



Singapore NanoH2O Report

Hiranmayee Vedam

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For further information

Contact:

NanoConsulting Pte. Ltd.

20 Maxwell Road #09-17

Maxwell House

Singapore 069113

Email: sgecosystem@nanoconsulting.com.sg

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The UN suggests that each person needs 20-50 liters of safe freshwater a day to ensure their basic needs for drinking, cooking and cleaning. Currently more than one in six people worldwide – 894 million – do not have access to this amount of safe freshwater¹. Access to clean water – a basic human need – is part of the UN Millennium Development Goals by 2015. This means that by 2015, water supplies for 1.5 billion people needs to be improved².

Drinking water needs account for an average of 8% of total water requirements in the world with industrial use accounting for 22% and agricultural use accounting for the remaining 70%³. Although total water availability in the world is 1.4billion km³, fresh water resources account for only 34million km³ or about 2.4% of the total water available⁴. Of this nearly 70% of freshwater is locked in icecaps in the mountainous regions and at the poles. In addition, as seen in Figure 1, the worldwide supply of fresh water is distributed unevenly around the world and in many countries total available water falls far short of demand. Even the available freshwater resources are increasingly polluted making them unsuitable for human use. Salt water though abundant is neither potable nor useful for agricultural and industrial use directly.

Areas of physical and economic water scarcity

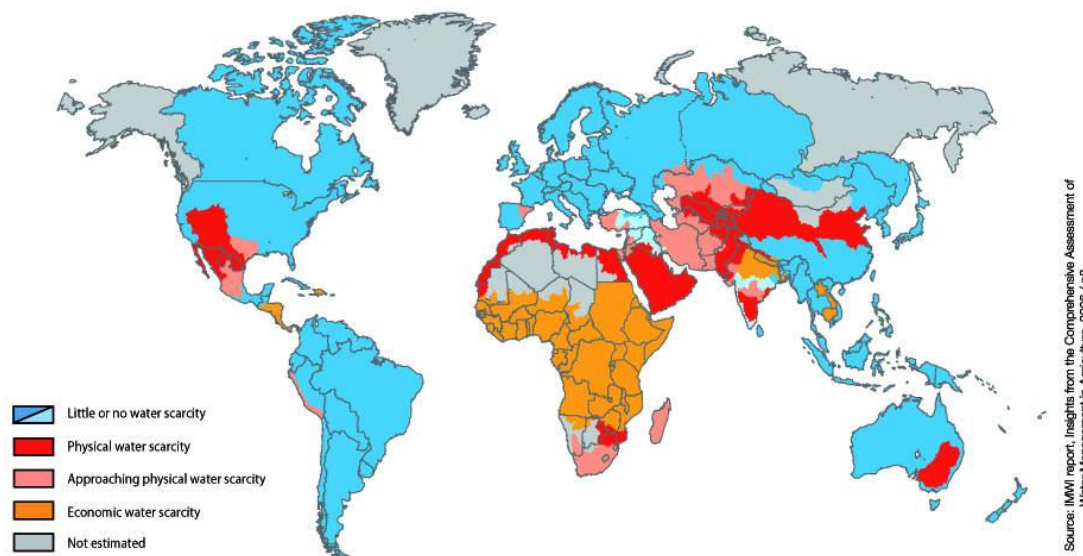


Figure 1: Areas of Physical And Economic Water Scarcity

1. Singapore Water Policy

Singapore – a city nation of almost 5 million people - doesn't have any natural water resources although it receives about 2800mm of rainfall a year. This is currently the

¹ http://www.unwater.org/statistics_san.html (Accessed May 25, 2010)

² http://www.unesco.org/water/wwap/facts_figures/mdgs.shtml (Accessed May 25, 2010)

³ UNESCO, “Water for People, Water for Life”, United Nations World Water Development Report, 2003.

⁴ http://www.unwater.org/statistics_res.html (Accessed May 25, 2010)

largest source of water for Singapore and is collected through a very efficient island wide network (only 4-5% of the rainwater is unaccounted for) and stored in 17 reservoirs. This accounts of 60% of its 300-million gallons of daily water requirements (including domestic and industrial use). Singapore has two long standing agreements with Malaysia to supply raw water that expire in 2011 and 2061. This source accounts for 40% of Singapore’s daily water requirements. This high dependence on its neighbor has led to an uncomfortable regional political relationship and Singapore has been trying to diversify its water sources and become more self-sufficient over the years. In 2003, Singapore embarked on an effective waste water recycling program – branded NEWater - with the opening of two recycling plants. With the launch of a fifth and largest NEWater plant in Changi in May 2010, and expansion of existing plants this recycling program currently accounts for 30% of Singapore’s daily water needs. A fourth source of water in Singapore opened up with the start of a reverse osmosis (RO) based desalination plant in 2005. This plant currently produces enough water to account for 10% of the water needs in the country. With this four pronged approach, Singapore plans to achieve self sufficiency in water by the time the second agreement with Malaysia expires in 2061⁵.

The general steps involved in a water treatment system using a variety of feed sources are shown in Figure 2 and many of the steps in this process are energy intensive.

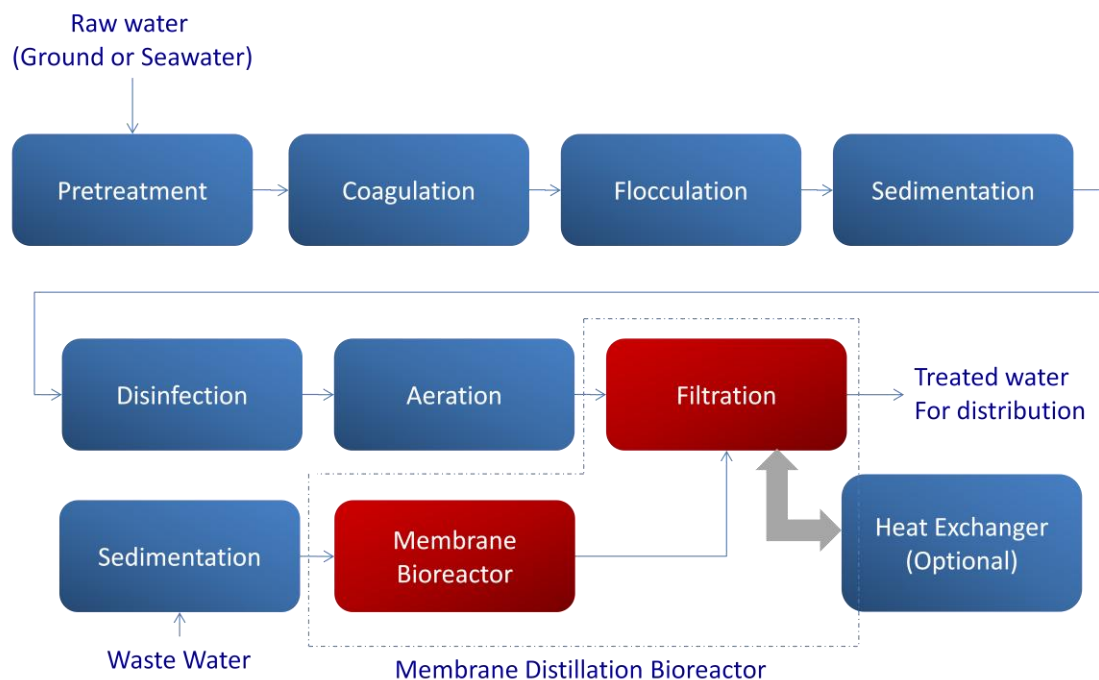


Figure 2: General flow diagram of a water treatment system

Due the strategic importance of water, land scarcity and energy scarcity in the country, Singapore committed to investing S\$330M from 2006-2011 into research and development related to more energy efficient water treatment systems that have a smaller foot print and into developing the industrial eco system to generate value out

5 http://www.straitstimes.com/BreakingNews/Singapore/Story/STISStory_519620.html (Accessed May 25, 2010)

of it for Singapore⁶. The goal of this funding is to achieve a value-add of S\$1.7 Billion in this sector and create 11000 new jobs by 2015. The overall strategy to achieve this is shown in Figure 3 and is executed by the Environment and Water Industry Development Council (EWI) under the Ministry of Environment and Water Resources (MEWR). EWI is a coordinating body among the various ministries and government agencies such as EDB, PUB, IE, JTC and NRF to provide a coherent approach to growing this sector.

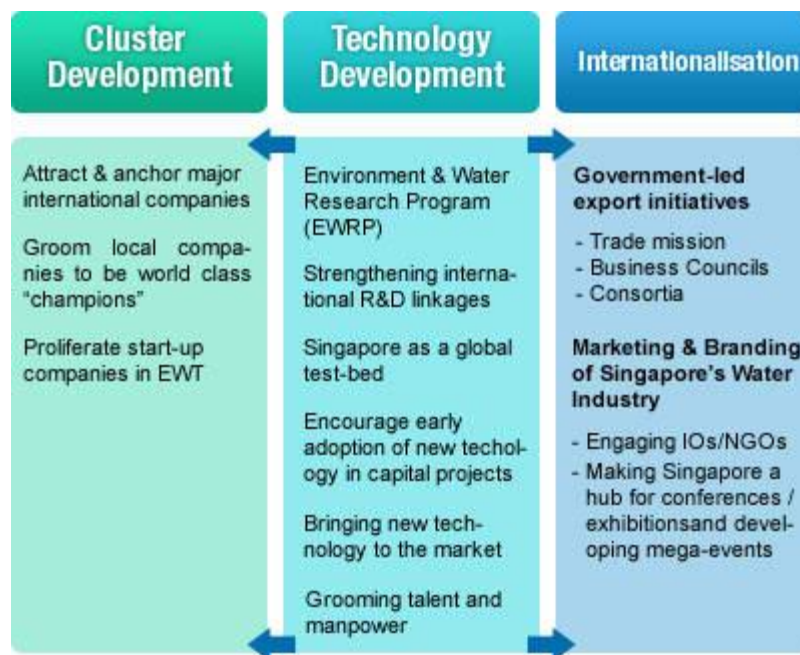


Figure 3: Strategy for Water Sector Development in Singapore (Source: EWI⁶)

1.1 Technology and Commercialization Infrastructure

Singapore Delft Water Alliance⁷

Established in early 2007, this centre of excellence for water knowledge was setup with a funding of S\$64M over 5 years to train manpower and carry out research on aquatic systems, smart sensing, and engineering and technologies relating to the urban water cycle. It is a collaboration between the National University of Singapore (NUS), PUB – a statutory board under MEWR and Dutch company Delft Hydraulics.

NUS Environmental Research Institute⁸(NERI)

This is a university level center established in 2007 with the objective of establishing NUS as a leading global center of interdisciplinary research, education and expertise in the Environment. Among its different research areas of focus is a program for safe water which investigates ways to provide potable water, control contaminants, and

⁶ <http://app.mewr.gov.sg/web/Contents/ContentsEWI.aspx?ContId=431> (Accessed May 29, 2010)

⁷ <http://www.sdwa.nus.edu.sg/>

⁸ <http://www.nus.edu.sg/neri/>

better management of catchment areas.

NUS-GE Singapore Water Technology Centre⁹

Established in June 2009, this S\$150million center – a collaboration between NUS and GE Water - is the first university collaboration for GE Water in the Asia Pacific region. Focus areas of research for this center include:

- New membrane materials and device development through feasibility studies and piloting of new membranes and membrane systems.
- Development of engineered systems for water treatment such as seawater desalination systems, membrane-based systems for drinking water production, systems for municipal and industrial water treatment and reuse, and equipment for generating ultra-pure water.
- Sensing and analysis systems for water and wastewater.

Nanyang Environment and Water Research Institute¹⁰ (NEWRI)

Established in March 2008, NEWRI is a focal point to consolidate Nanyang Technological University (NTU)'s capabilities in the environment and water research and reach out to the society and industry. Its single window approach has encouraged Toray to establish its R&D center in Singapore and local companies such as SembCorp to setup research collaboration with NTU. Its ecosystem consists of five centers of excellence:

- Singapore Membrane Technology Centre (SMTC): A center funded by EWI, it aims to lower the cost of developing alternative water resources using membrane technologies.
- Residues and Resource Reclamation Centre (R3C) that aims to find effective waste management systems.
- DHI-NTU Centre: A collaboration with DHI Denmark and funded by EWI, this center focuses on overall management of water resources and waste management using different modeling tools.
- Advanced Environmental Biotechnology Centre (ABEC): A collaboration with University of New South Wales, this center studies micro-organisms for water and environmental technologies.
- LIEN Institute for the Environment (LIFE): Funded by the Lien foundation, this center brings clean water and sanitation to poor communities in the region through a fresh injection of expertise and partners, and an inaugural environmental fellowship program.

Other Government Incentives

In order to grow the talent and manpower required for this growing sector, EWI provides PhD scholarships to qualified students to study in local and overseas university and serve their bond period in Singapore. In tandem, EWI setup an

⁹ <http://newshub.nus.edu.sg/pressrel/0906/220605.php>

¹⁰ <http://newri.ntu.edu.sg/>

Environment and Water research Program (EWRP) to accelerate the development and commercialization of R&D in environment and water related technologies. The Singapore water infrastructure will also be available to research institutions and industry to test bed new products and services. To encourage private sector adoption of new technologies in this sector, EWI introduced the TechPioneer Scheme under which the technology developer and user can get a grant of S\$2M or 30% of the project costs. To help new start-ups commercialize their environmental and water technologies, EWI set up an incubation grant scheme called Fast-Tech. This funding provides assistance through a repayable grant of up to S\$300K or 85% of the costs over 2 years.

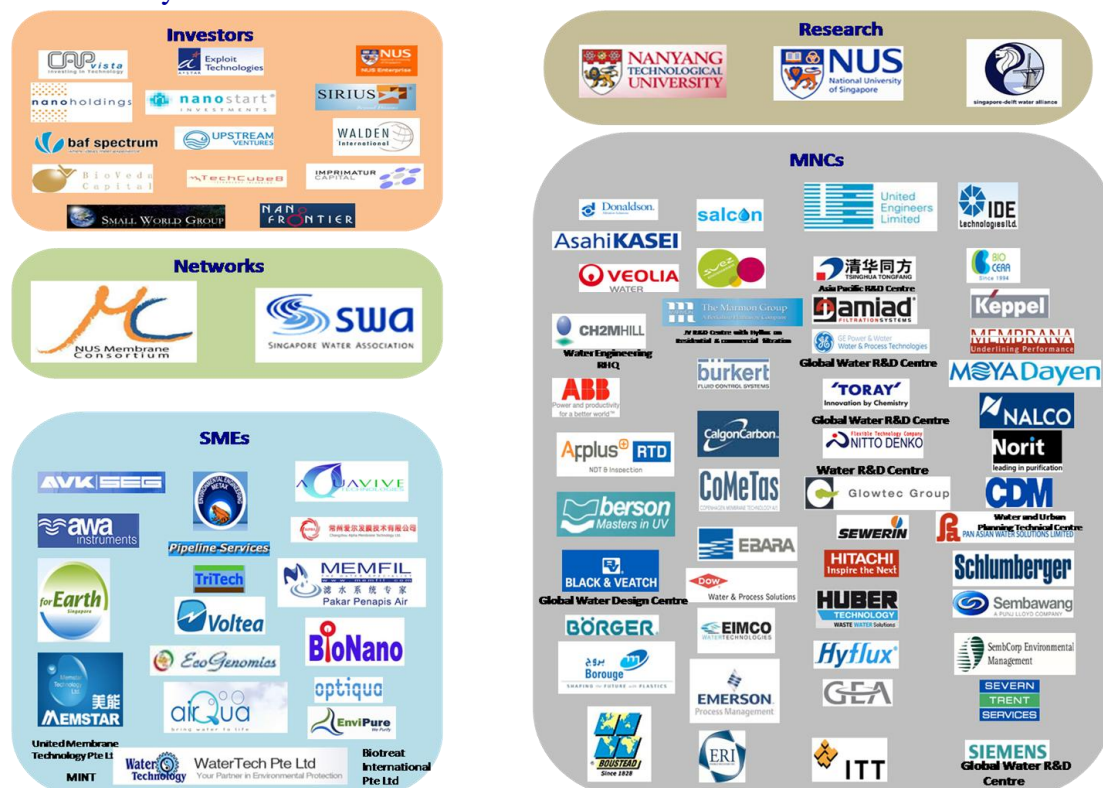
1.2 Commercial Water Eco System

EWI's cluster development strategies have resulted in a vibrant water eco system shown in Figure 4 in Singapore. Hyflux – a homegrown company – is the leading provider of sea water reverse osmosis membranes (SWRO) and built the most energy efficient SWRO plants in Singapore. It also built the world's largest SWRO desalination plants in Algeria. Keppel Seghers, a subsidiary of Keppel Corporation – another homegrown company – is a leading provider of comprehensive environmental solutions and provides full range of wastewater treatment and water recycling solutions for all types of municipal and industrial effluent. Its NEWater plant in Singapore is one of largest such plant in Asia. The increased focus on research by Singapore has led this company to invest in a S\$50million Keppel Environmental Technology Center focusing on – among other things – new membrane technologies for producing water from unconventional sources. SembCorp – another homegrown company – is an expert in industrial waste water treatment and operates the largest NEWater plant in Singapore. In addition to GE and Toray which have established technology centers in NUS and NTU respectively, Siemens and NittoDenko have established R&D centers in Singapore while companies such as Black Veatch and CH2MHill have established regional head quarters in Singapore. While spin-off activity in this area has been low, companies such as Membrane Instruments and Technology Pte. Ltd. (MINT) – a spin-off from NTU - and Alpha Membrane Technology Pte. Ltd. and BioNano International Singapore Pte. Ltd – spin-offs from NUS - have received considerable support from different funding agencies.

NUS announced the launch of a membrane consortium¹¹ which is a networking platform for industry and academia to develop the membrane sector and keep abreast of the latest developments in this area in Singapore. Recognizing the small domestic market in Singapore, EWI supports the internationalization of Singapore-based water companies and through trade missions. The Singapore water solutions alliance (SWSA) – an initiative supported under the IE Singapore's iPartners program - which was formed in 2006 is an example of how local industry can come together to access

¹¹ <http://hiranvedam.livejournal.com/4068.html>

overseas markets. EWI also organizes a flag-ship water event called the Singapore International Water Week (SIWW)¹² every year and is a must-attend event to understand the water-landscape in Singapore. This year's SIWW will be held from June 28- July 2.



Source: NanoConsulting Pte. Ltd

Figure 4: Singapore Water Eco System

2. Nanotechnology for Water

Nanotechnology is the technology of creating and applying materials and structures with at least one critical dimension below 100 nm which lead to new functionalities and properties¹³. Due to these novel functionalities, nanomaterials can lead to new products and improved performance of existing products at lower cost in a variety of industries. Hence, nanotechnology has the ability to boost economic development and employment, improving materials using less resources and environmental remediation, along with new ways of diagnostics and medical treatments^{14,15}. Recognizing this, governments around the world have invested USD40 billion (as of 2008) in

¹² <http://www.siww.com.sg/>

¹³ Wolfgang Luther, "Application of nanotechnologies in the energy sector", Volume of the series Aktionslinie Hessen-Nanotech of the Hessian Ministry of Economy, Transport Urban and Regional Development, August 2008

¹⁴ Royal Society & the Royal Academy of Engineering. 2004. Nanoscience and Nanotechnologies: Opportunities and Uncertainties. London: Royal Society.

¹⁵ Roco, M. C., Bainbridge, W.S. 2005. Societal implications of nanoscience and nanotechnology: Maximizing human benefit. J Nanopart Res 7(1):1-13.

nanotechnology research. The government funding in nanotechnology around the world for 2009 alone is estimated to be USD 9.75 billion¹⁶. Singapore has been no exception to this trend and has invested about US\$300 million between 2003 and 2007 in nanotechnology-related R&D and manpower development¹⁷.

Nano-scale materials and structures have significantly high surface-to-volume ratio and can exhibit many unique properties not found in bulk counterparts. For example, Dr. Xie Xianning at NUS has developed a new nanomaterial composed of polymer blend that is superhydrophilic and exhibits strong water-capturing behavior which has not been observed for existing superhydrophilic materials including TiO₂. They can be engineered to have specific pore sizes and with affinity towards certain substances while rejecting others. Due to these unique characteristics, nanotechnology has significant impact in the filtration step of the water treatment system shown in Figure 2. Novel membranes for membrane bioreactors (MBR) or membrane distillation bioreactors (MDBR) used for waste water reclamation or membrane distillation reactors (MDR) used for waste water desalination are also possible using nanotechnology.

2.1 Nano-based Membranes and Catalysts

Filtration can be achieved using membranes of different pore sizes that range from μm for microfiltration (MF) membranes to $<0.5\text{nm}$ for reverse osmosis (RO) membranes. As the size of the pores comes down, the pressure required to do the filtration goes up and the kind of particles that can be filtered out varies as shown in Figure 5. In an MBR or MDR, MF and Ultrafiltration (UF) happens within the reactor which is followed by a RO/NF membrane before the water is ready for domestic/industrial use. Nanofiltration (NF) membranes that have pore sizes of the order of 0.5nm - 5nm have the ability to filter all major contaminants while retaining key minerals and salts required to make the water suitable for human use unlike reverse osmosis membranes which remove all essential salts along with the contaminants. This implies that the permeate of NF membranes can be directly used for drinking and other uses while, the permeate of the RO process needs to be post-processed to add the essential salts to make it potable. NF membranes also operate at lower pressures and are less susceptible to fouling than RO membranes. In this section, we will discuss some of the membrane related research being carried out in Singapore.

One of the foremost experts in membranes area is Prof. Neal Chung from NUS. A specialist in polymeric membranes, he has developed a variety of membranes for not just water related applications but for gas separation and biological applications. He is the co-inventor of HyFlux's Kristal 600TM ultra-filtration membranes and has 75

¹⁶ Nanotechnology takes a deep breath...and prepares to save the world, Cientifica Report, April 2009.

¹⁷ <http://www.nanoconsulting.com.sg/doc/SingNanoReport2009Feb.pdf> and <http://www.nanoconsulting.com.sg/whatWeDo/singnanonews.php>

patents to his name. A major cost in desalination is the cost of pumping water across the RO membrane that requires pressures of 40-80 bar. This accounts for almost 1/3 of the cost and membrane life is low. An alternative method of forward osmosis using NF membranes can reduce the pressure requirements. Prof. Chung's group is the first to develop a novel polybenzimidazole (PBI) nanofiltration (NF) membrane with a narrow pore size and high flux for forward osmosis (FO) process. Another notable achievement in the water area from his group is the development of dual-layer microporous hollow fibers for membrane distillation (MD) processes which give it better flux than existing MD processes.

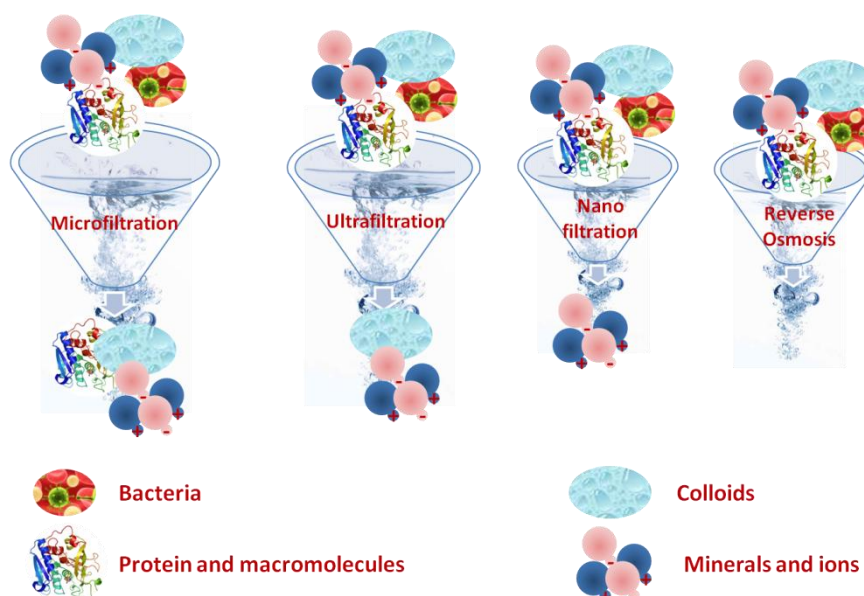


Figure 5: Types of Membrane Filtration Systems

Prof. Ng How Yong from NUS – a recipient of multiple awards - developed a new class of semi permeable membranes combining CNT with polymers to increase the flux rate and decrease the contaminants in the permeate. Prof. Seeram Ramakrishna's group from NUS – a world recognized expert in nanofiber synthesis – has developed novel energy saving salt-barrier nanofiber based membranes that have high flux, low fouling with no dead-end pores.

Prof. Anthony Fane is another recognized expert in this area from NTU/UNSW. He is investigating ways to reduce bio-fouling in different kinds of membranes – more specifically in MBR and RO processes by optimizing the membrane characteristics. Prof. Darren Sun's group from NTU is addressing the fouling problem and leaking of contaminants through the membrane by using free-standing TiO₂ nanofiber based membranes. He is also investigating concurrent hydrogen production and water purification using these membranes with the aim of making the water recycling system energy neutral.

NF membranes are good to remove multivalent ions but not particularly suitable for

monovalent ions such as fluoride and nitrates although advances are being made to remove such ions. To tackle this problem, Dr. Lim Tiek-Thye from NTU is developing a TiO₂/activated carbon photocatalytic system to remove organic micropollutants and other contaminants using a suspension system as a pretreatment system to a membrane reactor process to reduce membrane fouling. Prof. Xu Rong from NTU has been developing a new class of silver nanoparticle/MWCNT nanohybrids for use as anti-microbial membranes. She has also been developing different photocatalysts to accelerate the degradation of organic dyes in water and magnetic nanoparticles with applications in waste water purification. Prof. George Zhao and Prof. Renbi Bai from NUS have developed a new class of nano-crystalline and metal-doped TiO₂ photocatalyst that show increased activity in visible light making them useful for decontamination of waste water. They have also developed membranes made of modified chitosan to reduce bio-fouling.

2.2 Nano-based Sensors for Water Treatment

Due to their large surface area and high specificity, nanomaterials can be effective in detecting specific pathogens across a wide-range of concentrations. Of specific interest in the Singapore research community is the detection of *Cryptosporidium* – a common parasite that is highly resistant to chlorination and most important water borne pathogen in developed countries. The focus of the research is to devise ways to detect this pathogen in an hour instead of the 5-6 hours it currently takes. One approach devised by Prof. Lim Kian Meng at NUS uses acoustic signals to concentrate the *Cryptosporidium* before using nanoparticles to detect them. Prof. Ong Say Leong from NUS uses quantum dots to detect these parasites. Prof Thomas Gong from NTU uses a filtration method to capture *Cryptosporidium*, which is subsequently detected using advanced DNA-based techniques. Prof. Liu Aiqun from NTU uses a Micro-photonic-fluidic system (MPFS) system to perform the detection.

In other research in the nano-sensor based sensors, Dr. Liu Xiaogang from NUS has developed a mercury detection system that works at room temperature and can give immediate qualitative indication of presence of mercury in water using DNA-modified gold nanoparticles. Prof. C.S. Toh from NUS developed a nanoarray membrane-based sensor which can detect copper ions and formaldehyde at trace levels without additional sample treatment steps in fresh water. At the Institute of Bioengineering and Nanotechnology (IBN), researchers have developed an ultrasensitive electrochemical detection system for biomolecules using ZnO nanocrystals.

3. Conclusions

Singapore with no natural water resources has developed a sustainable strategy to meet its water needs by effectively recycling its water and purifying water from the surrounding ocean. It continues to invest in new technologies to reduce the energy,

foot print and cost of this solution on an ongoing basis. While nanotechnology can provide sustainable solutions to address these, safety concerns related to the use of nanomaterials in membranes and sensors associated with potable water are non-trivial¹⁸ and have to be carefully considered before deploying these solutions on a large scale.

18 Singapore Nanosafety Report, <http://www.nanoconsulting.com.sg/doc/SingNanoSafety2010.pdf> and NanoSafety daily news update <http://www.nanoconsulting.com.sg/whatWeDo/nanosafety.php>