WATER

GLOBAL ISSUES, LOCAL SOLUTIONS

"… What we want to provide is solutions. We don't want to provide chemicals, membranes or equipment. As a chemist, I don't look for a chemistry solution. Solutions do not come from one stream of science or engineering. They come from a group of people working together, using their skills. The understanding of how to approach a scientific challenge or problem is almost always now a multi-disciplinary approach."

– Adil Dhalla
Director, Singapore Water Technology Centre GE Water and Process Technologies

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Introduction

The global water challenge

With the world's population expected to rise from 7 billion in 2014 to 9 billion by 2050[1] and continuous industrial growth across the globe, water has become a critical strategic resource.[2] Although 70 per cent of our planet is covered with water, saline water in seas and oceans makes up about 97 per cent of this amount and only 3 per cent can be counted as freshwater. The total usable freshwater supply for ecosystems and humans is a mere 0.5 per cent of all freshwater resources. The remaining 2.5 per cent is locked up as ice in the Antarctica, the Arctic and glaciers. Currently, 748 million people worldwide lack access to an improved water supply and 2.5 billion lack access to improved sanitation.[3]

Today, 54 per cent of the world's population lives in urban areas. By 2050, this figure will increase to 66 per cent.[4] According to the United Nations (UN), the world's urban population is expected to surpass six billion by 2045, having grown from 746 million in 1950 to 3.9 billion in 2014. Asia, despite its lower level of urbanization, is home to 53 per cent of the world's urban population, followed by Europe with 14 per cent, and Latin America and the Caribbean with 13 per cent. By 2050, India is projected to add 404 million urban dwellers, China 292 million and Nigeria 212 million.

Coupled demographics and urbanization is the focus on water as a criterion for assessing the physical, economic and environmental viability of energy projects. Energy and water are interdependent and the water–energy nexus is a significant factor that cannot be ignored. Water is used extensively in power generation, the extraction, transportation and processing of fossil fuels, and agricultural irrigation. Similarly, energy is vital to power systems that collect, transport, distribute and treat water. In 2010, global water withdrawals for energy production were estimated at 583 billion cubic meters (bcm), or some 15 per cent of the world's total water withdrawals.[5] Of that, water consumption – the volume withdrawn but not returned to its source – was 66 bcm or about 11 per cent of energy-related water withdrawals.

Water resources are finite. Its unreliable and declining quality are major issues. Producing potable water to meet the demands of an increasing urban population is becoming a challenge of competing priorities: increased water re-allocation from agriculture to urban demands, degraded water quality, depleted groundwater, an increased need for water sanitation services, and threatened food and economic security. Harnessing water requires infrastructure for a steady supply of water, efficient equipment to collect and treat water, and the re-use of resources to conserve water. Industry players include petrochemicals, steel, oil and gas, mining, chemical and consumer goods, power generation, and municipal supplies. The diversity of stakeholders and their sometimes conflicting demands add complexity to an already challenging problem

[1] http://www.theguardian.com/environment/2014/sep/18/world-population-new-study-11bn-2100

[2] The Earth Institute at Columbia University provides interactive geo-charts that highlight water challenges around the world, using dependency ratios (the dependency ratio is the percentage of renewable water resources that originate outside a country). http://blogs.ei.columbia.edu/2013/02/28/geocharts-water-challenges-around-the-world/

[3] WHO/UNICEF, Millennium Development Goals, *2015 Report on Water & Sanitation*, Joint Monitoring Program, Geneva – "Water, sanitation and hygiene: WASH Post 2015," http://www.wssinfo.org/fileadmin/user_upload/resources/JMP-A5-English-2pp.pdf

[4] "World's population increasingly urban with more than half living in urban areas," July 10, 2014, http://www.un.org/en/development/desa/news/population/world-urbanization-prospects-2014.html

[5] International Energy Agency (IEA), "Water for energy: Is energy becoming a thirstier resource?" Excerpt from the World Energy Outlook 2012. http://www.worldenergyoutlook.org/media/weowebsite/2012/WEO_2012_Water_Excerpt.pdf

that perhaps could create new opportunities for collaboration and innovation.

Singapore: A story of four taps[6]

The Singapore water story is a unique example of how a country with a water supply that is more than 50 per cent non-potable, has used fore-sighting and stakeholder engagement to create a strategic response incorporating risk planning and public private partnerships. Dr. Lim Mong Hoo[6] talks about how Singapore's Public Utilities Board (PUB) has to work closely with land-use planning agencies such as the Urban Redevelopment Authority (URA) and the Economic Development Board (EDB) to better coordinate the siting of urban development projects and industrial clusters for more effective water management planning.

Two innovations in Singapore that merit greater attention are NEWater,[7] a high grade reclaimed water purified using membrane technologies developed by Hyflux, and the Deep Tunnel Sewerage System, a used water superhighway to centralize the reclamation of used water by linking existing sewerage pipes from homes and industries to water reclamation plants.

It is also important to note that Singapore uses pricing to recover the full cost of its water production and supply,[8] and create shared ownership and responsible usage of Singapore's water resources. Singapore's water tariff is one of the highest in Asia, excluding Japan.[9]

Singapore uses four "national taps" – local catchment, NEWater, desalinated water, imported water – to manage the entire water cycle from the sourcing, collection, purification and supply of drinking water, to the treatment of used water and stormwater management. Boasting one of the world's lowest percentages (5 per cent) for unaccounted-for water, Singapore has 17 reservoirs and a total catchment area that is two-thirds of the island's land area. Its largest catchment area, Marina Catchment, is an urban catchment of 10,000 ha that is 1/6 the size of Singapore.

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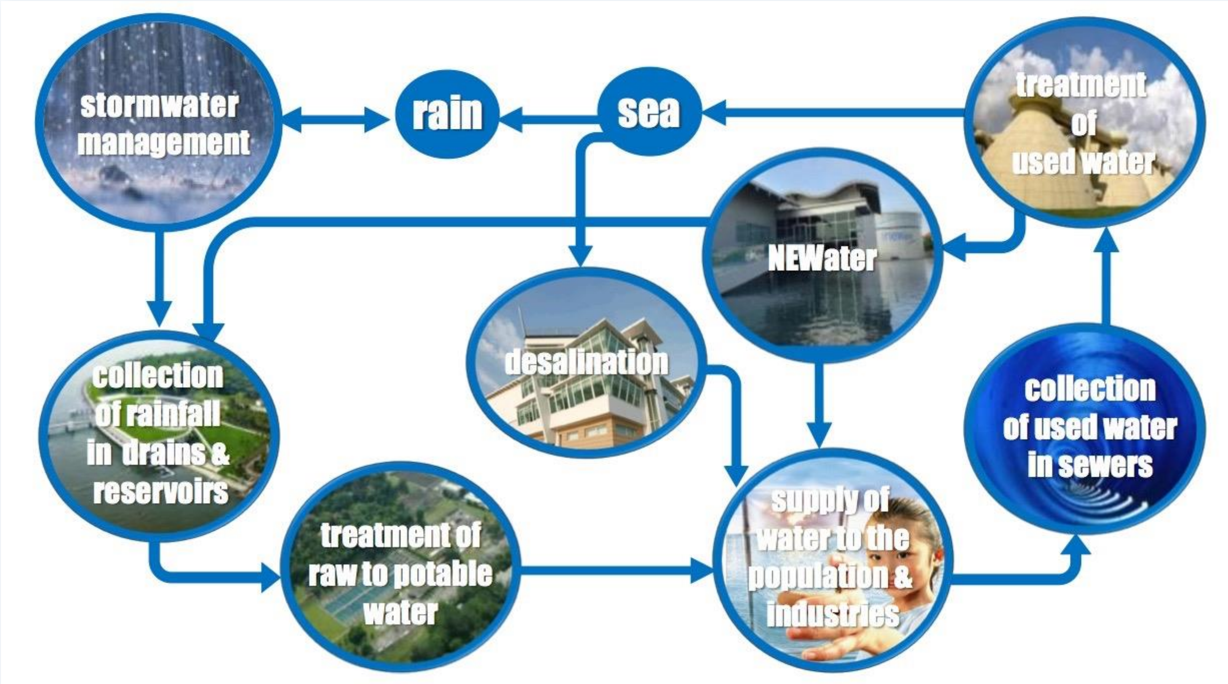
[6] Dr Lim Mong Hoo (Chief Specialist (Water Quality), PUB Water Quality Office) contributed significantly to this discussion. Presentation "Our Singapore's Water Story – ABC Programme."

[7] NEWater capacity currently meets 30 per cent of Singapore's water needs and expects to meet 55 per cent of Singapore's water demands by 2060. Hyflux membrane products and systems have been installed in 400 locations worldwide.

[8] http://www.pub.gov.sg/general/Pages/WaterTariff.aspx

[9] In Global Water Intelligence's 2012 survey of water tariffs for 308 cities in 102 countries, Singapore's water tariff of US$1.68 (S$2.07) per cubic meter (based upon consumption of 15 cubic meters per month) was marginally lower than the global average of US$1.98 per cubic meter. Gurdev Singh, "When the price is right," March 1, 2013, http://news.asiaone.com/News/Latest+News/World/Story/A1Story20130301-405631.html



Managing the complete water cycle

The Asia-Pacific region is home to 60 per cent of the world's population but has only 36 per cent of its water resources.[10] Per capita water availability is the lowest in the world. The region has some of the world's fastest-growing megacities, a development driven by internal migration and urbanization. Between 2010 and 2025, a predicted 700 million people will be added to the growing numbers requiring municipal water services.

It is no surprise that water-rich countries, such as Malaysia, Indonesia, Bhutan and Papua New Guinea, are facing urban water supply and quality constraints, particularly from domestic sewage. Approximately 150 to 250 million cubic meters per day of untreated wastewater from urban areas are discharged into open water bodies or leached into the subsoil.

[10] http://www.un.org/waterforlifedecade/asia.shtml

According to a January 2013 Bloomberg New Energy Finance study on water reuse, the USA and Europe discharge 90 per cent of their wastewater annually, but directly re-use only 6 per cent and 2 per cent respectively.[11] China treats around 80 per cent of its wastewater but directly re-uses only 8 per cent. In the Middle East and North Africa, only 40 per cent of municipal wastewater is treated for use in agriculture, and 8 per cent for reuse, while the remainder is discharged into the ocean or other water bodies.

An American Chemical Society report in 2012 anticipated that seven in 10 of the more than 3,100 US counties could risk freshwater shortages by 2050, owing to increasing water demand and climate change impacts.[12]

[11] Amena H Saiyid, "Water scarcity drives US communities toward smarter use, recycling," March 24, 2010, http://www.bloomberg.com/news/2014-03-24/water-scarcity-drives-u-s-communities-toward-smarter-use-recycling.html

[12] http://www.acs.org/content/acs/en/pressroom/presspacs/2012/acs-presspac-february-15-2012/climate-change-may-increase-risk-of-water-shortages-in-hundreds-of-us-counties-by-2050.html

Water shortages arise in three ways: environmental change (human-induced decline in the quantity or quality of a resource), population growth (reduction in per-capita availability), and unequal distribution (the concentration of resources in the hands of the few).[13] According to Thomas F Homer-Dixon, countries need technical ingenuity (to develop technologies that compensate for environmental loss) and social ingenuity (to create organizations and institutions to buffer people from the effects of scarcity and provide the right incentives for technological entrepreneurs) to manage scarcity.

Singapore, with a land area of 710 sq km, a population of 5.3 million, domestic water consumption per capita of 151 liters/day,[14] and an average water demand of 1.8 million cubic meters/day (400 million gallons/day), seems to have employed both technical and social ingenuity to manage its limited water resources. It uses a centralized approach to achieve water security and reduce dependency on external resources, and combines both supply-side and demand-side management strategies to create a large-scale urban water infrastructure and an integrated water resource management (IWRM) network that is dynamic, collaborative and sustainable.[15]

[13] Thomas F Homer-Dixon, "Environmental scarcities and violent conflicts: Evidence from cases," 1994, http://graduateinstitute.ch/files/live/sites/iheid/files/shared/summer/IA2009_readings/MD1.pdf

[14] The respective targets for 2020 and 2030 are 147 liters/day and 140 liters/day – http://app.mewr.gov.sg/data/ImgCont/1386/5.%20Factsheet%20-%20Water%20Demand%20[web].pdf

[15] In 2006, the Singapore government committed S$330 million to fund innovation and capability building in the environment and water sector. That year, the Environment and Water Industry Programme Office (EWI) – an inter-agency body led by the Public Utilities Board (PUB), the national water agency, and the Economic Development Board (EDB) – was established to manage this R&D funding. In 2011, an additional S$140 million was pumped into the sector. PUB won the 2007 Stockholm Industry Water Award and was named Water Agency of the Year at the Global Water Awards 2006. http://www.edb.gov.sg/content/dam/edb/en/resources/factsheetsnew/A%20Global%20Hydrohub.pdf

Public outreach and education

In 2000, the Los Angeles Department of Water and Power (LADWP) announced the completion of the Donald C Tillman water reclamation plant in Van Nuys, capable of providing water to 120,000 homes.[16] The plan was for sewage to be treated at the plant and then pumped to spreading fields near Hansen Dam where, over five years, it would filter through sandy soil and gravel into an underground reservoir.[17] Public opposition greeted the announcement, partly as a result of inopportune timing[18] and even though the LADWP assured residents that the treated water from the Tillman plant would be "almost potable" and have "a purity indistinguishable from unpolluted rainwater," it could not overcome the "yuck factor" that accompanied public perception.

In 2007, various stakeholders comprising community leaders, elected officials, environmental and recreational groups, and local visionaries completed the Los Angeles River Master Plan, outlining a 20-year blueprint for restoring and managing the river (to maintain flood protection and safety, as well as environmental conservation and celebration of community neighborhoods). In May 2014, the Army Corps of Engineers endorsed a $1 billion commitment in support of the plan to revitalize the river; funding will be shared among federal, state and local agencies. The LA story highlights the importance of timing, strategic

[16] The department is preparing a study on the feasibility of direct potable reuse in California by 2016, according to information on its website. By 2035, the city projects a demand for more than 168,000 acre feet per year of imported water even after implementing non-potable reuse and groundwater replenishment projects. http://www.bloomberg.com/news/2014-03-24/water-scarcity-drives-u-s-communities-toward-smarter-use-recycling.html

[17] Marc H Haefele and Anna Sklar, "Revisiting 'toilet to tap'," August 26, 2007, http://www.latimes.com/opinion/la-op-haefele26aug26-story.html Gerald Silver, President of Homeowners of Encino, was credited with popularizing the "toilet to tap" tag.

[18] The announcement was made just before an open mayoral contest in 2001 that included Valley secession on the ballot. Hence, the engineering triumph became clouded by political nuances.

preparation and stakeholder engagement.

Similarly, the Singapore water story embraces these three elements, together with public private participation, as critical success factors in the water innovation framework. Public outreach efforts through the organization of workshops, seminars, exhibitions and community engagement events help to educate citizens and create collective ownership of Singapore's water assets. Even then, the "yuck factor" associated with treated wastewater (NEWater) remains a barrier to public consumption.[19]

Singapore's IWRM achievements in the municipal sector have gained global recognition through the organization of an annual Singapore International Water Week (SIWW) that converges policy-makers, industry leaders, experts and practitioners to address challenges, showcase technologies and discover opportunities for collaborative entrepreneurship.[20] R&D is actively promoted through the establishment of a WaterHub in Singapore, providing shared facilities and lab testing capabilities, as well as networking, intelligence sharing and partnership opportunities.

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[19] NEWater is primarily used as non-potable water by industrial and commercial customers in Singapore, e.g., for cooling and wafer fabrication processes, and is located in industrial clusters to meet both supply and demand.
http://www.pub.gov.sg/E-Services/NEWater/Pages/default.aspx

[20] SIWW 2014 recorded S$14.5 billion in total value from deals made and attracted over 20,000 participants from 118 countries. http://www.siww.com.sg/media/collaborations-reinforce-singapore-international-water-week-premier-global-platform-share-and

Tanzania: a community response[21]

Access to, and use of, water resources has global implications. Water security and safety concerns have a direct impact on food security and safety, health, energy security and economic prosperity. Water security depends on the availability and reliability of water sources while water safety hinges on the quality of the source water and its protection from contamination. Risks include natural disasters (e.g., storms) and anthropogenic threats that encompass population growth, industry, agriculture, transport, water use practices, and climate change.

Water sources vary widely, depending on location and economic capacity, from municipal sources for urban communities to multiple sources (wells, boreholes, rivers, streams, rainwater harvest) for rural communities.

Singapore is an urban center that has access to funds and resources, including technology, that it can use in its water management program. In less industrialized countries, where access to, and use of, such resources is limited, the natural recourse is to create local solutions to address water issues. Prof Isai T Urasa talks about Tanzania where wastewater stabilization ponds (WSPs) are a natural method of wastewater treatment. They consist of a series of shallow, man-made, anaerobic facultative and maturation ponds that remove organic contaminants by natural biodegradation, requiring no external input, chemical treatment or disinfectant. WSP technology is particularly suited for tropical regions where the intensity of the sunlight is favored for the natural waste removal process, that is, for communities with limited economic capacities.

[21] Prof Isai T Urasa contributed significantly to this segment. Gii WITS Presentation: "Water Resource Development and Management."

A typical wastewater treatment facility in the USA uses mechanical and chemical processes, and may have up to three stages of treatment – primary, secondary and tertiary – while a WSP system comprises a primary and two secondary facultative ponds and maturation ponds, accompanied by a distribution chamber. The facultative ponds are designed to remove organic contaminants by natural biodegradation: the upper portion is aerobic while the lower portion is anaerobic. Facultative ponds also allow suspended solids to settle. Maturation ponds, on the other hand, are more aerobic, promoting oxidation processes and allowing the removal of nutrients and pathogens. Threats to pond efficiency include overloading due to increased input, sludge build-up, algal blooms, plant material, and other types of debris.

The Njoro community water project in Tanzania was established in 2000; in 2001, it established partnerships with Egerton University, a local institution, and the Catholic diocese of Nakuru, a non-governmental organization (NGO). The operational features of this project empowered it to develop capital, seek community participation, and use an integrated management technology to engage actively in policy making as well as incorporate poverty alleviation initiatives.

Njoro had 15,000 inhabitants who lived in a semi-arid region that experienced rainfall of 100 cm/year. The Njoro community used source water from boreholes and faced the challenge of suspect water quality involving microbiological contamination associated with poor sanitation services and agriculture, as well as a high salt content (where the fluoride levels were more than 10 ppm, compared to safe fluoride levels of 1.0 to 1.5 ppm).

The project established communal water supply points and set up a management committee comprising 11 members, including six women. It also introduced user fees and provided individual consumer connections that helped in the capacity building process. The partnership secured financial resources, provided water management and distribution expertise, and facilitated access to essential technical skills such as well construction, water distribution networks, water quality assessment and assurance.

According to Dr. Urasa, research opportunities for university faculty and students were created in the form of water quality index measurements: biochemical oxygen demand (BOD)/chemical oxygen demand (COD), pH, nutrients and heavy metals. Source water quality assessments were made using physical/chemical parameters to analyze the impact of pesticides and land use practices, as well as bacterial contamination.

To mitigate/remove the fluoride content in the water, a bone char purification process using cow or bovine bone was introduced. Animal bone was collected from the community and through a university/community/NGO partnership, the bone was converted to a defluoridation filter using a process of charring and grinding. The bone char was placed in packets fitted with faucets and communal water tanks were retrofitted accordingly.

The Tanzanian water project is a good example of a local community response to a water need. Significant features of this IWRM program included research and training strategies, consistent operational monitoring, the transfer of new technologies and new knowledge, aided by the presence of community guidelines and involvement.

Developing countries with predominantly rural populations can benefit from small infrastructure schemes that can provide water and sanitation services in a manner that consumes fewer resources, is flexible and sustainable, and costs less. Small infrastructure or distributed networks allow for better control over locally appropriate efficiency measures and promotes greater resiliency, empowering communities by creating a local multiplier effect through scalability and adaptability. Coordination between engineers, chemists and policy makers is both a prerequisite and an outcome, reinforcing the power of a multi-disciplinary approach toward a global challenge.

Water Innovation: the need for context and education[22]

Before embarking on a discussion of innovation in the water sector, it would be useful to determine the impetus for innovation (why), the priorities for innovation (what), where the efforts of individual innovators fit in the big picture (where and who), and how the global, multi-disciplinary, multi-stakeholder innovation efforts can be coordinated (how) to facilitate sustained access to water services and water quality standards for all.

According to Prof Garrick E Louis, innovation for water treatment and supply can be defined as the development of artifacts to improve the performance of the water sector. Artifacts include devices, policies, programs, and processes. Measures of performance in the sector include quantity,

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[22] Prof Garrick Louis contributed significantly to this segment. Gii WITS Presentation: “Innovation for Development: The Drinking Water Challenge.”

quality, accessibility, efficiency, affordability to users, profitability to service providers, the environmental impact and sustainability of the service lifecycle, and its resilience in the face of challenges.

Governments understand that water research and innovation currently lack a strategic approach to the highly diverse and interrelated challenges presented by the water ecosystem. The need for a coherent and unifying framework that embraces diversity, complexity and innovation is critical to the coordination of different public sector agencies, as well as the promotion of public private sector collaboration across geographical boundaries.

The water innovation grid: building capacity

Dr. Louis has identified eight capacity building factors that determine sustained access to adequate safe water and sanitation services.

1. Institutional	Policies, programs, procedures
2. Human resources	Professional, skilled, trained – literate, untrained – illiterate
3. Technical	Supply chain, support services
4. Economic/ Financial	Public and private suppliers, bond service, fees or general taxes, grants-in-aid
5. Environmental/ Natural resources	Carrying capacity of media, seasonal capacity of sources and sinks
6. Energy	Grid electricity, reliability, intensity
7. Socio-cultural	Effective participation rate
8. Service	Quantity, quality

These factors can be used to assess the priorities for water innovation across all the unit processes in water treatment and supply, such as abstraction, treatment, storage, distribution and re-use. Additionally other issues can be assessed, such as financing or O&M.

A discussion of water management issues inevitably revolves around three distinct elements: economics, water quality and the environment. In fact, these three issues are interconnected and need to be considered in context and relation to each other rather than separately. In order to manage water security effectively, the use of economic and policy instruments needs to be considered in terms of the impact on society and the environment, that is, the triple bottom-line (having economic, social and environmental implications), and as part of a wider IWRM framework.

IWRM is a framework designed to improve the management of water resources based on four key principles adopted at the 1992 Dublin Conference on Water and the Rio de Janeiro Summit on Sustainable Development. These principles hold that: (1) freshwater is a finite and vulnerable resource essential to sustain life, development, and the environment; (2) water development and management should be based on a participatory approach, involving users, planners, and policy makers at all levels; (3) women play a central part in the provision, management, and safeguarding of water; and (4) water has an economic value in all its competing uses and should be recognized as an economic good.[23]

Stakeholder engagement, as evidenced in public private partnerships, is recognized as a critical success factor in formulating local responses to meeting IWRM needs. Ultimately, the major benefits of IWRM include the alleviation of poverty and disease, water conservation and re-use, agricultural production and rural water supply, the protection of aquatic ecosystems, capacity building through public participation, and a multi-disciplinary approach to water treatment and innovation.

Singapore has achieved considerable success in its water management by anchoring its water sustainability measures in a strong institutional framework that includes integrated master planning and development and dynamic urban governance.[24] It understands that it needs to build a diversified and sustainable supply of water using, among other efforts, membrane technology[25] to develop new, low-cost and improved membrane systems to assist in water treatment, desalination and water reclamation. Its strategy for water sustainability includes outreach to the public through community engagement and education, and active participation with markets, reinforcing the importance of capacity development as identified in the water innovation grid.

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[23] Chris White, "Integrated water resources management: What it is and why is it used," June 10, 2013, http://www.globalwaterforum.org/2013/06/10/integrated-water-resources-management-what-it-is-and-why-is-it-used/ – citing the International Conference of Water and the Environment (ICWE), *The Dublin Statement on Water and Sustainable Development*, 1992 http://www.wmo.int/pages/prog/hwrp/documents/english/icwedece.html

[24] Centre for Liveable Cities (Singapore) and Civil Service College (Singapore), Liveable Sustainable Cities: A Framework, 2014 – http://www.clc.gov.sg/documents/books/CLC_CSCLiveable&SustainableCities.pdf

[25] The Singapore Membrane Technology Centre (SMTC), headed by Associate Professor Wang Rong at the Nanyang Technological University (NTU), was set up in 2008 to spearhead Singapore's R&D efforts in fundamental and applied membrane science and technology. The linkages between the economic development of Singapore and water sustainability are evident in the two stakeholder partners – the Environment & Water Industry Development Council and Economic Development Board – that support SMTC.

The power of education: MOOCs

In February 2014, the International Workshop on Governance 'of' and 'for' Sustainable Development Goals, organized by the United Nations University Institute of Advanced Studies (UNU-IAS), the Earth System Governance Project and the POST2015 project (hosted by the Tokyo Institute of Technology and sponsored by the Ministry of Environment, Japan), resulted in a series of policy briefs, the second of which advocated "water literacy" as a response to water-related sustainability challenges. In discussions about the Post-2015 Development Agenda, education was considered a major target domain.[26]

Global education outreach in the form of Massive Open Online Courses (MOOCs) is one way to focus on the needs of the "water–education nexus." In 2007, the first courses about water treatment were offered as OpenCourseWare (OCW).[27] In November 2013, Delft University of Technology (TU Delft) offered two MOOC courses on solar energy and an introduction to water treatment, the latter of which received a registration of 29,000 students on the edX platform.[28] In addition to the 19 MOOCs TU Delft offers are over 140 OCW courses that have 1,000 unique online visitors per day.

MOOCs provide a global platform for the delivery of knowledge on demand. Prof Doris van Halem[29] believes that water MOOCs can positively influence the way in which chemists and other scientists will access education.[30] In her opinion, increased knowledge across various experience levels and geographies will positively affect the field of water treatment globally. To increase the impact of MOOCs, TU Delft is planning translations into Arabic and Chinese, and collaborates with local partners in Mozambique and Colombia.

MOOCs also facilitate linkages between education and PhD research at TU Delft in the areas of urbanizing deltas of the world (wastewater reclamation project in Mozambique), hand pump arsenic removal (in Bangladesh and Nicaragua), and a riverbank and gravel filtration project (in Colombia).

The global outreach of online education has the potential to address inequality, poverty and exclusion issues experienced by developing countries and the financial, human capital and resource constraints that undermine progress toward achieving effective learning environments for quality education.[31] The implications for water education for chemists, engineers and other scientists, as well as the public, can only be positive. This outreach to a wider community to create greater awareness through MOOCs highlights the importance of education. Similarly, Singapore's efforts to educate its population through community engagement projects and campaigns are part of this global "water literacy" movement.

[26] Post-2015 UNU-IAS Policy Brief #2: "Linking education and water in the sustainable development goals," (United Nations, 2013a; OWG, 2014; SDSN, 2014) http://sdg.earthsystemgovernance.org/sdg/publications/linking-education-and-water-sustainable-development-goals

[27] The OpenCourseWare movement started in 1999 when the University of Tubingen in Germany published videos of its lectures online. In October 2002, MIT launched its OCW services, followed by Yale, the University of Michigan and the University of California Berkeley. Today, MIT offers materials from 2,150 courses and enjoys 125 million visitors at its OCW website. http://ocw.mit.edu/about/

[28] The MOOC phenomenon took off in 2012, dominated by three MOOC platforms: UdaCity, edX and Coursera. MOOCs provide courses on university-level subject matter delivered by university faculty, are free and have no admissions requirements. http://www.skilledup.com/articles/the-best-mooc-provider-a-review-of-coursera-udacity-and-edx/

[29] Prof Doris van Halem contributed significantly to this segment. Gii WITS Presentation: "Bringing Water Knowledge to the Mass: Online Water Treatment Education."

[30] *"MOOCs are fundamentally about outreach and social mission and they're not very expensive,"* says Prof Karl Ulrich, Vice-Dean of Innovation at Wharton, in an interview with Knowledge@Wharton, "Disruption ahead: What MOOCs will mean for MBA programs," July 16, 2014, http://knowledge.wharton.upenn.edu/article/moocs-mba-programs-opportunities-threats/

[31] "Envisioning education in the Post-2015 Development Agenda: Executive Summary," page 4, http://unesdoc.unesco.org/images/0022/002230/223025E.pdf

Innovations in water treatment

New water projects are complex and dynamic. In many developed and developing nations, government-controlled water operations are fragmenting and re-grouping under privatization. The adoption of technology is accelerating while international and domestic standards are becoming increasingly stringent. Today, engineering a large water project usually involves cross-border cooperation and the participation of talent that has a global profile.

The drivers for the growth and development of the water sector include declining freshwater resources, ageing water and wastewater infrastructure in the developed regions, a rapid increase in population in the developing countries and major urban centers, and increasingly stringent regulations, particularly in the areas of water re-use and wastage.

Risks include insufficient or unreliable water supply for existing and future operations, coupled with an insufficient capacity to treat and dispose of drinking water, wastewater, process water and utility water. In addition, it is becoming increasingly difficult to secure new permits and legal licenses to operate. Increased costs in raw and wastewater treatment and disposal further compound the problem. Already, historic disposal practices are creating future liability issues while the overcrowding of small and local players is contributing to unhealthy competition in the market.

Diminishing water resources, rapid industrial development and population growth are reducing the use of conventional water and wastewater treatment processes and making them less efficient. Today, synthetic organic compounds, nutrients and inorganic materials in the water can compromise water quality, health and the environment, and consequently, need to be removed from water. Producing high-purity water for drinking and industrial water, with improvements in quality and cost-effectiveness, makes advanced treatment technologies more demanding and widely accepted.

> **"Polluted water is the planet's deadliest foe**—killing 14,000 people a day according to the World Health Organization.
>
> Three problems:
>
> - a booming population (closing in on 7 billion worldwide)
> - increased standards of living (which correlate with freshwater use) and
> - damaged groundwater aquifers (which collect and store much of the world's fresh water).
>
> All are putting a serious strain on the global water supply. Hence the massive market for water-treatment equipment, which could hit

The global water market, worth $425 billion in 2010,[32] is divided into two distinct segments: water and wastewater utilities (58 per cent), and water solutions and services (42 per cent). Prof. Ellene Tratras Contis[33] understands that a big picture perspective is essential for greater clarity and identification of where the key issues and risks co-exist. The manufacturing and power generation industries have unique water requirements that, in turn, affect water quality through

[32] Frost & Sullivan, Environment & Water, Key 360º issues, http://ww2.frost.com/research/industry/environment-building-technologies/environment-water/

[33] Prof Ellene Contis contributed significantly to this segment. Gii WITS Presentation: "Water Treatment and Innovation: Background and Overview."

waste discharge. This, in turn, has consequences for downstream users and aquatic ecosystems. Access to water and its quantity and quality limits the production of oil, power, products and goods, as well as the consumption of end products and services. The lack of potable water increases the threat of water-borne diseases and epidemics while the risk of the destruction of ecology and ecosystems is very real.

Membrane technology

Today, membrane technology has emerged as a significant development in water treatment, particularly desalination. Traditional water treatment methods include physical separation techniques for particle removal, biological and chemical treatments to remove suspended solids, organic matter and dissolved pollutants or toxins, and evaporative techniques and other physical and mechanical methods.[34] Membrane separation replaces or supplements these techniques by the use of selectively permeable barriers, with pores sized to permit the passage of water molecules but small enough to retain a wide range of particulate and dissolved compounds.

According to Prof Wang Rong[35], the reliance on membranes in the water cycle has grown by at least 15 per cent per year, with almost a megaton of water passing through membranes in Singapore per day. Globally, desalination by reverse osmosis membranes now exceeds thermal desalination; membrane bioreactors are becoming widespread; and the use of low pressure membranes for water treatment, coupled with reverse osmosis, has more than doubled in the past five years.

[34] European Commission, "Membrane technologies for water applications: Highlights from a selection of European research projects," 2010, http://ec.europa.eu/research/environment/pdf/membrane-technologies.pdf

[35] Prof Wang Rong contributed significantly to this segment. Gii WITS Presentation: "Global Challenges and Solutions on Membrane & Desalination."

Prof Rong, however, thinks that while membrane technology has greatly enhanced our capability of tackling the challenges of increased population growth and scarcity of freshwater resources, as well as more stringent environment regulations, the current membrane processes still suffer from high energy consumption (for example, in reverse osmosis), chemical usage (such as oxidants for organics degradation) and the generation of a considerable amount of waste stream (such as reverse osmosis brine for inland applications). In addition, their benefits are also constrained by the less than ideal separations (low permeability and selectivity) of synthetic membranes due to the lack of functionality and controlled architecture.

One of the biggest challenges in desalination is its high energy consumption. Feed water salinity has the most significant impact on power consumption. The desalination process must overcome osmotic pressure to reverse the flow, forcing water from the "salty" feed side of a membrane to flow to the "purified" water (also known as permeate or product water) side of the membrane – hence, "reverse osmosis desalination."[36] Theoretically, about 0.86 kWh of energy is needed to desalinate 1 cubic meter of salt water (34,500 ppm).

Energy is the single largest expense for desalination plants, accounting for as much as half of the costs of transforming seawater into potable water, according to a 2013 Pacific Institute report.[37] A 25 per cent increase in energy expenses would raise the cost of producing water by about

[36] Water Reuse Desalination Committee white paper, "Seawater desalination power consumption," November 2011, https://www.watereuse.org/sites/default/files/u8/Power_consumption_white_paper.pdf

[37] Andrew Herndon, "Energy makes up half of desalination plant costs: Study," May 1, 2013, http://www.bloomberg.com/news/2013-05-01/energy-makes-up-half-of-desalination-plant-costs-study.html

9 per cent and 15 per cent at reverse osmosis and thermal desalination plants respectively.

Prof Rong is aware that membrane technologies consume high levels of energy and in fact, reminds us to pay attention to the water–energy nexus. She believes that forward osmosis and pressure retarded osmosis membrane technologies have great potential for water production and energy recovery.[38] Low pressure nanofiltration membranes can be used for the pre-treatment of seawater to enhance system performance and reduce energy consumption while hydrophobic microporous membranes can be used for membrane distillation. Aquaporins-based hollow fiber membranes offer promising performance for water re-use and desalination.

The biggest technical challenge with the use of membranes for wastewater treatment is the high potential for fouling. Membrane fouling – which can be caused by colloids, soluble organic compounds, and micro-organisms that are typically not well removed with conventional pre-treatment methods – increases feed pressure and requires frequent membrane cleaning, leading to reduced efficiency and a shorter membrane life.[39] Other technical barriers may include the complexity and expense of the concentrate (residuals) disposal from high-pressure membranes.

Dr. Li Dongfei adds to the question and answer portion on membrane technology by sharing his company's innovations in this area and emphasizing the importance of the pre-treatment of membranes as a key factor in successful sea water reverse osmosis (SWRO). He discusses the design of membranes and proposes an outside-in design as opposed to an inside-out design for more effective air scouring/enhanced cleaning as well as greater foulant acceptability. Hyflux built Singapore's first SWRO plant in 2003 and China's largest SWRO plant in 2004 and today, lays claim to the world's largest SWRO plant in Magtaa, Algeria, with a capacity of 500,000 cubic meters/day.

R&D using local knowledge and ecosystems

Research institutes pursuing environmental and water studies deliver global impact by providing interdisciplinary collaborative research platforms to facilitate the conduct and coordination of strategic thematic research. At Prof Ong Choon Nam[40]'s research institute, environmental surveillance and treatment, green chemistry and sustainable energy, and the impact of climate change on the environment provide research tracks for scientists and graduate students.

The water–energy nexus continues to be a significant research topic in Singapore. Mangrove system integration is being investigated as a natural desalination model. Water channels ("aquaporins") in the tree's salt glands provide selective passage that allows only water molecules to pass through while salts are being retained.[41] Researchers are continuing the study of the salt glands' rhythmic salt removal mechanism, excretion and re-absorption of water as it is clear that each salt gland serves as a micro-desalination factory. They hope that the mangroves will

[38] On 12 December 2012, Statkraft, Norway's largest supplier of renewable energy closed down the world's only pilot scale river/seawater powered PRO plant at Tofte in Norway after three years of operations because of the lack of high performing and reasonably priced PRO membranes. http://www.forwardosmosistech.com/statkraft-discontinues-investments-in-pressure-retarded-osmosis/

[39] Khalil Z Atasi, "Membrane technology advances wastewater treatment and water reuse," http://cdmsmith.com/en/Insights/Viewpoints/Membrane-Technology-Advances-Wastewater-Treatment-and-Water-Reuse.aspx

[40] Prof Ong Choon Nam contributed significantly to this segment. Gii WITS Presentation: "Connecting Water, Chemistry and Material Science."

[41] "Surviving saline environments the saline way," August 22, 2013, http://www.nus.edu.sg/neri/mangrove.html

yield lessons for the next novel, bio-inspired model for future desalination.

Since the advent of the first green fluorescent protein (GFP) transgenic fish in 1995, this fish technology has been used for the analyses of gene expression patterns and tissue/organ development, cellular localization of protein products, etc. Today, GFP transgenic fish are being used as biomonitoring organisms for the surveillance of environmental pollution.

Another dimension of global environmental concern are blue-green algae blooms (also known as cyanobacteria), found particularly in nutrient-enriched water, such as western Lake Erie in 2011. Heavy spring rains had flushed a large amount of phosphorus into the lake, nurturing the growth of the harmful algae blooms.[42] In August 2014, nearly 500,000 residents in northwestern Ohio were warned not to drink or boil their tap water.[43]

Blue-green algae can produce toxins that affect the liver and nervous systems when the water is consumed in sufficient quantities. The most effective method of preventing blue-green algae blooms is to minimize the nutrient load entering waterways through actions such as planting or maintaining riparian vegetation, conserving soil, and implementing appropriate treatment and disposal of stormwater, agricultural, industrial and sewage effluent.[44] Scientists are currently experimenting with magnetic nano iron and online phosphate sensors, and developing cost-effective carbon nanotube electrochemical filters to remove such contaminants.[45]

Growth areas in the water sector include industrial water solutions, particularly in the light of emerging contaminants, and smart water management incorporating information technology (IT), data analytics and smart meters in water plants and networks. Researchers in Singapore have developed the New Smart Water Assessment Network (NUSwan), using low-cost, autonomous robotic swans capable of real-time sampling in freshwater bodies, acquiring diverse data through autonomous sensing nodes and centralized data storage tools.[46]

At GE's Singapore Water Technology Center, Dr. Adil Dhalla and his team are focused on innovation in water recycling and reuse, wastewater treatment, and advanced analytical solutions. Their technology development focuses on recycling and reuse solutions for both domestic and industrial sectors. Some of the solutions developed include various combinations of pressure driven separations (e.g. Reverse Osmosis and Nanofiltration), Ultrafiltration, Membrane Bioreactors, Electro-separation systems, and membrane chemicals. Another key part of the centre is an Analytical Technology Lab, which provides analytical chemistry and scientific support. This includes research and development into membrane autopsy, corrosion testing and analyses of wastewater.

Water–energy nexus: new opportunities

The power consumption of water and wastewater treatment processes influences the choice of technologies and methodologies to maintain environmental sustainability, particularly when

[42] http://www.dec.ny.gov/docs/water_pdf/bga20140808.pdf

[43] Brad Plumer, "A toxic algae scare has left 500,000 people in Ohio without drinking water," August 3, 2014, http://www.vox.com/2014/8/3/5963645/a-toxic-algae-bloom-has-left-400000-people-in-ohio-without-drinking

[44] Australian government: Department of Sustainability, Environment, Water, Population and Communities, "Blue-green algae (cyanobacteria) and water quality," November 2012, http://www.environment.gov.au/system/files/resources/5a8c0861-1d4c-424a-9bcd-ae9c4304fb5e/files/blue-green-algae-cyanobacteria-and-water-quality-fs.pdf

[45] Prof Ong Choon Nam contributed significantly to the discussion in this segment.

[46] http://www.nus.edu.sg/neri/nuswan.html

considering remote or under-resourced areas. For Prof Jean Andino, the water–energy nexus is a seminal component of the water scarcity issue. The use of alternative water sources may lead to enhanced energy demands for treatment, ultimately increasing GHG emissions, and exacerbating both global climate change impacts and water availability. Thus, it is important to develop novel treatment methods that employ lower-energy alternatives (e.g., the use of sunlight and new materials).

Prof Andino believes that new photocatalytic materials could be used either for minimizing the direct release of a GHG (specifically carbon dioxide) by recycling it to a useful resource (e.g., in the presence of a surface and water vapor, the product might be methane, a fuel),[47] or using the novel materials for the light-driven treatment/removal of organic compounds in aqueous treatment systems. To further investigate this opportunity, more materials development, characterization and testing are needed.

Maintaining a dynamic relationship between chemistry, nanotechnology and materials science is critical for innovation and the discovery of new solutions to address the global water challenge. In Singapore, the research institutes, universities and policy makers participate in a continuing dialogue that brings together collective knowledge and insights that hopefully will result in more environmentally sustainable water technologies.

[47] [1] Liu et al. ACS Catalysis, 2012, 2, 1817-1828
[2] Zhao et al., J. Materials Chemistry A, 2013, 1, 8209-8216
[3] Rodriguez et al., J. Phys Chem. C, 2012, 116, 19755-19764
[4] Zhang et al., Appl. Cat. B: Env, 2012, 257-264
[5] Andino and Gao, Non-provisional patent application 14/076,764 (2013) US Patent and Trademark Office.

The future of water: global issues, local solutions

From 1980 to 2010, China was the largest creator and emitter of nitrogen globally.[48] The country's use of nitrogen as a fertilizer increased about threefold while livestock numbers and coal combustion increased about fourfold, and the number of automobiles about twentyfold (all of these activities release reactive nitrogen into the environment). Increased levels of nitrogen lead to decreased air quality, acidification of soil and water, increased GHG concentrations and reduced biological diversity.

Nitrogen-based fertilizers contribute to GHG emissions by stimulating microbes in the soil to produce more nitrous oxide, the third most important GHG behind carbon dioxide and methane. [49] Agriculture, primarily in the form of increased nitrogen fertilizer use, accounts for around 80 per cent of human-caused nitrous oxide emissions worldwide. Globally, agriculture is the principal user of water, accounting for 70 per cent of water use, followed by industry (including mining and power generation) at 19 per cent and municipal networks, which serve the water needs of public and private users, at 11 per cent.[50]

Water scarcity occurs when demand for water exceeds the available sustainable resources. Water scarcity is an increasingly frequent and worrying phenomenon that affects at least 11 per cent of the European population and 17 per cent of EU territory.[51] It is estimated that some 20–40 per cent of Europe's available water is being wasted because of leakages in the supply system, lack of installed water saving technologies, too much unnecessary irrigation, and dripping taps. In a "business as usual" scenario, water consumption by the public, industry and agriculture would increase by 16 per cent by 2030.

Population growth and increasing social pressures on global water resources are forcing communities and governments to focus on the future of water availability. Climate change is expected to further exacerbate the demands on water-stressed regions, home to 5 billion of the world's 9 billion people in 2050.[52]

The issues of water access, availability and quality are global issues that require urgent attention today. Ultimately, the solutions that can address global water issues will come from the collaborative efforts of different groups of people – including chemists, engineers, materials scientists and policy makers – who understand that the most effective way of approaching a scientific challenge or problem is to adopt a multi-disciplinary approach.

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[48] Rob Jordan, "Key component of China's pollution problem: Scale of nitrogen's effect on people and ecosystems revealed," February 26, 2013 (source: Stanford University), http://www.sciencedaily.com/releases/2013/02/130226092136.htm

[49] Science Daily, "How much fertilizer is too much for the climate?" June 9, 2014 (source: Michigan State University), http://www.sciencedaily.com/releases/2014/06/140609153518.htm

[50] UN FAO, 2012, cited by IEA, "Water for energy: Is energy becoming a thirstier resource?"

[51] European Commission, "Water scarcity and drought in the European Union," August 2010, http://ec.europa.eu/environment/pubs/pdf/factsheets/water_scarcity/en.pdf

[52] Alli Gold Roberts, "Predicting the future of global water stress," MIT Joint Program on the Science and Policy of Global Change, January 9, 2014, http://newsoffice.mit.edu/2014/predicting-the-future-of-global-water-stress

Lessons learned

It is necessary to remember that clarity, coherence and collaboration are critical for the success of any water management program. The UK, for example, has developed a Water Research and Innovation Framework 2011-2030 to highlight key water research and innovation priorities and mechanisms. The UK Framework recognizes that government, research organizations, academia, non-governmental organizations (NGOs) and industry need to work with other users of water to "provide the evidence to support effective decision-making, joined-up policies, and a co-ordinated coherent approach to the development and dissemination of new knowledge, technologies and skills."[53]

Singapore's journey toward self-sufficiency and sustainable development in the water sector is highlighted by collaboration, strategic foresight and successful implementation. Strategies include the expansion of water catchment areas, development of water demand and supply mechanisms, water pollution control, investments in R&D, and public-private partnerships.[54]

The water innovation grid is a useful reference for governments and agencies that want to have greater clarity in capacity building and a framework for sustainable practices. Rural communities in developing countries can learn from the Tanzanian water project while chemists are reminded that their research work cannot be successful in isolation. The water–energy nexus demands that different elements in the ecosystem have to interact, adapt and respond to each other to co-exist harmoniously to create innovative and sustainable solutions to the global water challenge.

A big picture perspective is essential to a more critical understanding of key issues and risks and leads to more insightful strategic visioning in the water sector. Astronaut Ron Garan talks of the need to develop an "orbital perspective"[55] which is essentially an awareness of our common humanity and an understanding that global problems have local solutions and can be resolved through tolerance, dialogue and cooperation.

Where do we go from here?

Water has 60 properties which differentiate and distinguish it from most liquids.[56] To deepen and expand our knowledge of water and create innovative solutions to address critical water issues, a multi-disciplinary focus is needed. As Dr Adil Dhalla says, "Solutions do not come from one stream of science or engineering. They come from a group of people working together, using their skills. The understanding of how to approach a scientific challenge or problem is almost always now a multi-disciplinary approach." There is no other way.

[53] http://www.lwec.org.uk/sites/default/files/Taking%20Responsibility%20for%20Water%20Full%20doc.pdf

[54] In a personal interview, when asked about the factors that contributed to Singapore's success in turning water from a vulnerability to a strength, the late Prime Minister Lee Kuan Yew said, "it was critical circumstances, determination to succeed, comprehensive planning and the technology….The same process can be repeated by any country. But you must have the determination, the discipline, the administrative capability and its implementation. And you keep on looking for new technology." Cited by Cecilia Tortajada, "Water diplomacy: The Singapore Water Story: A journey towards self-sufficiency and sustainable development," http://www.thirdworldcentre.org/blogwatdiplomacy.pdf

[55] http://orbitalperspective.com

[56] In May 2015, it was announced that Anders Nilsson, Professor of Chemical Physics at Stockholm University, had been awarded a grant of 2.5 million Euros from the European Research Council for a five-year project on "Probing the structure and dynamics of water in its various states." http://www.su.se/english/about/profile-areas/atomic-and-chemical-physics/large-research-grant-to-explain-the-water-mystery-1.236327

Appendix

The following people participated in the Gii WITS forum in December 2014 and contributed to the composition of this white paper.

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