and systems, the community should play a role, alongside governments and other stakeholders.

The role for policy makers
To aid in effective transfer of water-related nanotechnology, stakeholders should seek to enhance co-operative mechanisms, including i) the development of public-private partnerships in order to foster business development of water-related nanotechnologies, and ii) international co-operation between developed and developing economies.

Intellectual property (IP) rights in water-related nanotechnology

A sound intellectual property strategy is an important component of efficient sustainable business-models for technology based business. Intellectual property rights are particularly important for small and start-up companies, for whom IP is a key asset that must be protected, at the same time protecting their knowledge and inherent value from any “infringement by large corporations” (Bastani, 2003). The interdisciplinary nature of nanotechnology add further dimension to the importance of intellectual property in its commercialisation and application.

Nanotechnology research is still in its infancy and few water-related products incorporating nanoparticles have yet reached the market. The rapid ongoing development of nanotechnology can best be supported by knowledge sharing and easy access to information. The involvement of developing and emerging economies in the development and implementation of water-related nanotechnology, coupled with beneficial access to nanotechnology IP, is an important contributory factor to assuring access for all countries to scientific and technical knowledge, and to avoid the development of a “nano-divide” between developed and developing countries.

The role for policy makers
An appropriate intellectual property strategy is a core element in ensuring the wide availability of nano-enabled water technologies to all. The involvement of emerging and developing economies during all the key phases of development and delivery of nanowater technologies will assist in avoiding the development of a “nano-divide”.
Adoption challenges

Discussions with stakeholders revealed that there were a variety of issues limiting the adoption of nano-water technologies, and that relative importance of these issues vary depending on the applicable circumstances. In developing countries, limiting issues include:

- Cost (both capital and running costs, including the provision of trained staff)
- Potential to acquire materials and equipment locally (without over-dependence on centralised suppliers)
- Ease of local management (for both operation and maintenance)
- Safe disposal of any waste material; and
- Reluctance to adopt any new behaviour, except in times of extreme need (e.g. famine, flooding) (this point is highly dependent on individual countries and groups of people)

In developed countries, issues may include those above, in addition to the following issues:

- Cost – reluctance to pay for what is seen as an entitlement
- Regulation and standards
- Uncertainty over risks to environment, health
- Confidence – and the reluctance of an often public sector industry to be the first adopter of novel technological solutions.
- Conservatism of the water industry (although the perception of this is perhaps greater amongst researchers and potential suppliers than in the industry itself).

The role for policy makers

The cost of new nano-water technologies is likely to be a factor limiting its adoption in many countries. In developing countries, inability to pay for these technologies may require a change in aid and international funding strategies, for example redirection or increase of funds. However, the issue of reluctance to adopt a new behaviour and concern over health and safety would remain and may only be resolved over time. In developed countries, a reluctance to pay for new developments in water treatment may be effectively addressed through education and communication.

Economic feasibility

In order to effectively bring nano-water technologies to the marketplace, they need to be cost competitive and economically viable. The technologies also need to be financially and economically adapted to the place where they will be implemented. A recent OECD (OECD, 2009b) report examined the economic and financial aspects of water management, highlighting the need for a cross-sectoral perspective to address water challenges and emphasising the importance of establishing a firm evidence base to support policy development and implementation (see Box 13).

However, technological solutions are only a complement to required economic and social measures.
Box 13. Main messages coming from the OECD Horizontal Water Project report on:

Managing Water for All: An OECD Perspective on Pricing and Financing
Key Messages for Policy Makers

1. Integrated water resources management should be implemented more effectively to manage the increasing competition for water between agriculture, other uses and environmental needs; this requires better information.

2. Substantially more investment is needed in both OECD and developing countries to achieve water and, especially, sanitation policy objectives, and to realise the associated economic, social and environmental benefits.

3. Better governance can optimise investment needs, promote more efficient use of existing resources, enhance the ability of the water sector to attract finance, and harness the efforts of all stakeholders, including the private sector; this requires, amongst other things, improved regulatory oversight, incentives, and accountability of water operators, whether public or private.

4. Strategic financial planning that blends tariffs, taxes and transfers – the “3Ts” – provides an important means for agreeing on water- and sanitation-related investment targets, and how they will be achieved; it can also help to leverage additional sources of finance.

5. Well-designed tariffs are crucial for achieving sustainable cost recovery; they should be established through transparent processes, taking account of local circumstances, and with appropriate measures to ensure that poor and vulnerable groups have access to sustainable and affordable water and sanitation services.

6. Aid flows to the water sector should continue to increase and to align with country-owned strategies; they should be used strategically to complement and reinforce developing countries’ efforts to achieve the water and sanitation targets, and thus contribute to achieving several Millennium Development Goals.

7. The current financial crisis presents risks but also opportunities to reinforce commitments to the water sector, and to invest in water infrastructure as part of fiscal stimulus packages.


A number of programmes are being put in place to measure the cost effectiveness of water solutions as a function of their region of implementation. The Arsenic Water Technology Partnership Program, for example, is expected to be a multi-year effort that moves technologies from the bench-scale to demonstration, with assistance being provided to utilities on implementation. This program will enable water utilities, particularly those serving small, rural communities and tribes in India, to implement the most cost-effective solutions to their arsenic treatment needs (Arsenic Water Technology Partnership, 2009). The consortium WERC, Consortium for Environmental Education and Technology Development, will evaluate the economic feasibility of the technologies investigated and conduct technology transfer activities (WERC, 2009).

Most of the time, the assessment of the implementation of a water project in a region is done through cost-effectiveness analyses, where water technologies are evaluated primarily in monetary terms. However, increasingly analyses include formal evaluation of the environmental and social impacts of these technologies. Whilst it is difficult to evaluate these criteria, there are some validated approaches, such as multi-criteria analyses or the sustainable water resources management and planning approach.
There remains a need for more studies evaluating the economic feasibility and impact of investments in water-related nano-infrastructures, focused on planned regions of implementation. The short and long term economic impact of the recent economic stimulus packages on the implementation of new water-related technologies also requires further investigation.

Many of the issues in the section above are not unique to nanotechnology. They are, however, made more acute because water provision is a conservative and traditional industry and nanotechnology is an emerging technology.

<table>
<thead>
<tr>
<th>The role for policy makers:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Economic impact assessment of the implementation of nano-water technologies through cost-effectiveness studies is of key importance. The environmental and social impacts of these technologies should also be measured. The relative impact of these issues will largely depend on the location of implementation of the technology.</td>
</tr>
</tbody>
</table>

Goals and proposed actions to address the key challenges to the adoption of nanotechnology water solutions

In order to address these key challenges, water and nanotechnology industry professionals identified actions that can be applied in the local context, in order to reach the following goals:

The first goal is to strengthen science, engineering and commercial linkages by drawing on national good practice examples in the use of other technologies for the enhancement of water systems, and to support activities in water and nanotechnology which have the potential to enhance communication, understanding and collaboration between stakeholders. For example, government agencies could promote and facilitate co-operation between nanotechnologists, process engineers and managers in the water industry with the aim of leading to more effective engagement on issues such as research, technological development, testing, incubation, prototyping, upscaling to pilot plants; and water resource management.

The second goal is to foster international linkages through identifying national good practice in managing international co-operative arrangements which are addressing the issues of access to and management of water, and supporting the national development of and/or engagement in such co-operation for water and nanotechnology. International linkages can also be fostered by countries supporting national engagement in international programmes to apply nanotechnology in developing countries in ways best suited to the local situation (e.g. facilitate foreign researchers to undertake research on nanotechnology-based applications to water problems by providing a supportive local environment for their work).

The third goal is to develop supportive platforms to increase coherence and coordination in the funding of nanotechnology for water research and development, including water resource management and fiscal measures. By supporting a complete system of research and industrial development (including research, development, testing, prototyping, pilot plant operation, recycling and water resource management activities) governments can assist the water industry to adopt and adapt new technologies such as nanotechnology. Working to overcome the technical challenges of transferring technologies from the research laboratory to industrial scale use is of
particular importance with an emerging technology such as nanotechnology and collaborative projects and a supportive environment are essential.

The fourth goal is fostering informed and balanced approaches to support and engage in work on the risks and benefits of nanotechnology in accessing clean water at both national and international levels. This work should be based on a determination, at the national level, of the best ways of engaging with this international work. Countries may also engage in national and international evaluations of the characteristics and likely impacts of nanoparticles in water, whether from water treatment or from external sources, in order to strengthen the basis for sound decisions relating to the operation of water monitoring and treatment systems. The work of the OECD Working Party on Manufactured Nanomaterials is at the forefront in many of these areas.

The fifth goal is to develop strategic roadmaps by considering at national and international levels the best financial means for water provision and good resource management and implementing them in parallel with technology-based solutions. Countries can work to achieve complementarity of actions focussed on nanotechnology with those addressing fiscal, economic and social issues, at national and international levels. For example, countries may engage in education and communication activities to raise awareness of the importance of good water resource management and to encourage stakeholders to understand the cost of water provision and to take responsibility for it. At the international level, the OECD Horizontal Water Programme (working in conjunction with the Global Water Partnership, the UN and its agencies, Aqafed, other business organisations, NGOs and other groups) is developing tools and methodologies to assist countries with water pricing, governance and effective and efficient delivery.

Initial steps to achieve these goals are identified below. These recommendations have been developed in light of the actions proposed by relevant professionals and practitioners. They are put forward to stimulate debate within national governments and in international contexts.

**Recommendations**

Governmental and intergovernmental bodies supporting collaborative research and development should consider ensuring that the potential of nanotechnology as a solution to global challenges such as water is reflected in their funding allocations. This will bring researchers in institutions and in industry together thereby establishing a mechanism and a dialogue on bringing nanotechnology solutions to bear on the water challenge. By supporting a complete system of research and industrial development (including research, development, independent testing and verification, prototyping, pilot plant operation, recycling and water resource management activities), funding bodies can help the water industry to adopt and adapt new technologies such as nanotechnology while encouraging further work to
overcome the technical challenges of diffusing technologies from the research laboratory into industrial scale use.\textsuperscript{7}

**Stakeholders** – government, non-government, international bodies and industry – **should support and engage with work on addressing fiscal, economic and social issues** at national and international levels for different types of source waters in conjunction with national and international initiatives on nanotechnology and water. Pricing water will not only improve its management, but will also strengthen incentives for innovation related to water. Communication on social issues related to water will lead to better solutions matched to local and regional needs and resources. Increased awareness of risks and benefits of new technologies in the water sector will strengthen the basis for sound decisions relating to the operation of water monitoring and treatment systems. Organisations engaged in this work, with whom stakeholders could interact to achieve this goal, include the OECD Horizontal Water Programme; the Working Party on Manufactured Nanomaterials; the Global Water Partnership; the UN and its agencies; business organisations such as BIAC and Aquafed; humanitarian and non-governmental agencies and other civil society groups. The overall aim would be to connect pricing and social issues related to the water problem, including water quality and risk issues, with technological tools and methodologies in a comprehensive and balanced approach to the challenge.

**Countries should consider coming together in an international event on nanotechnology and water** bringing together participants from the water industry, the nanotechnology industries including materials, and sensors, the science and public health communities, OECD governments and the OECD enhanced engagements countries\textsuperscript{8} to discuss the key issues raised in this paper, from needs to technological solutions; to exchange good practice examples in the use of nanotechnology and other technologies for the enhancement of water systems; and to identify steps to be taken by national and international governmental bodies to optimise the use of nanotechnology in the water sector. The event, hosted by interested countries, would enhance communication and networking for participants, increase awareness of the issues, facilitate clarification of the challenges, and provide an opportunity for agreement on future actions and activities.

By considering and debating the recommendations at national and international levels, it is anticipated that progress can be made towards taking appropriate measures to address global water challenges.

\textsuperscript{7} It has been suggested that collaborative research programmes for development in the following main activities would be useful in addressing the global challenge of water: \textit{i)} membranes for ultra-filtration, nano filtration and reverse osmosis for water treatment, gas separation membranes that may be useful in energy saving and fuel cells; \textit{ii)} nano catalysis and nano-adsorption and their technologies for contaminant removal from water; \textit{iii)} new devices for identification of different bacteria in drinking water; \textit{iv)} better techniques for on line identification of organic and inorganic contamination; and \textit{v)} a range of techniques for removal of contaminants from different industrial wastewaters. It is estimated that such programmes would require collaboration between at least three countries, of duration approximately three years and at a cost of EUR 15 million each. If two such programmes were funded it is estimated by their proposers that product development by companies could generate a multiplier effect of between 10 and 50 times on the R&D investment. It is recommended the selection committee be comprised of stakeholders.

\textsuperscript{8} OECD enhanced engagement countries are Brazil, China, India, Indonesia and South Africa.
ANNEX 1: OECD WORKING PARTY ON NANOTECHNOLOGY WORKSHOP

“Nanotechnology and the Global Challenge of Access to Clean Water”
Nanotech Northern Europe 2008 Conference, Copenhagen, 25 September 2008


Nanotech Northern Europe is Europe’s largest annual nanotechnology conference and exhibition and in 2008 took place in parallel with the two exhibitions Biotech Forum (www.biotechforum.org) and Scanlab (www.scanlab.nu). Attendance numbers were in the thousands for the exhibition with approximately 50 attending the workshop. The programme for the workshop was as follows:

<table>
<thead>
<tr>
<th>Nanotechnology and the global challenge of access to clean water</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Session One: Nanotechnology-enabled water purification</strong></td>
</tr>
<tr>
<td><em>Welcome – opening statement by OECD</em></td>
</tr>
<tr>
<td>Dirk Pilat, OECD Directorate for Science, Technology &amp; Industry</td>
</tr>
<tr>
<td><em>Harnessing nanotechnology for clean water – nexus to economic output</em></td>
</tr>
<tr>
<td>Mark A. Shannon, The WaterCAMPWS (The Centre of Advanced Materials for the Purification of Water with Systems), United States</td>
</tr>
<tr>
<td><em>Nanotechnology: innovation diffusion, a global perspective</em></td>
</tr>
<tr>
<td>Claire Weill, Institut du développement durable et des relations internationales, France</td>
</tr>
</tbody>
</table>

| **Session Two: Nanotechnology-enabled water purification**     |
| *Chair: Prof Maggy Momba, Tshwane University of Technology*   |
| *Roadmap for the production of clean water using nanotechnology in Russia* Marina Doroshenko, State University - Higher School of Economics, Russia |
| *Nanotechnology and Process Engineering for the Water Industry* Bruce Jefferson, Cranfield University, United Kingdom |
| *Nanosystems for Water Quality Monitoring and Purification*    |
| David Rickerby, European Commission Joint Research Centre, Italy |
| *Panel discussion: Barriers to the development and application of cutting-edge nano-enhanced water purification techniques* |

| **Session Three: Challenges of commercialisation and use of nanotechnology-enabled water purification** |
| *Chair: Dr Mostafa Analoui, Head of Healthcare and Life Sciences, The Livingston Group* |
| *Efficiency and Life-Span of Capillary Polysulphonate Ultra-filtration Membrane for the Removal of Indicator Bacteria* Maggy Momba, Tshwane University of Technology, South Africa |
| *The Water Initiative* Kevin M. McGovern, McGovern Capital LLC, United States |
| *Enhancing solar disinfection of water for application in developing regions* Tony Byrne, Nanotechnology and Integrated BioEngineering Centre, University of Ulster, Northern Ireland, United Kingdom |
| *Panel discussion: Challenges in commercialisation, industrial uptake and broader use* |
ANNEX 2: OTHER POLICY ACTIVITIES RELATED TO WATER

UNESCO

www.unesco.org/water/about.shtml

Since 2003, UN-Water has been the official United Nations mechanism to support member states in their efforts to achieve water and sanitation goals and targets. The work of UN-Water encompasses all aspects of freshwater, including surface and groundwater resources and the interface between fresh and sea water; freshwater resources (quality and quantity, development, assessment, management, monitoring and use); sanitation (both access to and use of sanitation by populations and the interactions between sanitation and freshwater); and water-related disasters, emergencies and other extreme events and their impact on human security. UN-Water acts at global, regional and country level, linking the activities of separate UN agencies and programmes and co-operating with external partners.

The World Water Assessment Programme (WWAP) within UN-Water is an UN-wide programme which monitors freshwater resources and ecosystems in order to provide recommendations, develop indicators and case studies, enhance assessment capacity at a national level and inform the decision-making process. Its World Water Development Report is a periodic review of the state of the world’s freshwater resources.

United Nations Food and Agricultural Organisation (UN FAO)

www.fao.org

The Food and Agriculture Organization of the United Nations leads international efforts to defeat hunger. Serving both developed and developing countries, FAO acts as a neutral forum where all nations meet as equals to negotiate agreements and debate policy. FAO is also a source of knowledge and information. It helps developing countries and countries in transition modernize and improve agriculture, forestry and fisheries practices and ensure good nutrition for all. Since 1945, it has focused special attention on developing rural areas, home to 70% of the world’s poor and hungry people.

The Water Development and Management Unit (NRLW) takes a programmatic approach to agricultural water management addressing water use efficiency and productivity, and best practices for water use and conservation, throughout the continuum from water sources to final uses. Specific targets are integrated water resources management, water harvesting, groundwater, use of non-conventional water, modernization of irrigation systems, on-farm water management, water-quality management, agriculture-wetlands interactions, drought impact mitigation,
institutional capacities, national water strategies and policies, river basin and trans-boundary waters management.

NRLW collaborates with all other technical departments of FAO in order to generate a coherent and comprehensive FAO-Water programme effectively contributing to the achievement of the related Millennium Development Goals. With its continually updated water information system AQUASTAT, and tools for analysis such as CROPWAT, AQUACROP and MASSCOTE, NRLW is able to contribute in the formulation of national and regional water management strategies and perspective studies.

The World Health Organisation
www.who.int/water_sanitation_health/en/

WHO works on aspects of water, sanitation and hygiene where the health burden is high, where interventions could make a major difference and where the present state of knowledge is poor:

- Drinking water quality
- Bathing waters
- Water resources
- Water supply and sanitation monitoring
- Water, sanitation and hygiene development
- Wastewater use
- Water-related disease
- Healthcare waste
- Emerging issues in water and infectious disease.

Its work on water sanitation and hygiene includes the six core functions of WHO:

- Articulating consistent, ethical and evidence-based policy and advocacy positions.
- Managing information by assessing trends and comparing performance; setting the agenda for, and stimulating, research and development.
- Catalysing change through technical and policy support, in ways that stimulate co-operation and action and help to build sustainable national and intercountry capacity.
- Negotiating and sustaining national and global partnerships.
- Setting, validating, monitoring and pursuing the proper implementation of norms and standards.
- Stimulating the development and testing of new technologies, tools and guidelines.
WaterAid
www.wateraid.org/uk/default.asp

WaterAid is an international charity. Its vision is of a world where everyone has access to safe water and sanitation and it seeks to overcome poverty by enabling the world’s poorest people to gain access to safe water, sanitation and hygiene education.

WaterAid works with local partners, who understand local issues, and provides them with the skills and support to help communities set up and manage practical and sustainable projects that meet their real needs. It also campaigns locally and internationally to change policy and practice and ensure water and sanitation’s vital role in reducing poverty is recognised. WaterAid works in 17 countries providing water, sanitation and hygiene education to some of the world’s poorest people.

The Global Water Partnership
www.gwpforum.org/servlet/PSP

The Global Water Partnership is a working partnership among all those involved in water management: government agencies, public institutions, private companies, professional organisations, multilateral development agencies and others committed to the Dublin-Rio principles.

GWP actively identifies critical knowledge needs at global, regional and national levels, helps design programs for meeting these needs, and serves as a mechanism for alliance building and information exchange on integrated water resources management.

The mission of the Global Water Partnership is to "support countries in the sustainable management of their water resources."

The GWP's objectives are to clearly establish the principles of sustainable water resources management; identify gaps and stimulate partners to meet critical needs within their available human and financial resources; support action at the local, national, regional or river basin level that follows principles of sustainable water resources management; and help match needs to available resources.

OECD Horizontal Programme on Water
www.oecd.org/water

See Box 3 in the main body of this document.

OECD Working Party on Biotechnology
www.oecd.org/biotechnology

The OECD has been working on biotechnology-related topics for over 25 years. These include scientific, industrial, health and agricultural applications. It also has a strong record on safety issues in biotechnology. Current work in biotechnology and water is focusing on aspects of research and development in the food and pharmaceutical sectors.
The Working Party on Biotechnology (WPB) has held a series of workshops which focused on two sets of issues: i) water use and conservation; and ii) water quality and safety. They include the workshop on “Biotechnology for Water Use and Conservation” (Mexico, 1996), “Molecular Technologies for Drinking Water” (Switzerland, 1998), and the Cuernavaca expert meeting on “Emerging Risks to Water Supplies: Best Practice for Improved Management and Preparedness to Protect Public Health” (2003).

Following up on this past body of work, the WPB will engage in work on water quality and availability as part of its activities on the environmental applications of biotechnology. In 2008, the WPB will scope what work is being done on environmental biotechnology R&D with a special focus on water. The scoping report will draw on and update seminal work from the Cuernavaca meeting on “Biotechnology for Water Use and Conservation”. The outcome will be recommendations for next steps by the WPB in 2009-2010.

**OECD Working Party on Manufactured Nanomaterials**

www.oecd.org/env/nanosafety

The OECD Working Party on Manufactured Nanomaterials (WPMN) was established in 2006 by the Chemicals Committee in the Environment Directorate. The objective of the WPMN is to promote international co-operation in human health and environmental safety related aspects of manufactured nanomaterials (MN), in order to assist in the development of rigorous safety evaluation of nanomaterials. Under this remit, it will cover many of the regulatory and safety aspects of nanomaterials as they relate to water purification including sensor technologies.

The work of the WPMN is being implemented through the eight projects listed below:

- Development of a database on human health and environmental safety research.
- Research strategies on manufactured nanomaterials.
- Safety testing of a representative set of manufactured nanomaterials.
- Manufactured nanomaterials and test guidelines.
- Co-operation on voluntary schemes and regulatory programmes.
- Co-operation on risk assessment.
- The role of alternative methods in nanotoxicology.
- Exposure measurement and exposure mitigation.

In its work on regulation, risk, health and safety, the work of the WPMN will have implications for water purification in business, research and society.
The World Bank

The Water Resources Management Strategy of the World Bank comprises the institutional framework (legal, regulatory and organizational roles); management instruments (regulatory and financial); and the development, maintenance and operation of infrastructure (including water storage structures and conveyance, wastewater treatment, and watershed protection).

The Strategy reflects the broad global consensus of the Rio Earth Summit (1992) which stated that modern water resources management should be based on three fundamental principles (known as the Dublin Principles): i) the ecological principle (that independent management of water by different water-using sectors is not appropriate; that the river basin should be the unit of analysis; that land and water need to be managed together; and that much greater attention needs to be paid to the environment); ii) the institutional principle (including that water resources management is best done when all stakeholders participate and that resource management should respect the principle of subsidiarity, with actions taken at the lowest appropriate level); and iii) the instrument principle (that water is a scarce resource and that greater use needs to be made of incentives and economic principles in improving allocation and enhancing quality).

The operational programme of the Bank for water resources management entails support for providing potable water, sanitation facilities, flood control, and water for productive activities in ways that are economically viable, environmentally sustainable, and socially equitable. The Bank helps borrowers to develop a comprehensive framework for designing water resource investments, policies and institutions; to adopt pricing and incentive policies for cost recovery, water conservation and better allocation of water resources; to decentralise water service delivery through public and private sector bodies; to restore and preserve aquatic ecosystems and to avoid problems resulting from irrigation; to develop legal and regulatory frameworks to meet social concerns, protect environmental resources and prevent monopoly pricing.

MEDRC

Organisations operating as public-private partnerships and/or not-for-profit entities include the Middle East Desalination Research Centre in Muscat, Oman (MEDRC). Its mission is discovering, developing, and improving methods of desalination through basic and applied research; initiating training programmes in the field of desalination to develop expertise as well as technical and scientific skills; promoting electronic networking communications to improve the dissemination of technical information on desalination; and establishing regional co-operation and work to foster progress in the development, improvement, and use of water desalination and related technical areas. It was established through donations from a number of countries and organisations within the context of the Middle East Peace Process.
The EU Seventh Framework Programme
“Converging Technologies for Clean Water”
http://cordis.europa.eu/nanotechnology/

There is a running call of the European Union Seventh Framework Programme (FP7) for proposals on R&D in Nanotechnologies for Water Treatment run jointly by the Environment (ENV.2008.3.1.1.2) and the Nanotechnology (NMP-2008-4.1.2-2) programmes of FP7. The funding is for collaborative projects (small or medium-scale focused research projects). The aim is to support research and technological development in the field of water treatment by applying developed or adapted nano-engineered materials to promising separation, purification and/or detoxification technologies. There is a particular focus on improving processes, in terms of their selectivity, robustness, stability and performance, and reducing energy requirements and by-product generation. The programme covers all types of water (e.g. domestic waste or drinking water, industrial process or waste water, seawater, brackish water, groundwater, bottled or mineral water).

International Water Association
www.iwahq.org/ (see specialist groups)

The aim of the IWA is to connect water professionals worldwide to lead the development of effective and sustainable approaches to water management. It is a not for profit organisation with members from utilities, regulators, researchers, consultants and manufacturers, who collaborate to share experiences, debate key issues and to develop policy positions, best practice approaches, and to contribute to program development for conferences, workshops and publications. Its 50 specialist groups form its technical arm and cover a wide range of important topics in the urban water management sector. Each group has its own programme of conferences and other meetings and a regular newsletter or web-based discussion forum.

In 2009, the IWA established a specialist group on Nano and Water – Application of Nanoparticles, Nanoengineered Materials and Nanotechnology. The objectives of the specialist group are to:

- Stimulate research and provide objective information towards water utilities, policy makers and the general public on fate and stability in the environment, and possible health risks and environmental effects of nanoparticles.
- Provide a platform and create a network for exchange knowledge and expertise on the development and possible application of nanotechnology and nanomaterials for drinking water and wastewater.
- Stimulate the development of nanotechnology from lab scale to technological scale for drinking water and wastewater applications and simultaneously reducing the risks associated to the specific technologies.
- Form “eyes and ears” for the water sector on the development of nanotechnology in other fields (technology scouting).
AquaFed

www.aquafed.org

AquaFed is the International Federation of Private Water Organisations. Over 200 water and wastewater companies in over 30 countries have joined together in an association which aims to collaborate with other stakeholders to find practical solutions to improve areas of global water development such as service provision, economic development, health and living conditions, poverty alleviation, and climate change.

The EU Water Supply and Sanitation Technology Platform (WssTP)

www.wssttp.eu/site/online/home

The Water supply and sanitation Technology Platform (WssTP) is a European initiative for European Research and Technology Development in the water industry. The WssTP develops an overview of the current state of water supply and sanitation technologies in their respective branches and identifies the most promising areas of innovation.

The US Strategic Water Initiative (USSWI)

http://usswi.org/

A new organisation has been established in the US involving the government, companies and venture capitalists. The United States Strategic Water Initiative (USSWI) aims to enhance US competitiveness in water purification science and technology. The USSWI was launched at the Congress for Water Purification Science and Technology in the 21st Century in New Orleans 6-10 April 2008.

European Membrane Institute

www.membrane-emi.nl/

The European Membrane Institute Twente (EMI Twente) was founded by the Membrane Technology group of the University of Twente in 1995 to offer industry and public organisations a facility for short-term research and development projects in the field of membrane science and technology. It mainly focuses on the European market, but also works together with American and Asian companies. It has special expertise in membrane development (hollow fibres as well as flat sheet membranes) and membrane characterization, as well as in process optimization and other membrane technology related topics, e.g. foams. The EMI Twente participates in National (EET, STW, NWO) and European (Joule, Fair, Brite, Leonardo da Vinci, Thematic Networks) sponsored research projects. The institute also provides courses on water purification using membranes.
See also:

The United Nation Secretary General’s Advisory Board on Water and Sanitation
www.unsgab.org/

The MESA+ Institute for Nanotechnology
www.mesaplus.utwente.nl/

EAWAG, the Swiss Federal Institute of Aquatic Science and Technology
www.eawag.ch/index_EN

The Grand Institute, Israel
http://gwri.technion.ac.il/

The Water Initiative
www.thewaterinitiative.com/

Tsinghua University
www.tsinghua.edu.cn/eng/board1/boardlist.jsp?boardid=35&bid2=64&pageno=1

Working for Water programme, South Africa
www.dwaf.gov.za/wfw/

NanoMemPro
www.nanomempro.com/
1. Water filtration: a start-up company.
2. Nanobiosensors and early warning systems for detection of pathogens.
3. Solar disinfection: improving health in developing countries.
5. Water and nanotechnology: views from a water provider.
8. Water and nanotechnology: views from an applied research university.
11. Treating and reusing municipal wastewater effluence: reverse osmosis.

### Water filtration: A start-up company

#### The technology

The effectiveness of water filtration membranes is greatly reduced by the common problem of fouling (clogging and coating of the membrane). A start-up company in Germany has developed a ceramic filter membrane system with both nanoparticles and membrane filtration to reduce fouling. By combining biological and physical water purification techniques the system also filters out bacteria, viruses and fungi, extracts enzymes and antibiotics and produces cleaner drinking water.

#### The organisation

iTn Innovation (iTn Innovation, 2009) was founded in 2000 with a team of five people and has grown to having a staff of over 100 located on two sites. An additional production plant was established in 2003 with national and EU subsidies. The company is heavily involved in research and development, with five projects being supported through public funding in 2007. The subsidy rate for those projects was between 37 and 60% and the amount in 2007 was EUR 155 000. The company has continuously expanded its patent portfolio with at total of 24 patents granted in 2007. In 2007, the company held over 170 patents worldwide.

Research staff at the company have been working on nanomaterials since the 1990s, originally at a nanotechnology research institute. The company formed on the basis of developing catalytic coatings for kitchen ovens for a multinational
company on an exclusive basis, using private finance in the first year and acquiring venture capital support thereafter. Its products now use nanoparticles in:

- Impervious ceramic nano coatings for power plants and metal casting and for anti-fouling in liquid transfer systems.
- Highly porous ceramic nano coatings for domestic ovens and industrial flues.
- Ceramic tubular and flat membrane filters for water purification, supplied either as components or as complete filtration systems.

Engagement with the water sector is developing slowly, partly due to the highly regulated, traditional and public sector nature of the industry. The markets for the products are, for example, sewage plants in remote areas and those without mains sewers. Proof of concept work was successfully undertaken in Dubai and at a golf and hotel complex in Germany (at which the waste water from the hotel complex was treated and could be used for the golf course). Other uses in Germany are unlikely as 99% of the population are connected to centralised sewage systems in contrast to, for example, the United States where the figure is less than 70%. A contract in Dubai for 20 mobile wastewater treatment plants with 12 filtration units each was signed in 2008 with delivery to be complete by July 2009. The plants are designed to filter waste water in construction worker camps. The contract is worth EUR 5 million.

**The challenges for the company**

- Confidence of clients and the difficulty of getting established users to take on a new technology. People willing to act as partners and references can be hard to find.
- The risk associated with nanotechnology as perceived by those buying the product. While venture capitalists are comfortable with nanotechnology and even attracted by it, the companies buying the technology are concerned about potential risks and about the perceptions of their customers.
- The lack of business expertise of researchers starting up a company.

**Nanobiosensors and early warning systems for detection of pathogens**

**The technology**

Early Warning water testing biosensor systems are based on a number of technologies including water microbiology, wireless networks, design engineering, environmental technology, microfluidics and nanotechnology. Prototyping and small-scale fabrication are key parts of the development process. The biosensor products in this case are based on carbon nanofibre and nanotube technology.

The carbon nanotubes (or fibres) are made by chemical vapour deposition from graphite and can transmit measurable electrical signals when pathogens are present. Oriented on an electronic chip, they can detect signals from probe biomolecules which are attached to their ends. The probe biomolecules emit the signals when they come into contact with biomolecules of the target substance. The
resulting signal passes through the nanotubes to the chip which communicates the presence of a contaminant.

**The organisation**

The privately-owned Canadian start-up company, Early Warning Inc (Early Warning Inc., 2009) was founded in mid-2007 and has 25 employees and contractors in product development. The company has locations in Montreal, New York and Waterloo (Ontario). Its biosensor product is based on carbon nanofibre and nanotube technology licensed from NASA. Its initial market will be in testing of water for pathogens. Field testing of the product is scheduled in the third quarter of 2008.

The biosensors are designed to simultaneously detect over 30 specific strains of waterborne micro-organisms including the highly pathogenic E. coli 0157:H7. Two systems are being developed – one portable system which can be transported as required and one automated stand-alone system used in sensor networks by water treatment plants, water distribution networks and automated food and beverage production applications. In outline, the equipment consists of an inlet to sample water from the source, pumps to take the sample to pre-treatment and processing, the sensor itself and the information processing and reporting systems. One important benefit is in the projected testing time of two hours, in comparison with two to seven days for laboratory-based tests.

The biosensor systems have engendered strong interest in the water sector and public water provision in Ontario, where there was a fatal E. Coli O157:H7 contamination outbreak in 2000 (OECD, 2003).

**The challenges**

Key issues for the company starting up were the availability of expertise and organisations for specific prototyping, fabrication, upscaling and other outsourced developments. The company’s nanotechnology activities are undertaken entirely in the United States. The need for such a system in all countries seeking to benefit from the commercialisation of nanotechnology was highlighted by the company. Furthermore, the willingness of some countries to buy leading edge products (without them having been proven to work elsewhere) was seen as critical to success in emerging technologies and will drive the expansion of this company. The public sector companies of only a few countries have the capacity and the confidence to take the risk of purchasing untried products and services.

A system in which government supports companies to start and become established in support areas and where the public sector is willing to be first buyer of untried technologies was seen as optimal. The full system of supports would include:

- Research and development (academic and at public research organisation).
- Support companies (testing, proof of concept, pilot plants, prototyping, small-scale fabrication).
- The public sector as first customer of high-end, high-risk technology-based products.
It was proposed that such a system could be established using a budget for preventative measures *e.g.* to take some of the funds to find better treatments for people made ill by water borne pathogens and to use it to develop preventive measures.

One issue which arises in using academic institutions and public research organisations as testing or prototyping resources is the expectation that they would be entitled to share the intellectual property rights of the product of service. This is not experienced with commercial suppliers.

To date there have been no issues of skills shortages in the required areas, partly due to the wide contact network of the company management. There have also been no ethical, legal or social issues. In responding to a question about applicability of the technology to testing in the medical sector, it was said that while that was on the long-term plan there would be many more regulatory and testing hurdles to be overcome and approvals to be sought before use for blood testing, for example.

**Solar disinfection: Improving health in developing countries**

*The technology*

Solar disinfection (SODIS) is a technique for making contaminated drinking water safe where transparent bottles are filled with contaminated water and placed in direct sunlight. The water is safe to drink after six hours exposure to the sun.

*The organisation*

SODISWATER is a research project funded by the European Union (EU) under the Sixth Framework Programme (FP6) (Sodis Water 2009). Its aim is to demonstrate that solar disinfection of drinking water is an effective intervention against a range of waterborne diarrhoeal diseases at household level and as emergency relief in the aftermath of natural or man-made disasters. It is also evaluating and testing different diffusion and behavioural change strategies in areas with different social and cultural conditions for sustainable adoption of solar water disinfection; disseminating research outcomes throughout the international aid and emergency relief communities; and developing a range of simple SODIS enhancement technological innovations that can be matched to varying socio-economic conditions.

The project is being carried out by an international team of researchers from nine different groups in seven countries within Africa (Kenya, South Africa, and Zimbabwe) and Europe (Ireland, Spain, Switzerland, United Kingdom). In addition, the Irish Government is funding an identical study in Cambodia.

Nanotechnology is a small but important part of the project, as one of the technological enhancements being examined. WHO had previously shown that users may reject solar disinfection if the process takes too long: nanotechnology may speed up disinfection through photocatalytic effects. Glass tubes coated with immobilised nanoparticle titanium dioxide are being used for disinfection enhancement tests in sunlight following successful laboratory testing. The project proposes to modify the solar disinfection bag with titanium dioxide (less than 100 nanometre in diameter) as a photocatalyst to accelerate and enhance water disinfection.
Work on solar disinfection within the research consortium has been ongoing since 1992 and increased following the Indian Ocean tsunami in 2004. Health impact assessments are being undertaken in the African countries. Local issues are impacting the work, for example:

- In South Africa, approximately 790 children are taking part in the study and initial measurements of height, weight, disease incidence and microbiological quality of the drinking water have been completed. There is an increasing, and welcome, drive within the country for chlorinated water to be made available from standpipes, which may reduce the study group. There is also a reluctance to adopt any unknown technology or new behaviour except in times of extreme water shortage.

- The Kenyan study recruited 900 children and initial measurements of height, weight, disease incidence and microbiological quality of the drinking water had been completed by the time of the general election in December 2007. The risk to safety for ICROSS (Icross.ie, 2009) personnel in January 2008 resulted in all operations being suspended for approximately 4 weeks as a result of post-election civil unrest and lawlessness.

- Population displacement due to unrest resulted in 300 of the original children being missing from the study areas. Resumption of monitoring has indicated a steady but slow increase in the numbers of children returning with their families to the study areas and re-participating in the study.

- The deterioration in the economic situation in Zimbabwe has placed increasing stress on the viability of the study. A cohort of 780 children had been identified to January 2008 but civil unrest and continuing difficulties obtaining fuel for transport in the run up to the general election in March 2008 led to the decision that operations should be scaled down and perhaps even suspended for a few months.

**The challenges**

This case study illustrates the problems of testing and introducing water purification in less developed countries including:

- Reluctance to adopt.
- Civil unrest.
- Displacement of population.

Indications are that solar disinfection (with or without nanotechnology) is more readily accepted in times of extreme water stress and disease, for example, following natural disasters *e.g.* earthquake, tsunami and flood.
Nanoporous membranes: Desalination and water purification

The technology

An early potential product investigated by the company used a nanomaterial as an osmotic agent to draw water through a membrane. This was effective for brackish water but was slow and did not have sufficient commercial potential. The company is currently evaluating a capacitive membrane which has a high surface area due to the presence of nanopores. The membrane separates salt from water in a desalination process.

An important aspect of this technology is its ability to reduce the amount of energy required to purify the water (the reduction being currently about 20%). In addition, the infrastructural costs are less: reverse osmosis requires the use of pressure vessels and pumps (to force water through a membrane) but this technique of forward osmosis does not. There are no nanoparticles in the process. Unlike the hydrophobic process of reverse osmosis, this technique is hydrophilic which reduces the chance of fouling, a major problem in membrane-based water purification.

The organisation

The company, Apaclara (Apaclara, 2009), is currently evaluating membranes produced by sub-suppliers (for example, those developed for use in hybrid vehicles, which maybe suitable for this new application) and measuring both the surface area and salt carrying capacity. A bench top demonstration model of a desalination system using the technology is being constructed.

The end-product for the company will be point-of-use, personal water purification systems which are portable if required and suitable for outdoor, as well as indoor, use.

The company has established agreements with a small but well-established company selling outdoor equipment to the public and the military. It is also working with the US Office of Naval Research under a joint agreement. It has benefited from relationships with small companies and university groups.

The challenges

The system in use is exploiting properties which are not yet well understood. The nanoporous membrane is just one part of the system which involves the use of charged particles to increase the osmotic pressure (which moves the water through the membrane), impacting the performance of the system as a whole. The optimal osmotic pressure for the membrane needs to be determined. A second aspect of this is the balance between the speed of separation and energy required. Forward osmosis is slower than reverse osmosis but brings significant energy savings.

Forward osmosis is not a well-known water technology although it is used in a hydrating sports drink. It may therefore be a challenge to achieve acceptance by water companies. In anticipation of a reluctance to adopt, the company proposes to
take a stepwise approach, first proving the product as a back-pack system and then moving to point-of-use residential systems. For hospital use, for example, there may be issues of chemical attack on the membrane (from solvents) and, while cryptosporidium is removed by the system, urea is not, hence a pre-cleaning system may be required in conjunction with the forward osmosis system.

The nanoporous membranes currently available are expensive because they are not in great demand. They are produced by a small number of large suppliers (e.g. GE, Dow Corning).

The reverse osmosis based water industry has benefited from the use of modelling expertise developed with US public sector funding. Modules can be theoretically tested in this way, with their pumps and pressure vessels. The system is not adaptable for forward osmosis modules as they do not use the same structural components as reverse osmosis. In addition to modelling for new water technologies, test sites are not readily available. One possibility would be for an independent evaluation to be undertaken to establish what facilities are needed to support new water technologies through the development, proof of principle and piloting phases. Funding for this type of activity is unlikely to come from the private sector (as it is too far from the market). In general, funding for new water technologies is difficult to obtain from the private sector.

The high surface area components used in forward osmosis have a long lifetime. It is, however, important to ensure that there will be no negative environmental or health effects from their long-term degradation and/or disposal.

Other challenges are those familiar to start-up companies in general, e.g. continuity of funding. One issue, not exclusive to the water industry but also to other traditional industries including those providing public utilities, is communication difficulties but this is being addressed in part by middle managers at water companies joining the start-up company.

Water and nanotechnology: Views from a water company

The technology

Areas of nanotechnology which are on the horizon for use by water companies are principally in the areas of sensors and membranes. Membranes with enhanced efficiency (e.g. through reduced bio-fouling characteristics or coatings which help to remove pollutants) can reduce costs in the future, in areas such as maintenance and energy usage. Sensors are important for water quality in areas such as distribution but also for monitoring the water quality of the catchment area over time. Sensors are often developed for other areas (e.g. automotive, medicine, the chemical industry) and adapted for water applications.

The organisation

Global utilities are increasingly working in partnerships with academic researchers, other companies and the public sector in an effort to improve their service provision through the use of technology. They are also involved in flood control and dams, treatment of wastewater and industrial effluent, management of
water sources, treatment and recycling of sludge, infrastructure development (e.g. pipes) and contamination detection.

Suez Environnement, based in France and operating through subsidiaries in over 14 countries, have a designated research body (CIRSEE) (Suez Environnement, 2009), established in 1981, which focuses on research and development (R&D) and has collaborations with over 50 partners in France and abroad. In addition to technology being transferred from the R&D arm to the wider set of companies of Suez, personnel are exchanged and training is provided. In 2007, CIRSEE had a budget for research, development and technology of EUR 65 million in areas including resource management, energy, metering, odours, sludge, water and health and storm water management. It also engages in technology watch activities and seeks to apply existing technologies in new ways.

Multinational water companies are now routinely involved in joint projects funded under EU and other international funding schemes, some looking at new technologies and materials while others consider the detection of industrial and agricultural waste products including nanoparticles. Within France, CIRSEE is a partner in the project NANOSEP which is developing a treatment process for industrial effluents containing nanoparticles which combines three techniques relevant to water purification: flocculation, flotation and filtration. The role of the company includes development and testing at pilot scale. A second French project AQUANANO is looking at the presence of nanoparticles in aquifers in France, their mobility and degradation. CIRSEE was also the co-ordinating organisation for a European project on Improved Energy Efficiency in Membrane Processes – Water Desalination and Purification – under the European-Mediterranean Energy Co-operation Projects (EUROMED).

The challenges

For a company engaged in R&D in a broad area such as water, the key challenge is to establish partnerships through which to develop, access and use new technologies. The company may build pilot plant and conduct trials with earlier stages of R&D being undertaken externally.

A funding gap for small companies, particularly start-ups was identified. Support for small companies is important and generally comes from governments rather than the private sector e.g. venture capitalists. The small companies are an integral and important part of the value chain on which larger companies rely.

Funding for partnerships is also of importance and needs to form a system of support for projects up to at least the level of first prototype.

A water technology networking centre of excellence: Wetsus

The organisation

Wetsus (www.wetsus.nl) is a Centre of Excellence for Sustainable Water Technology based in Leeuwarden in the Netherlands and funded by the Dutch Ministry of Economic Affairs, the European Fund for Regional Development, the
Samenwerkingsverband Noord-Nederland Kompas and the city of Leeuwarden and Province of Fryslân. The organisation is 50% funded and obtains the remainder of its budget (equally) from its industry and university partners.

The networking and research organisation consists of partnerships and a platform based on joint R&D between research bodies and industry. The projects are multi-disciplinary, market driven and application-oriented and focus principally on waste water, drinking water and sensors. The over 60 member companies of the platform (mostly Dutch), together with 25 research groups in six “know-how” institutes include technology providers, public water boards, drinking water companies, end users, consulting engineers, high-tech companies, financial institutions, universities and research institutes.

The centre also provides business supports to companies (such as testing) and incubation facilities, runs a seed capital desk (to facilitate interactions between companies and researchers) and seeks to strengthen research capabilities in the region. Wetsus is involved in education at BSc level (supporting a number of schools in the Netherlands), MSc level (running a designated course since September 2008) and at PhD level (in multidisciplinary training including business skills).

The technology

Research is carried out by Wetsus within the framework of the Technological Top Institute for Water Technology (part of the Dutch Innovation Program on Water Technology). Areas include:

- Water distribution (network inspection and replacement) – with companies Vitens and BTO.
- Salt (removal and reuse of salt from seawater, ground water and waste water) – with companies including Shell Global Solutions, Hubert Stavoren BV, Frisia Zout BV, Friesland Foods.
- Capacitive deionisation (removal of salts from water through deionisation) – with Unilever.
- Biofouling of membranes (cleaning and fouling inhibition) – with Bioclear, Evides, Global membranes, Norit, PWN, Vitens, Shell Global Solutions and others.
- Waste water treatment (sustainable waste purification) – with Heineken and Ingrepro.
- Algae (for biofuels) – with Biosol, Dow Chemicals, Eneco Energie, Friesland Foods, Syngenta and others.
- Sensoring (developing small, accurate and robust sensors at viable cost) – with 2M Engineering, Bright Spark, Easy Measure, Schlumberger and others - the products closest to market for water industry are sensors, which have many applications and need to be small and economical.
- Membrane bioreactors (to make them more robust, less energy demanding and more economical) – with DSM Solutech, Evides, Norit, Nuon, Shell, Vitens and others.
Energy from water (bioelectricity from waste water and electricity from mixing salt and fresh water) with Dow Chemicals, Eneco Energy, Frisia Zout, Fuji Film and others.

The challenges

Added value for water is very low (a cubic metre of water was estimated at EUR 1.50) in contrast to food and this impacts nanotechnology based products entering these sectors. There is a need to communicate the value of water and to fund appropriately.

The communication and technical challenges needing to be overcome between those working on water in microlitres per minute (researchers) and in metres cubed per second (the water engineers) were highlighted. Moving from laboratory to industrial scale can happen by scaling down or scaling up but for nanotechnology it is perceived as easier; for water, to scale up from the laboratory. Communication, technical and education issues arise from the early stages of development, and even within research in understanding the problems to be addressed. Understanding by those in the technical areas of water, outside of the laboratory, can be made easier where technologies and techniques are transferred from other sectors (such as food and healthcare) and there are concrete examples of successful applications. Companies need to see success stories before adopting new technology, it was indicated.

The Wetsus organisation is working to network its members (companies and universities) and its work is demand driven. Each of its company members has access to the results of several research units. The importance of having a system in which technological solutions are funded (in part) from the research stage to the marketplace was seen as very important. Demonstration sites, technology transfer and export assistance are examples of relevant areas where support is needed.

The areas of environment, health and society are currently unclear and while Wetsus has largely not been asked to address this it is seen as of great importance in the future. Work to investigate these areas would be welcome and essential for the water sector into the future.

Diversification: view from a multinational

The technology

Multinationals and large companies such as Dow Chemicals, Siemens and Bayer AG are diversifying into new areas of technology and adapting their existing technologies to new applications. One such multinational is using nanotechnology in many areas of research, development and even manufacturing. For water applications, nanotechnology is being explored as applicable in nanofiltration, membranes and coatings but also in new (and confidential) areas. Key technologies include a wide range of reverse osmosis (RO) and electrodialysis reversal (EDR) systems. They also package desalination systems with clean, efficient energy sources of almost any size.
**The organisation**

GE Water (GE Water 2009) applications include membranes for agriculture, systems for the reuse of industrial water and dialysis. The company built the largest membrane-based wastewater reclaim facility and has the world’s largest installed base of desalination systems for seawater and brackish waters. It operates the world’s largest mobile desalination fleet for critical peak demands and emergencies. Mobile water units are used for problems on many scales: they were used to help victims of the 2004 Asian tsunami and a Thailand chemical plant, which avoided a production shutdown during a chronic fresh water shortage.

The company is dependent on sub-suppliers for raw and processed materials. While it develops some in-house, it has a significant sub-supply chain of nanomaterials for a variety of uses. The company is also seeking to take materials with which it is familiar and to improve them using nanotechnology, for new and better (e.g. cheaper, more effective or with new functionalities) applications.

The company recently merged its water and energy divisions, an interesting development and related to the use of large amounts of water in a variety of energy production systems and the use of energy in water purification and provision.

**The challenges**

The demand for nanomaterials is growing and guidelines and standards (for production, packaging, transportation, use and disposal) are important both for the large company and its sub-suppliers.

The company participates in industry consortia and fora dedicated to general education about nanotechnology issues and to the establishment of nomenclature, standards and EHS practices relative to nanotechnology research. Several key companies (Dow and Dupont were mentioned) are contributing and requiring their suppliers to undertake responsible production, transportation and disposal too, although risks are unclear for nanomaterials at present.1 In particular the company is supporting increased government funding of research on EHS aspects of nanomaterials as part of overall government initiatives on nanotechnology.

The quality of the material being supplied is also a focus for the company. Consistent (and known) properties are essential for reproducibility.

The company is also supporting efforts to clarify applicability of existing laws and regulations to nanotechnology as well as evaluations to determine whether modification of existing laws and regulations is needed.

The company has a good network from which to draw its researchers (at PhD level) and provides any necessary nanotechnology related training for technicians.

---

1. Information was passed on to the company about the work of the OECD Working Party on Manufactured Nanomaterials.
Water and nanotechnology: Views from an applied research university

The technology

Nanotechnology is principally being used to enhance existing water purification technologies within the university group. For example, titanium dioxide and ultraviolet light combined can clean water by neutralising contaminants, the titanium dioxide acting as a catalyst for the process. Nanoparticles of the catalyst have a larger surface area per volume than larger particles and therefore have the potential to be a more effective catalyst.

An additional area of interest to the water industry is that around concerns about nanomaterials entering into the water system. While nanoparticles are low risk, in that they will be captured by filtration systems, aggregations of particles can avoid removal and continue within the system. Work on this is underway at Cranfield University’s Center for Water Science (Cranfield University, 2010), in collaboration with water companies.

The organisation

Cranfield University is a post-graduate and research university, with no undergraduate tuition. Research generally focuses on working to find solutions for industry and investigating areas of value and interest to companies. Areas of research related to water include removal of pesticides and bulk organics from drinking water; waste recycling and use of grey water (where water cannot be cleaned for human consumption) and other water purification systems. Membrane chemical reactor pilot plants are operated by the university, an illustration of the focus on business client needs.

The challenges

Technical challenges include the difficulty of obtaining robust, effective and well quantified nanoparticles from companies. For example, the titanium dioxide particles in the example above need to have a substantial catalytic effect or there will be no value in changing from the material currently in use. Laboratory based particle production does not take into account the need for bulk production nor the robustness required of particles used in engineering processes.

Communication between scientists/researchers and engineers/companies was again highlighted in this case study. Also emphasis was placed on the need for a complete system of supports from the research laboratory to the marketplace if nanotechnology is to be widely used. While there are some grant schemes, the water industry is not generally one which attracts funding for high-technology based solutions. Much of the work currently would have to be funded by the industry itself and it is too early stage for that to happen in a widespread way.

Another issue is the lack of confidence of the water industry in new technologies, as perceived by those working with them. There is a need to demonstrate the use of new materials and processes at a scale which is relevant to the industry. The industry is slow to change, being a traditional public service provider and of
necessity highly regulated. When one company is prepared to adopt a new technology, others will follow.

Skills issues related to nanotechnology are similar to those for any new technology being used in industry. Typically, systems are no longer as automated as they were previously and require operator intervention from a skilled technical person, with sometimes multiple sites being under one group of operators. It is being seen at Cranfield that more people with Masters qualifications are going into operational aspects of the water industry than previously, due to this need.

**Fluid filtration: Nanotubes for clean water**

**The technology**

Fused nanomesh material based on carbon nanotubes is being used to provide clean water, free of bacteria and viruses, cysts and spores and with reduced contents of arsenic, lead, selenium and many other contaminants. Nanotubes have a large surface area, high strength combined with light weight, and high electrical and thermal conductivity. They are the active component of the mesh enhancing filtration properties relative to standard filter materials.

Third party testing has shown that the nanomesh materials are suitable for fluid filtration for ground water, fuel and air purification. They have been shown to purify water to US Environmental Protection Agency (EPA) drinking water standards. The products may also be used in cleaning sea water (e.g. for fish farming). The water flow rate is high: for example, cleaning 700 US gallons (2600 litres) of water in 24 hours with Seldon’s WaterTap™. The company developed tests to determine whether there was any carbon nanotubes released from the filtration mesh of the products, given that concerns had been reported. Testing, which showed that no carbon nanotubes are in the water flowing from the product, has been undertaken by third party laboratories.

**The organisation**

Seldon Technologies (Seldontechologies, 2009) was founded in 2002 and currently holds multiple patents and patent applications for materials, devices and manufacturing based on the technology. Its funding has included a Technology Investment Agreement (TIA) with the US Air Force; Small Business Innovation Research (SBIR) agreements with NASA and DARPA (the US Defence Advanced Research Projects Agency); and contracts with the US Air Force Research Laboratory. Three products all based on carbon nanomaterials are currently available: the WaterStick; the WaterTap; and the WaterBox.

The WaterStick is a lightweight, low pressure water purification stick for outdoors use for backpacking, camping, hiking, cycling, field work or international travel. It can be incorporated into a conventional hydration system and will absorb contaminants from up to 70 US gallons (260 litres) of water. It is a low pressure system and water can be drunk from the bite valve of a hydration pack or by pumping using a hand bulb.
The WaterTap relies on standard domestic water pressure to drive an under-sink system and will clean up to 2000 US gallons (7,500 litres) of water. It does not require electricity and can be used on boats, in holiday homes and in camping vans.

The WaterBox is a plug in system which cleans up to 1200 US gallons (4,500 litres) of water in 24 hours. It uses either electricity (e.g. from a vehicle or generator) or a hand pump to draw water from the source into the filtration system (pre-filters and nanomesh filters). The WaterBox has been field tested in Rwanda and can be employed to purify water for villages, relief workers, field hospitals, defence forces etc.

**The challenges**

Markets: The company is aiming to develop its markets by targeting segments of the drinking water products sector. In addition to uses in mobile products, disaster relief and the military, there are opportunities outside of Europe and the US in countries such as India, Vietnam and China but only in the more affluent sectors of the community. While efforts were made to address water provision for the whole community, it was found that the products could not be provided to rural villages through purchase by individuals as they cannot afford them, intervention by governments or nongovernmental bodies would be required. However, provision of clean water is only one part of an overall sanitation and cleanliness problem which would have to be addressed as a whole. Clean water only remains clean if it is used in good sanitary conditions. The company is therefore looking at the upper middle class markets in the countries outside of Europe and the US, as well as mobile uses within Europe and the US.

Public procurement by governments and non-governmental organisations comprise a large market for water filtering products. Given the age of water delivery systems (pipes and storage tanks), replacement of many components is desirable at this stage. The cost of replacing municipal and national water grid infrastructure is immense. Rather than replacing the whole system, point of use systems appear to be a practical solution for public bodies to procure as water only needs to be clean at the point of use not all along the grid. Leakage issues could be addressed separately as required. However, public procurement procedures are often complicated and time consuming and the time to delivery tends to be short, all of which can exclude small companies from tendering. If governments/NGOs allowed a longer time to delivery (e.g. nine months), the deposit paid would enable smaller companies to borrow money and partner out some of the work, thereby meeting the delivery date.

Testing costs: Testing of water to regulatory standards can be conducted by third party laboratories, which the company has done to date. The products can be sold using these test results as an indication of safety and effectiveness. However, in order to build credible relationships with potential clients and partners, full standard EPA (US Environmental Protection Agency) test certification is often required. Testing can cost up to USD 85,000 for one product and can take six months to complete. Furthermore, any change in the product or its manufacture requires new testing at the same cost. Given the importance of clean water and the level of support already given to the development of the technology, the company proposed that the cost and time taken to undertake testing be reduced for products which have applications in disaster relief and for the public good. One possibility would be
for the public system to undertake the testing to EPA standards in order to accelerate accreditation and reduce costs. The public sectors laboratories (e.g. military facilities) have the capacity to provide the service but are not tasked to provide it. Costs could be recouped later from commercial sales if required.

The water industry: The water industry is seen by the company as being fragmented with eight or more sub-sectors including drinking water products. A small number of companies dominate the drinking water sector in the US and Europe making it hard for a new and small company to break into. The sector is also reluctant to adopt new technologies, the last entrant being reverse osmosis which has now been in widespread use for over 20 years. It is also difficult to form alliances with large companies, taking time and persistence to build strategic relationships.

Finance: While some venture capital funds are indicating a move towards longer term strategies, the expectations of rapid returns on investment remain prevalent. New technologies require time to reach the market and support through the various stages of development and commercialisation. One possibility would be for governments to set up an investment bank venture capital fund for entrepreneurs, providing seed capital to cover the transition from research and development to manufacturing. This would provide a source of longer term funding for entrepreneurs and help them to retain control of their inventions.

Patent protection support: The patent laws in the US, where many companies choose to patent their inventions, are being changed in a manner which, in the view of this company, could adversely affect small companies. The revised method for computation of damages is perceived as resulting in higher litigation costs rendering small companies unable to challenge patent infringements or to defend themselves against allegations of having themselves infringed the patents of others. If the changes in the law go through, a patent support system could help smaller companies and start-ups to defend their intellectual property.

Technical challenges: The technical challenges were met by the company within the first five years of development. One important factor in their success was that they scrutinised the market before developing their products and therefore took the decision to use tried and tested techniques e.g. using paper production methods and equipment. Other organisations have struggled to scale up from the laboratory to pilot plant and production volumes.

In addition, large scale facilities such as SEM equipment are increasingly being made available by governments, for example at the centre in Albany in the US. Such supports for the engineering cycle are of great importance for small companies which cannot afford such specialised equipment.
Providing a sustainable water supply for a country: PUB Singapore

The challenges

In the last four decades, Singapore has overcome water shortages despite its lack of natural water resources, flooding and the pollution in its rivers in the 1960s and 1970s. With a population of about 4.8 million and a surface area of only 710 km², Singapore has the third highest population density of any country. Only 1.4% of its surface area is water, leading to a severe shortage of that resource and a need to optimise its collection, use and reuse from catchment areas, desalination sources and imported water sources.

The company

PUB, the national water agency of Singapore (Singapore’s national water agency 2009), is responsible for the collection, production, distribution and reclamation of water in Singapore. Rainwater is collected through rivers, streams, canals and drains, and stored in 14 reservoirs. Various reservoirs are linked by pipelines so that excess water can be pumped from one reservoir to another, thus optimizing storage capacity. Untreated water is piped to the waterworks for treatment and then stored in covered reservoirs before being distributed to customers. Used water is collected via an extensive sewerage system and treated at water reclamation plants. So called NEWater is reclaimed from the sewerage systems, treated and provided for purposes up to and including drinking supplies. PUB has also built the Deep Tunnel Sewerage System (DTSS) to channel used water to a centralised water reclamation plant for treatment after which it can be discharged into the sea or further purified into NEWater.

The technology

Driven by its need to be sustainable in water, Singapore has invested in research and technology. For example, the high-grade reclaimed water known as NEWater, has been made possible through state-of-the-art membrane technologies. The Singapore government has identified water as a new growth sector and will invest about SGD 330 million in water R&D in the next five years. One research project, a collaboration between PUB and KIWA (www.kiwa.nl) in the Netherlands, is on the development of an innovative osmotic membrane bioreactor (OMBR) which uses nanotechnology and forward osmosis to improve water quality and reduce the energy costs of production relative to conventional methods. Since March 2007, an OMBR pilot plant has been in operation at the Ulu Pandan Water Reclamation Plant.
Treating and reusing municipal wastewater effluent: reverse osmosis

The challenge

On the southwest tip of the Netherlands, in the province of Zeeland, is located the small, water-stressed town of Terneuzen. The town is home to 55,000 residents, a major manufacturing facility for The Dow Chemical Company, and a public-private partnership in the area of water management.

The company

The Dow Chemical Company is a USD 54 billion company with more than 46,000 employees around the world. It uses water in its industrial processes and also makes products that distribute and treat water. Since 1995, the company has reduced the amount of wastewater produced per pound of product by 35% and reduced its freshwater intake by more than 55 billion gallons per year.

The technology

Approximately two years ago, Dow began working with town officials in Terneuzen, the Netherlands, to treat and reuse municipal wastewater effluent using reverse osmosis.

Working with a local water company, Evides Industriewater, Dow now consumes 7,500 cubic meters of treated wastewater from the Terneuzen community every day. In the past, the Dow facility in Terneuzen used desalinated water for its steam generation and industrial processes. Today, the municipal effluent from residents is treated using reverse osmosis. Dow takes the local treated wastewater — which is less expensive and requires 65% less energy to demineralise than saltwater — and reuses it twice (first in manufacturing plants and then again in cooling towers) before releasing it into the atmosphere. As a result, every litre of water is used three times instead of once, reducing energy use for water purification by 65%. This is the equivalent of lowering carbon dioxide emissions by 5,000 tons per year. The company believes that the partnership with the municipality of Terneuzen can be easily duplicated throughout the world, and is working with the Zeeland Water Board and the Dutch central government to offer it as a solution to water-scarce regions.

“Private and public sectors simply have to work together (to further good water management practices). Today, availability, quality and security are all critical challenges to water. These issues are admittedly complex, but solvable. And that’s why the solutions will require multiple types of stakeholders. The primary driver for success is the willingness of the private and public sectors to work together using an integrated approach that goes beyond technology to include the will and commitments of all stakeholders: Government must have the will to drive pragmatic, integrated policies that ensure affordable water across entire watersheds; society must have the will to conserve and reuse existing supplies; businesses must have the will to create technology solutions that solve problems and make economic sense.”
Dow has won four awards for this project including the 2007 CEFIC environmental prize.

References


Arsenic Water Technology Partnership (2009), home page, www.arsenicpartners.org


Galcon (2009), Home page, www.galcon.co.il/index.php?goto=bep&page_from=

Go Green (2005), “A biological reactor refers to the complete water treatment system, that acts to stimulate the biological decay of the influent”, www.gogreenwastewater.com/terminology.htm


Icross.ie (2009), home page, www.icross.ie/


Millennial.net (2009), home page, www.millennial.net/

Ministry of Water Resources of China (2009), Water Resources in China.

Ministry of Science and Technology of Israel, “The German – Israeli Water Technology Co-operation Programme”, www.most.gov.il/English/Services/Calls+for+Proposals/water+tech+germany.htm


OECD (2003), Improving Water Management, OECD, Paris
OECD (2006a), *Improving Water Management: Recent OECD Experience*, OECD Observer OECD.


Seldontechologies (2009), home page, www.seldontechologies.com


Suez Environnement (CIRSEE) (2009), home page, www.cirsee.com

Syngenta (2009), home page, www.syngentaprofessionalproducts.com/to/prod/primo


WERC (2009), home page, www.werc.net/


