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Michele Y.C. Chew
Chihiro Watanabe

CHITKARA UNIVERSITY

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Hybrid Management of Technology for Global Co-evolution: Insight from Singapore's Water Industry

Michele Y.C. Chew
Chihiro Watanabe
National University of Singapore

Abstract

Ensuring a sustainable water supply is crucial in all economies. Technological breakthrough has made possible the idea of using membranes to treat water. Recycling water and desalination are substitutes for the traditional water treatment process. While sea water is plentiful, the process of desalination depends largely on electricity, making the process costly. Singapore's success in NEWater (recycled water) depended on its stepwise advancement of membrane technology with sophisticated complementary engineering systems based on advanced information technology. This advancement contributes to electricity efficiency improvement in desalination which in turn accelerates dramatic advancement of the complementary engineering systems. Synergistic effects between NEWater and desalination can be expected by constructing a hybrid management of technology fusing indigenous strength and the effect of learning leading to a new phase in Singapore's NEWater development and also the trigger of its desalination endeavor. By means of an empirical analysis of Singapore's pioneer challenge, this paper demonstrates the significance of this endeavor for global sustainability.

Keywords: *Hybrid management of technology, Fusing indigenous strength and learning, Synergy*

INTRODUCTION

The hydrological cycle takes care of the availability of water that can be harvested from rain water. Given the geographical constraints facing Singapore’s insufficient harvest from rain water, Singapore has made every effort in technology substitution for conventional water like creation of technology-driven water. Technological advancement in membranes and subsequent complementary technology for their operation and management has made it possible to harvest potable water (water of quality fit for human consumption) from other sources, such as used water and seawater. The product from processing seawater is known as desalinated water while that obtained from used water is known as recycled water, otherwise branded as NEWater in Singapore. Singapore has accomplished its ambitious target to supply 30% of water by NEWater by 2010 and now attempts to supply 80% of water by technology-driven water: 50% by NEWater and 30% by desalination by 2061 (PUB, 2011) as demonstrated in Table 1. This super-ambitious challenge can only be enabled by hybrid

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management of technology maximizing synergistic effects between NEWater and desalination.

Table 1: Dependency on Technology-driven Water in Singapore (%)

Year	NEWater	Desalination	Total
2011#	30	10	40
2061^	50	30	80

 # comprising 5 NEWater factories and 1 desalination plant
^ comprising 5 or 6 NEWater factories and 2 desalination plants
Source: PUB (2011)

This paper attempts to identify the synergistic effects between NEWater and desalination water via the hybrid management of technology model in illustrating the successful fusion of indigenous strength and the effects of learning.

The success of eco-systems depends on the tandem evolution of the various stakeholders, such as the industries and the institutions (Watanabe and Fukuda, 2006). The concept of co-evolutionary economics emphasizes the importance of institutional systems in the learning process that is essential to stimulate greater R&D and it ultimately results in raised economic competitiveness (Watanabe and Zhao, 2006). The following two studies conducted in developing countries on different industries enforces this point. Addressing the issue of food security in Brazil and Argentina, Fuck and Bonacelli (2009) emphasized the importance of institutional arrangements between private and public research organizations, specifically with regards to the issues of intellectual property and technology transfer. The study involved the in-depth case study of the institutional arrangements in two institutions: the Brazilian Agricultural Research Corporation and the Argentina's National Institute of Agricultural Technology in the proposal for a pro-active government intervention strategy maximizing the effects of mutual learning.

Focusing on the automobile industry in Mexico, Barragán and Usher (2009) investigated the increase in the competitiveness of the automobile industry in Mexico and the extent to which the increase is attributed to the emergence of a national industry of auto parts suppliers. The analysis was conducted at two levels: the automobile industry in general and the automobile cluster located in the state of Puebla. In this study, it was found that the North America Free Trade Agreement, a national treaty was able to elevate the competitiveness of the automobile industry in Mexico up to a moderate level. The in-depth study of the automobile cluster located in Puebla revealed that there was a spillover from the multinational companies located in the state to the local companies, measured by the number of new start-ups.

Addressing the national issue of power security, Watanabe *et al.* (2005) proposed the survival strategy for Japan's energy industry through fusing the effects of learning and the building up of indigenous strengths in order for the nation to be energy efficient. Addressing the survival of a company, Watanabe *et al*. (2009) looked at Canon, a multinational company with a long history. They studied Canon's printer business development between the period 1975 and 1999. The study illustrated the success of Canon in fusing indigenous strength in printer technology and the effects of learning. In this study, the authors attempt to apply the hybrid management model used in the study by Watanabe *et al.* (2009) to map the synergistic effects between NEWater and desalination in Singapore. Similar to the studies on the agricultural industry and automobile industry, this analysis focuses on an industry that is targeted to elevate the national competitiveness of Singapore.

The following section reviews the concept of substitution of technology-driven water for conventional water and then provides an overview of the comparative advantage of NEWater and desalination in Section 3. Section 4 maps the synergistic effects for desalination and NEWater, followed by a brief conclusion of the proposed concept in Section 5.

SUBSTITUTION OF TECHNOLOGY-DRIVEN WATER FOR TRADITIONAL WATER

The conventional sources of water include extraction from wells or harvesting from catchment areas. As water demand increases, there is a need to look for additional sources of water as illustrated in Figure 1. Thus, extracting water from seawater (otherwise, known as desalination) and reusing water (otherwise known as water reuse) are the popularly known as unconventional sources of water. The global annual additional capacity by desalination has increased from about 1 million m^3/d in 1990 to about 8 million m^3/d in 2010. The value is predicted to increase to about 9 million m^3/d in 2014. For water reuse, the global annual additional capacity rose from less than 1 million m^3/d in 1990 to about 5 million m^3/d in 2010. The contribution is predicted to increase to about 7 million m^3/d in 2014.[1]

In 2001, the government recognised that Singapore's water catchment and supply systems, draining systems, water reclamation plants, and sewerage systems are part of a comprehensive water cycle and constituted the Public Utilities Board (PUB) to be the nation's national water authority, overseeing the entire water loop. As illustrated in Figure 1, NEWater and desalination are alternative sources of water supply for Singapore and they are identified as the unconventional sources of water.

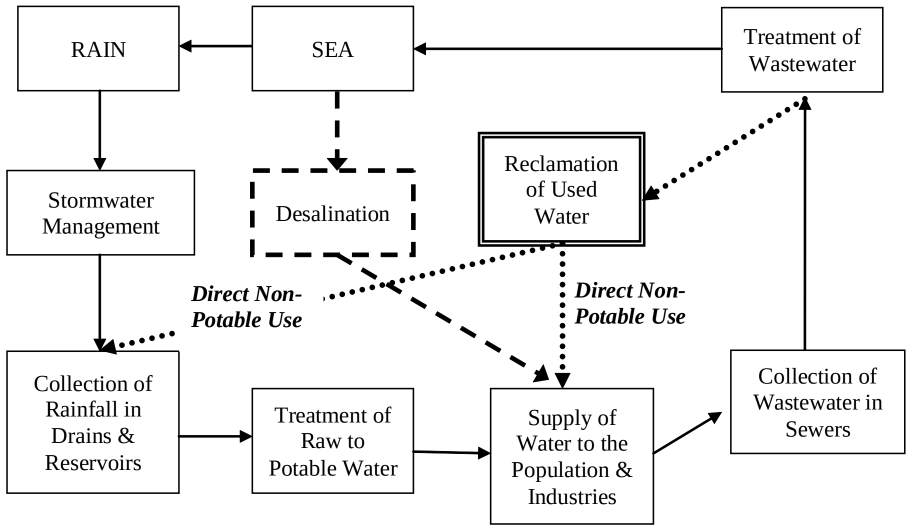


Figure 1: PUB Manages the Complete Water Cycle

The conventional sources of water are water collected from reservoirs (Singapore's First National Tap) and water imported from Malaysia (Singapore's Second National Tap). Until the early 2000s, nearly half of the nation's water supply was imported from Johor, Malaysia under two bilateral agreements which expire in 2011 and 2061. The nation was at a very high risk of relying, for a large portion of the nation's water supply, on imported water, especially when the value-add from the non-domestic sector (comprising mainly the manufacturing services) contributed to the bulk of the economy. Demand from the manufacturing industry was increasing[2] and with increasing cross-border issue's[3] related to water arising between the two nations, a sustainable solution had to be found. After various study trips abroad and with the advancement in membrane technology, it was decided that recycling water and desalination were the two feasible sources (Tan *et al.*, 2009). Thus, NEWater was identified as Singapore's Third National Tap while desalinated water was identified as Singapore Forth National Tap.

The idea of recycling or reclaiming water was intensively studied and reviewed through a comprehensive 2-year study (between 2000 and 2002). A demonstration plant was also built and an independent panel was convened to advise on the study (Tan *et al.*, 2009). The expert panel was tasked to review the sampling and analysis of NEWater, conduct toxicological and carcinogenic risk assessment and other relevant health studies. In addition to the expert panel's conclusion that NEWater was safe for potable use, NEWater passed more than 65,000 scientific tests and surpassed the requirements by the World Health Organisation. With the above testimonies of its high quality and reliability, NEWater factories were built to produce NEWater with milestones to meet 30% of the nation's water demand by 2010 and 50% of the nation's water demand by 2061.[4] With NEWater, PUB was able to close the water loop (Figure 1) by recycling used water. This closure has enabled PUB to manage all aspects of the water cycle in an integrated manner – from the collection of rainwater to the supply of water, the collection and treatment of used water, and water recycling.

Singapore is a small island surrounded by the sea. With limited land to develop catchments and the sea at its doorstep, it was inevitable not to harness some of the seawater for its water supply. Desalination was already considered in the first Water Master Plan in 1972 (PUB, 2009). However, the high energy cost,[5] and the low effectiveness and reliability of membrane technology back in the 1970s, deterred the decision to embark on desalination. In the 1990s, R&D in membrane technology gave rise to effective and reliable membranes. In addition, the wide spread use of membranes brought down the cost of membranes. Like NEWater, desalinated water is independent of rainfall and can be used to supplement water from local reservoirs in an extended dry spell. With the aim to be drought resilient, the PUB held a pre-qualification exercise in 2001, to select private suppliers to tender for the Design-Build-Own-Operation (DBOO) of a 30 mgd (136,000 m^3/day) desalination facility in Tuas. A total of 11 suppliers were shortlisted. Tenders were received from four companies in 2002. SingSpring Pte Ltd, a home-grown company was awarded the contract. The SingSpring desalination plant was successfully commissioned in September 2005. Currently, desalinated water meets 10% of the national water demand. The figure is targeted to reach 30% in 2060[6] (Table 1).

COMPLEMENTARY RELATIONSHIP BETWEEN NEWATER AND DESALINATION

Pioneer Challenge in NEWater.[7]

The terms "water reclamation", "water recycling" and "water reuse" are used synonymously. In Singapore, the term "water reclamation" is used as it is more readily accepted by the public and the product is branded as

NEWater. The following describes the process involved in the creation of NEWater in Singapore. As in desalination, the used water is pre-treated during which debris are removed. The treated used water is then passed through the first stage known as microfiltration. During this stage, suspended solids, colloidal particles, disease-causing bacteria, some viruses and protozoan cysts are removed. The filtered water then goes through the second stage known as reverse osmosis. At this stage, bacteria, viruses, heavy metals, nitrate, chloride, sulphate, disinfection by-products, aromatic hydrocarbons and pesticides are removed. The last stage involves ultraviolet disinfection to ensure that all organisms are inactivated. Typically, alkaline chemicals are added to the water to restore the pH balance of the water.

During the course of the successive development of five NEWater factories in Singapore over the period 1998 (initiative of the Singapore Water Reclamation Strategy) and 2010 (operation of the fifth factory in Changi), membrane technology and its complementary technology as system operation, management, simulation and monitoring have dramatically advanced and disseminated to broad area of relevant industries (Chew *et al.*, 2011).

Desalination

There are primarily two methods for desalination. One method is known as thermal desalination, in which raw water is boiled and the vapour condensed as pure water. Techniques include multi-stage flash and multi-effect distillation. The other method is known as membrane desalination, which involves the use of a semi-permeable membrane to filter out dissolved solids. Techniques for membrane desalination include reverse osmosis, nanofiltration, electrodialysis and electrodeionisation. Reverse osmosis is the most widely used technique among the four. According to data available from GWI DesalData, for desalination contracts awarded since 2000, reverse osmosis occupies the largest market share (61%) by process technology. This is followed by multi-stage flash, occupying a market share of about 26%.

This paper focuses on desalination via the reverse osmosis technique on which Singapore desalination plants operate. The process of desalination comprises of the pre-treatment stage, the reverse osmosis stage and the post-treatment stage. In the pre-treatment stage, seawater is taken in a submerged intake culvert and is passed through filter screen to remove debris. The seawater is then pumped to the Dissolved Air Flotation Filtration units where contaminants such as oil, grease and suspended solids are removed. This water is now ready to pass through the reverse osmosis stage. During this stage, the pre-treated seawater is pumped at high pressure through semi-permeable reverse osmosis membranes. This removes bacteria, viruses, chemicals and dissolved minerals. The pre-treated seawater passes through two reverse osmosis process – known as the 1st Pass RO (reverse osmosis) and the 2nd Pass RO. Typically, 45% of the influent seawater is recovered from the 1st Pass RO, for treatment in the 2nd Pass RO. The 2nd Pass RO further treats the water and recovers 90% of the water. The final stage is the post-treatment stage where minerals and fluorides are added to the processed water to balance the pH of the water.

The greatest challenge for desalination is the high energy consumption. Desalinated is an energy intensive process because high pressure is required to drive water molecules through the membranes. Due to the high salinity of seawater, desalination is more energy intensive and hence more costly than conventional water treatment and NEWater. A comparison of three desalination techniques by the PUB revealed that the energy demand by reverse osmosis is the highest at 3.5 kWh/m^3, followed by electrochemical desalting (less than 1.5 kWh/m^3 and biometric membranes (0.75 kWh/m^3).[2] In theory, the success of a reverse osmosis plant is determined by the optimal combination of the following factors: (i) the feed pre-treatment including intake; (ii) the design parameters (internal diameter, total number of tubes) on the recovery ratio module choice and module arrangement; (iii) the operating parameters (such as the feed flow rate, feed pressure); and (iv) the cleaning procedure. The above factors are in turn dependent on the feed concentration, the price of water and the price of energy (Koltuniewicz and Drioli, 2008).

The capital cost for a plant producing water from seawater is about twice the cost of a plant reusing secondary sewage. The higher costs are related to the pre-treatment and the reverse osmosis process. In the pre-treatment stage, desalination requires larger seawater pre-treatment systems, as the recovery rate for seawater is 50%; while the recovery rate for secondary effluent is 75%. Another reason for the higher cost is because the reverse osmosis process is operating at a much higher pressure, lower permeate flux, lower recovery, and must be made of materials that resist corrosion in seawater. The operation and maintenance cost for producing desalinated water are also twice that of reusing secondary sewage. Reason being during the pre-treatment stage, a coagulant has to be continuously added. In addition, a higher operating pressure (about 4 times higher), a higher feedflow (about 1.5 times higher) and membrane replacement contribute to the higher operation and maintenance cost. The membrane modules consume about 74% of the total energy input. Initial research by

Al Suleimani and Nair (2000) reported that the average cost of production was US\$6.52/m^3 over a 20-year lifetime. With advancement in research and development, and successful assimilation of their advancement, Escobar and Schäfer (2010) reported the total life cycle cost of desalting seawater can be US\$0.62/m^3 and that of recycling water can be US\$0.28/m^3. Figure 2 illustrates the complementary relationship between NEWater and desalination.

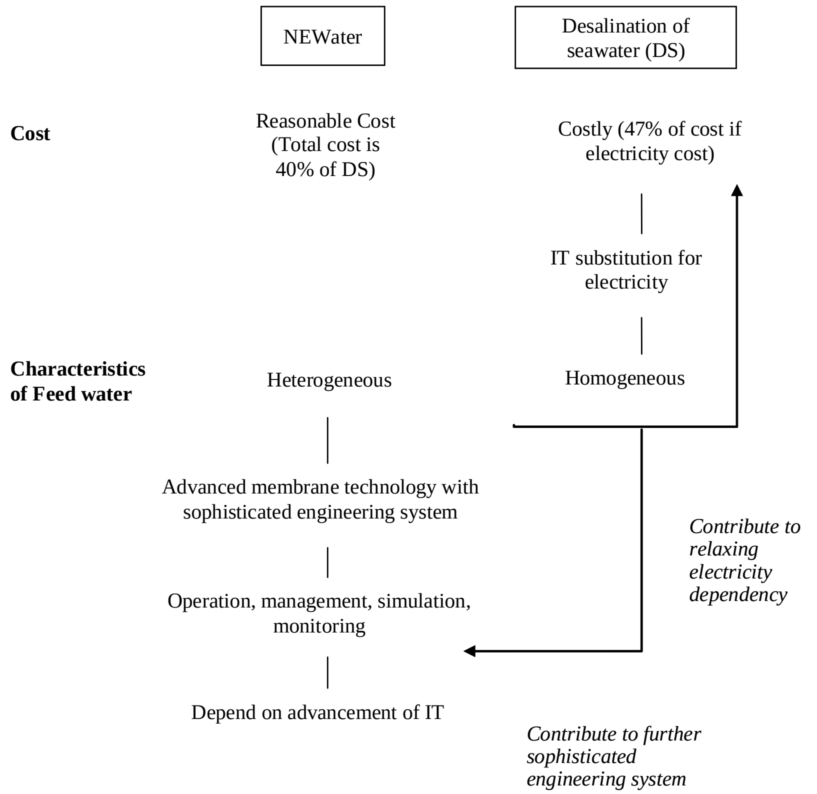


Figure 2: Complementary Relationship between NEWater and Desalination

HYBRID MANAGEMENT OF TECHNOLOGY: CASE STUDY OF SINGAPORE

Learning from NEWater

Based on the technology background in the preceding section, NEWater and desalinated water are important sources of Singapore's long-term water supply. NEWater provides a multiplier effect through recycling while desalinated water is a primary source of water. Both have the advantage of being independent of fluctuations in rainfall.

From one NEWater demonstration plant set up in 2000, Singapore now boasts of five NEWater factories – located in Bedok, Kranji, Seletar, Ulu Pandan and Changi, commissioned in 2003, 2003, 2004, 2007 and 2010, respectively. The first and second NEWater factories were built under the Design-Bid-Build model, while the third was built under the Design & Build model. Under these two models, the public sector, which is the Public Utilities Board (PUB), is the effective owner and bears the operation and maintenance responsibilities of the plants. The construction and design responsibilities of the projects were outsourced to international plant operators (such as Veolia Environment and Suez Environment) that had the experience and expertise to deliver. The other main players in the water reuse business in Singapore can be categorised into (i) the membrane manufacturers and system suppliers, which include Asahi, Dow, GE Zenon, Nitto Denko, Hyflux, Koch Membrane Systems, Norit X-Flow, Pall, Siemens Memcor, Toray and Woongjin; (ii) UV and advanced disinfection suppliers, which include ITT Wedeco, Mitsubishi Electric Power Products, Siemens Water Technologies and Trojan UV; (iii) the advanced wastewater treatment plant suppliers which include GE Water, Hyflux, Keppel Seghers, Siemens Water Technologies, Veolia Water Solutions & Technologies; (iv) Engineering firms, which include Black & Veatch, CDM, CH2M Hill and MWH. PUB took the role of the "main contractor" – managing the construction of the plant, managing the various players and operating and maintaining the plant. In this way, opportunities were created where possible, for local companies to be involved as sub-contractors. For example, in the course of delivering the projects, the international plant operators had to engage and work with local companies to complete portions of the larger project. Also, the complex nature of the plant also requires the plant operators to work closely with the membrane manufacturers and system suppliers. Local firms involved acquired "learning" from this intense interaction, which lead to the creation of indigenous capabilities. In the area of membranes, Graham Tek and Hyflux are examples. These companies carried out research and development work on membranes or membrane modules.

As a result of managing the first three NEWater factories, PUB built up indigenous strength in complementary technology as systems operation, management, simulation and monitoring. The indigenous strengths both in advanced membrane technology and complementary technology were further diffused to other local firms and to other industries through the introduction of the design-build-own-operate (DBOO) model for the fourth and fifth NEWater factories. The success of these DBOO NEWater factories was a result of the combination of the learning from the first three NEWater factories and the resultant indigenous capabilities created. The fourth and fifth NEWater factories were supported by sophisticated engineering systems that was possible with advancement in Information Technology (IT).

Learning from Desalination

Singapore's first desalination plant was commissioned in 2005 under the DBOO model. The contract was awarded to the affiliate of Hyflux Ltd, SingSpring (Pte) Ltd in 2003. Black & Veatch, an international plant contractor, worked closely with Hydrochem (Hyflux group company), the local engineering, procurement and construction contractor on the membrane technology portion and designed the plant for operational flexibility, allowing fluctuations in water demand and electricity price. This flexibility is the result of advancement in IT for efficient electricity usage. This strength can largely be attributed to the effect of technology spillover through relevant projects such as the Deep Tunnel Sewerage System (DTSS) project in which many of the firms that participated, contributed either directly or indirectly to the construction of the desalination plant.

Concurrently with the initial NEWater projects and the first desalination project, such water development projects as the Deep Tunnel Sewerage System (DTSS) Changi Water Reclamation Plant and the Marina Barrage projects were undertaken. Majority of NEWater and desalination firms were involved in these projects and gained significant technology spillover. The DTSS involved the excavation and construction of 48 kilometres of concrete tunnel, lining the tunnel walls with corrosion-resistant membranes, construction of link sewer systems and a centralized water reclamation plant with a 5-kilometre-long deep sea outfall. This massive project required the dedication and commitment of 49 main contractors and consultants, more than 300 subcontractors and suppliers and 4,000 workers, from all over the world (Austria, China, Japan, Korea, Germany, India, United Kingdom, and United States), including Singapore. The critical element of this DTSS project was that it was carved out into a number of smaller contracts rather than packaged as one large project. This gave more contractors, local and international, the opportunity to participate; and also built up PUB's close partnership with the local private sector. In Phase I of the project, local contractors were participants of 12 out of the 15 link sewer contracts that PUB awarded. International contractors brought with them their experience and expertise in construction, systems operation and maintenance. By working with these international contractors, local contractors learned and absorbed from their international counterparts. Knowledge in such large-scale construction, systems operation and maintenance (indigenous strength) contributed to the innovative Changi NEWater factory constructed on the rooftop of the Changi Water Reclamation Plant (effects of learning). This large-scale project required advanced IT systems that enabled many stakeholders to work simultaneously and react instantaneously. The increasing capacity of the NEWater plants and desalination plant can largely be attributed to the synergy effects of respective plants through involvement in the mutually relevant projects as the DTSS. Figure 3 illustrates such synergy effects.

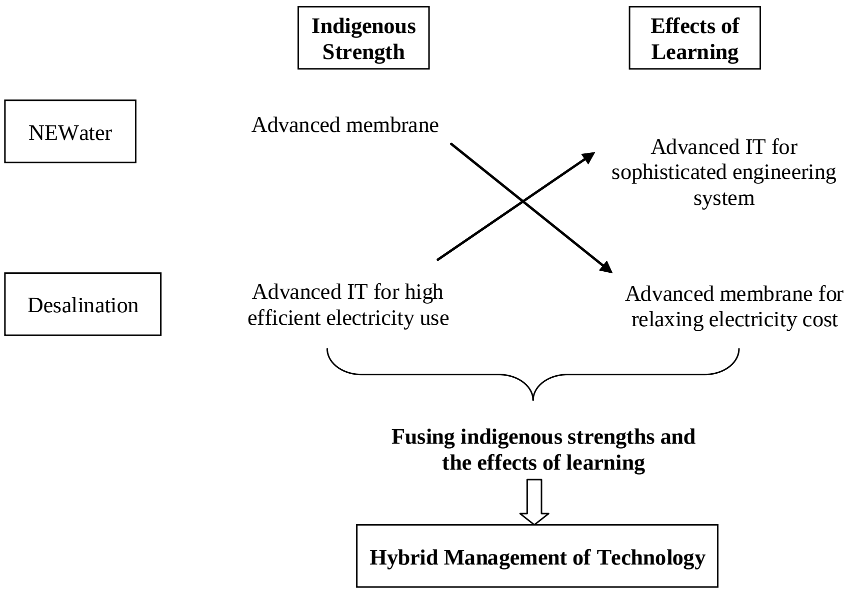
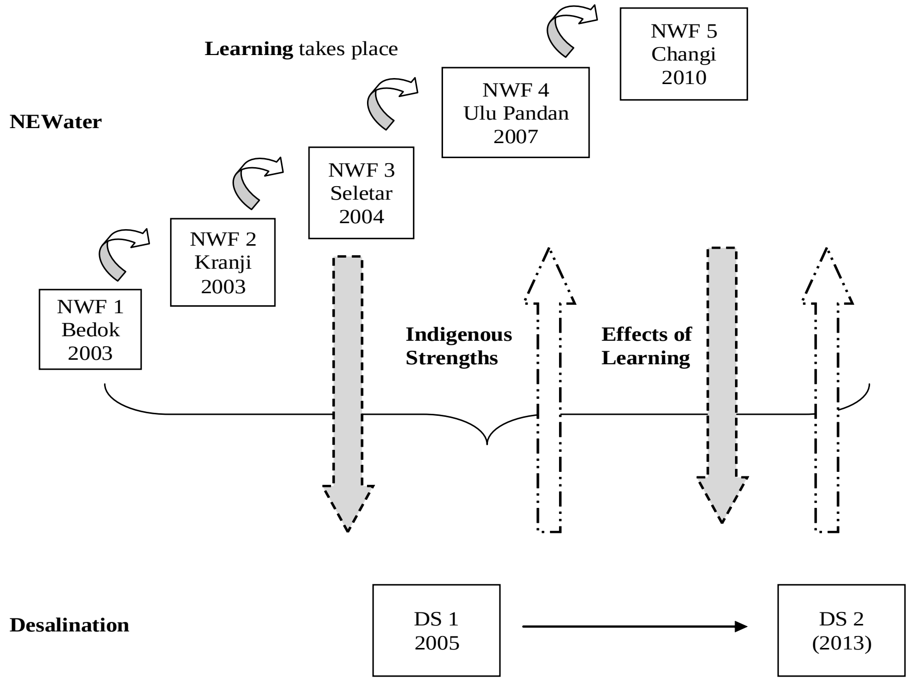


Figure 3: Synergy Effects of the Development of NEWater and Desalination

The fusion of this indigenous strength in IT with the learning from the first three NEWater factories, was evident from the success of the fourth and fifth NEWater factories. Similar fusion of the effects of learning of membrane technology resulting from the five NEWater factories and the indigenous strength of highly energy efficient systems through the use of IT contributing to bringing the cost of desalinated water down has led Singapore to take a decision regarding the construction of the second desalination plant as illustrated in Figure 4. The hybrid management of technology, fusing indigenous strengths and the effects of learning has thus enabled Singapore to envision an ambitious plan to supply 80% of water by technology-driven water by 2061.



NWF - NEWater Factory; DS - Desalination Plant; the year indicated the year of commission

Figure 4: Hybrid Management of Technology for NEWater and Desalination

CONCLUSION

NEWater and desalinated water are similar in that they are dependent on membrane filtration technology. The two, however, differ greatly in operating energy usage. The electricity consumption for the production of NEWater is about half that of desalinated water. By identifying the effects of learning and the indigenous strengths developed as a result of both undertakings, the synergistic effects between the two were illustrated conceptually via the hybrid management of technology model. The indigenous strength in membrane technology developed as a result of NEWater fused with the indigenous strength in IT for flexible and efficient systems operation, developed as a result of desalination, has enabled Singapore to embark on a new phase towards global sustainability. In addition, the indigenous strength developed thereafter will assist Singapore's companies in securing projects globally in the future.

The synergistic effects reinforce the importance of a vibrant ecosystem that is necessary for an industry's development and is a good input to companies and business associations for in-depth strategic planning. Hybrid management of technology maximizing the synergistic effects should be thus, pursued for global co-evolution.

FOOTNOTE

1. Global Water Intelligence (2010). Global Water Market 2011, Global Water Intelligence, Media Analytics, Oxford.
2. Demand by non-domestic sector was 55% of total demand. Source: Public Utilities Board (2011) 'Water For All - Conserve, Value, Enjoy', (online) Last assessed on 26 May 2011. http://www.pub.gov.sg/LongTermWaterPlans/index.html
3. It is beyond the scope of this article to discuss international conflicts related to water. Case studies can be found in Clarke, R. (1993) 'Water: The International Crisis', London, MIT Press, Chapter 7.
4. Asiaone News (2010) '2061: Singapore Fully Self-sufficient in Water', (online). Last assessed on 26 May 2011. http://www.asiaone.com/News/AsiaOne+News/Singapore/Story/A1Story20100629-224310.html
5. 47% of desalinated water cost depends on purchased electricity resulting in 2.5 times higher than NEWater cost (ADB, 2008).
6. Public Utilities Board (2011) 'Water For All - Conserve, Value, Enjoy', (online) Last assessed on 26 May 2011. http://www.pub.gov.sg/LongTermWaterPlans/index.html
7. See the details of "NEWater journey" Chew et al. (2010 and 2011).

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Michele Y.C. Chew is National University of Singapore, Division of Engineering & Technology Management, Faculty of Engineering, Singapore.

Watanabe Chihiro is Professor, National University of Singapore, Division of Engineering and Technology Management, Faculty of Engineering, Engineering, Singapore.

CHITKARA UNIVERSITY
Administrative Office
Saraswati Kendra, SCO 160-161
Sector-9-C, Madhya Marg, Chandigarh-160009, India.
Phone : +91.172.4090900, Mobile: +91.95011-05644
Email: journal@chitkarauniversity.edu.in
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