PLANT AVAILABILITY OF SEAWATER DESALINATION ON MEMBRANE TECHNOLOGY AND BIOTECHNOLOGY

Masaru Kurihara
Toray Industries, Inc., 3-2-1 Sonoyama, Otsu, Shiga 520-0842, Japan

Hiromu Takeuchi
Toray Industries, Inc., 2-1-1 Nihonbashi-muromachi, Chuo-ku, Tokyo 103-8666, Japan

Keywords: Seawater reverse osmosis, low pressure seawater reverse osmosis membrane, low pressure two-stage high recovery SWRO system, biofouling monitoring technology, pressure retarded osmosis (PRO), renewable solar energy, green desalination, brine concentration, and green hydrogen

Contents

Summary

President Kennedy's dream of obtaining fresh water from seawater seemed has been realized as a great scientific achievement and as Norihito Tambo predicted, seawater reverse osmosis desalination (SWRO) has become a major technology in Middle Eastern countries.

SWRO requires less energy compared with the distillation method and even Middle Eastern countries, where the distillation method is still a major technology, have started to adopt the RO method in new desalination plants in accordance with government policy and following the trend of developing larger (half mega-ton per day and larger) so-called

Mega-SWRO plants. With these trends in the global market, the requirements of sustainable SWRO desalination as green desalination for the 21st century are as follows: 1) Conservation of energy resources: Renewable energy, 2) Innovation of desalination technologies: New advanced membrane and membrane systems, 3) Reduction of marine pollution: Green desalination. The government-supported Mega-ton Water System project has been conducted to solve issues related to 2 and 3.

The combination of a low pressure SWRO membrane and a low-pressure, two-stage, and high-recovery SWRO system, also referred to as a SWRO-PRO hybrid system, it has enabled 20% energy reduction and 30% energy saving in total. Likewise, low environmental impact as green desalination has established a reliable operation using less chemical and chemical cleaning. Low-cost renewable energy, in particular, solar energy is now available to solve issues related to renewable energy. By combining these sophisticated technologies, desalinated water has become affordable at \$ 0.50/ m^3 or less (as low as \$0.28/ m^3).

SWCC has announced their future plans for SWRO. The main topic is directed to brine mining to obtain precious materials from the brine of SWRO. This plan will be connected to water and green hydrogen for a sustainable future.

The highlights of this chapter are as follows:

• Rapid growth of SWRO market
• Mega-SWRO plants in excess of half mega-ton/day or mega-ton/day size
• Low pressure SWRO membrane
• Low pressure two-stage high recovery SWRO system
• Biofouling monitoring technology
• Sustainable system for future SWRO system as Green Desalination
• SWRO-PRO hybrid system allows 30% energy reduction
• Brine concentration
• Green hydrogen

1. Introduction

1.1. President Kennedy's Speech

President Kennedy delivered a speech (1961) at a news conference on a desalination plan to see the deserts bloom on April 12, 1961. The desalination plan was as follows: *If we could ever competitively, at a cheap rate, get fresh water from salt water, that it would be in the long-range interests of humanity which could really dwarf any other scientific accomplishments. I am hopeful that we will intensify our efforts in that area*.

President Kennedy made this statement 17 times during his career in the Senate, 9 times before he was elected to the presidency, and 8 times after taking office.

1.2. Tambo's Prediction

Tambo's prediction (Tambo, 2002) of the increase in the world population and the development of water treatment technologies are shown in Figure 1. In this we see that evaporation (Distillation) and membrane treatment is the newest technology in comparison with other conventional technology on a very long range of time frame. Membrane treatment technology, which enables highly precise control of water quality and high-speed treatment, is an essential countermeasure to the water shortages we face in the 21st century.

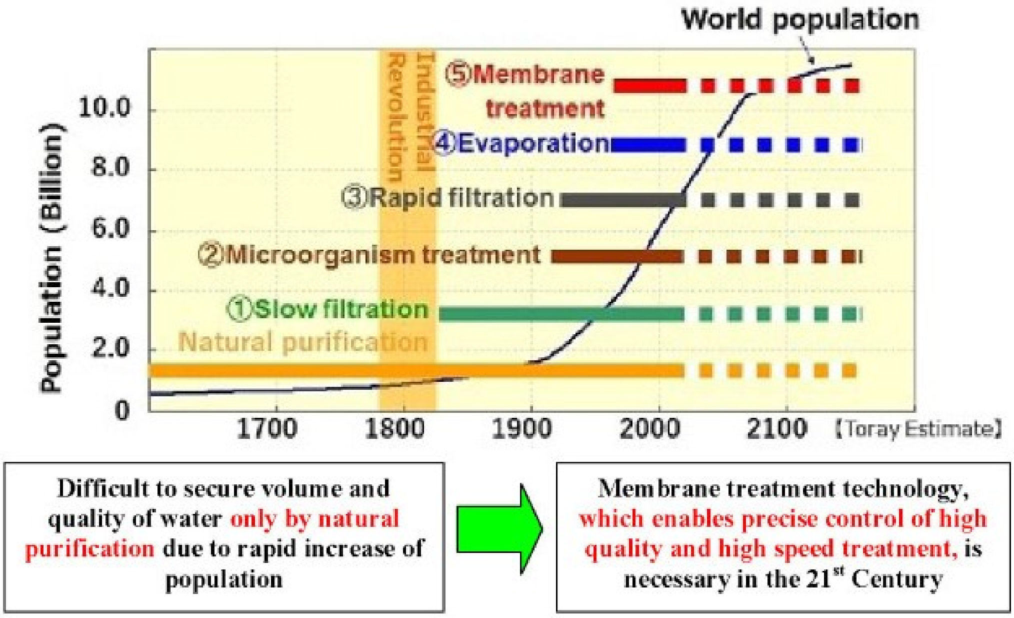

Figure 1. Increase of world population and development of water treatment technologies (Tambo, 2002)

2. Current Global Market Status of SWRO Plants

2.1. Technology Transition from the Distillation Method to Membrane Method

Research and development on seawater desalination systems such as the distillation process and membrane process began in the United States in the early 1960s. The distillation process became major technology used in actual plants in the 1970s. Around 2010, there has been a transition in the technology used from the distillation to the reverse osmosis membrane process, as shown in Figure 2. Now, the membrane process has become the major technology (Global Water Intelligence: Desal Data, Desalination Projects, December 2020; Kurihara et al, 2016).

The cumulative online capacity (m^3/day) of RO is much higher than that of MSF and MED. And the growth rate of RO is also much higher than MSF and MED. The large number of RO plants means the average size of RO plants will still be small compared with MSF and MED. However, recently there have been moves towards developing Mega-SWRO in Middle Eastern countries became reality.

Considering the dramatic change from distillation to SWRO in Middle Eastern countries, the desalination market forecast for the Gulf and the rest of the world is shown in Figure 3 (Weaver, 2018). 2018 and 2019 are major years for SWRO as shown in Figure 3 and

Figure 4 (Water Desalination Report, 2018). More than 6 million m^3/d (1,585 MGD) of new production capacity is expected to be contracted during 2019-2020. Figure 4 show that more than half of that new capacity is forecast for the six GCC countries.

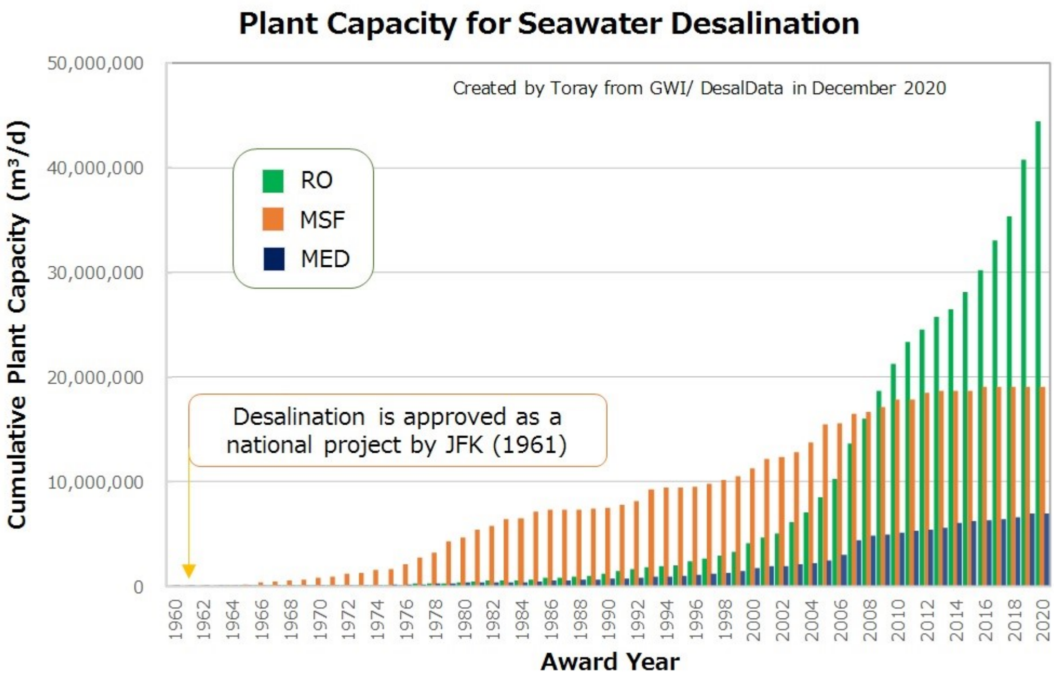

Figure 2. Technology transition from distillation to membrane (Global Water Intelligence; DesalData, 2020; Kurihara et al, 2016)

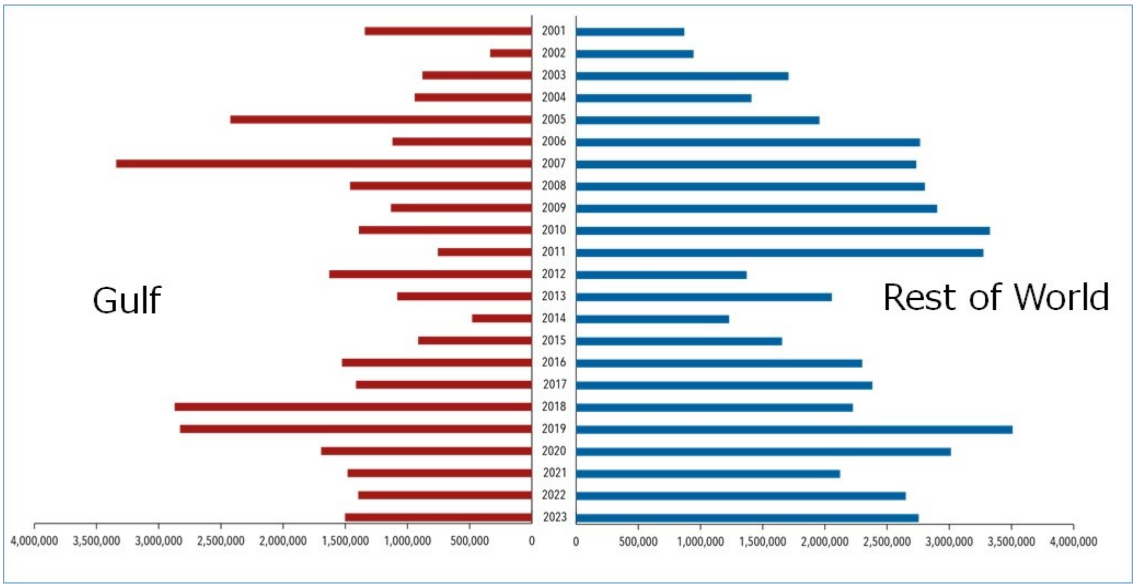

Figure 3. Market forecast: the Gulf vs the rest of the world contracted desalination capacity (Weaver, 2018)

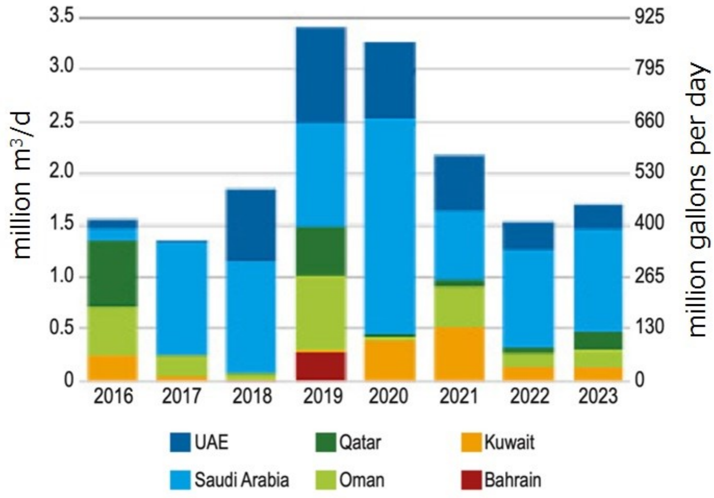

Figure 4. Major years expected for SWRO (Water Desalination Report, 2018)

2.2. From Small Plants to Mega-size SWRO Plants

The trends since 1970 of the largest and the top 20 largest RO plants are plotted in the desalination and the wastewater reclamation plants as shown on the left side of Figure 5 as reported in 2009 (Kurihara and Hanakawa, 2013).

The scale of each desalination plant has been increasing year by year, thus we predicted in 2009 that Mega-SWRO : large plants of the mega-ton per day scale (1,000,000 m^3/day) would be required from the market by 2020.

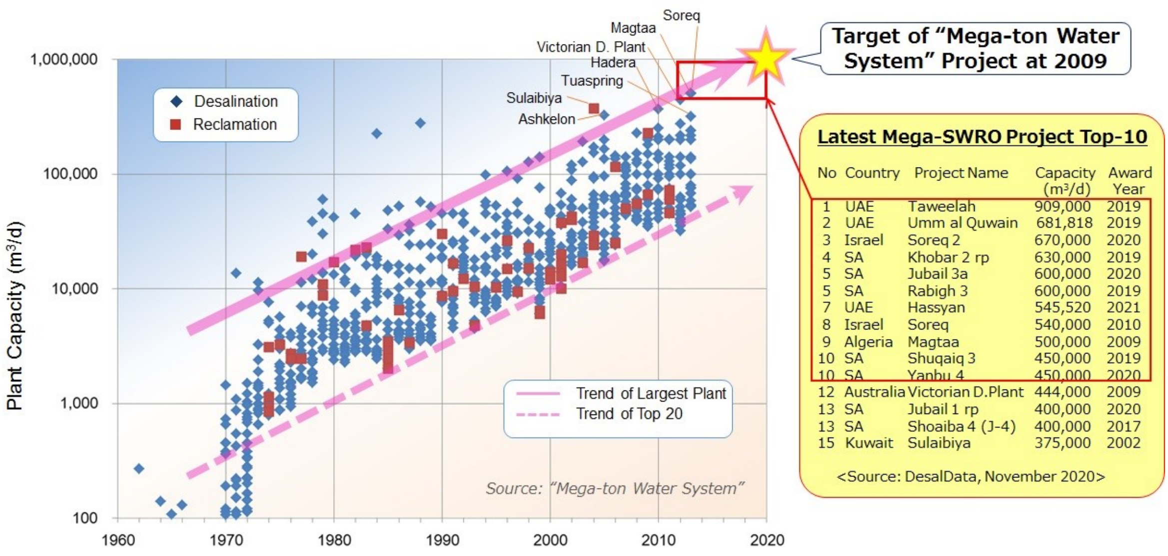

Figure 5. Global SWRO desalination plant capacity development (Kurihara and Hanakawa, 2013; Althman, 2019; Kurihara and Ito, 2020)

This prediction has been realized as shown on the right of Figure 5 (Althman, 2019; Kurihara and Ito, 2020). Construction started on many large plants over the 500,000 m^3/day, the so-called Mega-SWRO, in 2018–2020 in Middle Eastern countries such as Saudi Arabia and the UAE.

2018/19 Tenders are shown on the right of Figure 5, presented at the Saudi Water Forum in 2019 by Mr. Altmann (2019) and by the authors (Kurihara and Ito, 2020).

2.3. Affordable Price of Desalinated Water

The rapid changes in the price of desalinated water since 2000 have been presented by Mr. Christopher A Gasson, as shown in Figure 6 (Water Desalination Report, 2018). The price of desalinated water in large-size plants (Mega-SWRO) has rapidly decreased since 2018 (Kurihara and Ito, 2020).

- Rabihg 3 (Saudi Arabia):600,000 m^3/d , \$0.53/m^3
- Shuqaiq 3 (Saudi Arabia): 380,000 m^3/d , \$0.51/m^3
- Taweelah(UAE): 909,200 m3/d , \$0.49/m^3
- Jubail 3A (Saudi Arabia): 600,000 m^3/d, \$0.41/m^3
- Soreq 2 (Israel): 672,000 m3/day, \$0.40/m^3
- Hassyan (UAE) (Saudi Arabia): 545,000 m^3/d, \$0.28/m^3 (Water Desalination Report, 2020).

The price has dropped to \$0.28/m^3 in Dec. 2020

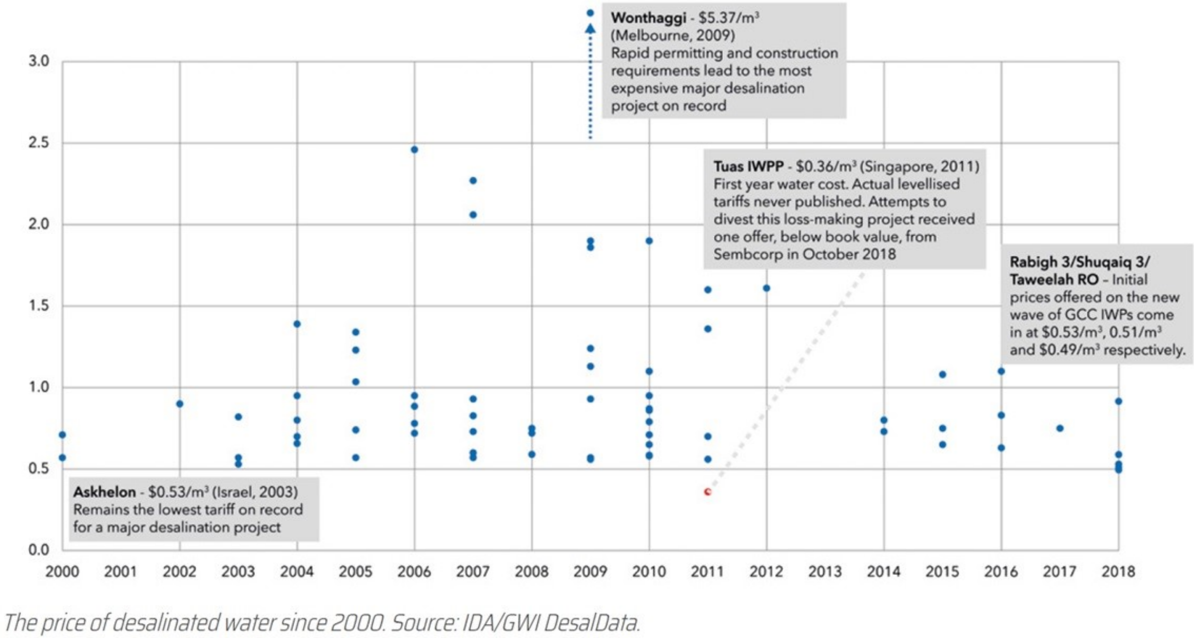

Figure 6. Rapid change of the price of desalinated water since 2000 (Gasson, 2019)

(**Askhelon:** \$0.53m^3 (Israel, 2003) Remains the lowest tariff on record for a major desalination project; **Tuas IWPP:** \$0.36m^3 (Singapore, 2011) First year water cost, actual levelized tariffs never published. Attempts to divest this loss-making project received, one offer, below book value from Sembcorp in October 2018; **Wonthaggi:**\$5.37m^3 (Melbourne, 2009) Rapid permitting and construction requirements lead to the most expensive major desalination project on record; **Rabigh 3/Shuqaiq 3/ Taweelah RO:** Initial prices offered on the new wave of GCC IWPs come in at \$0.53m^3, \$0.51m^3, and \$0.49m^3 respectively)

3. Results and Discussion

3.1. Sustainable SWRO Desalination as Green Desalination

To realize sustainable seawater desalination as green desalination for the 21st century, the following issues must be tackled: (1) Energy resources, (2) Seawater RO system, and (3) Reduction of marine pollution.

The Mega-ton Water System project (Kurihara et al, 2016; Kurihara and Hanakawa, 2013; Kurihara and Ito, 2020) was conducted with the aim of developing sustainable water treatment core technologies. The missions of the seawater RO system were: (1) energy saving (20% or 30%), (2) low environmental impact, (3) reliable plant operation, and (4) low water production cost as illustrated in Figure7 (Kurihara and Ito, 2020).

The Mega-ton Water System project envisions green desalination.

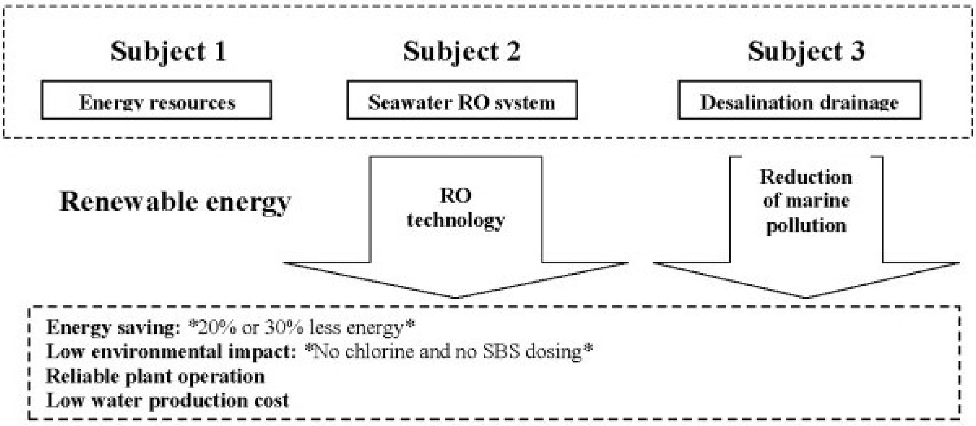

Figure 7. Requirements for sustainable SWRO desalination as green desalination for the 21st century (Kurihara and Ito, 2020)

As described in Section 1, the global market for SWRO, especially in Middle Eastern countries, has changed with increases in plant size (Mega-SWRO) and decreases of Specific Energy Consumption (SEC: kWh/m^3) of the plant systems followed by a reduction of the price for desalinated water.

This paradigm shift has occurred in the design and optimization of SWRO plants (Sanz, 2013). Another trend has been the continuous technological innovations such as the Mega-ton Water System as energy reduction, low environmental impact and reliable plant operation for green desalination.

3.1.1. Subject 1: Energy Resources: Renewable Energy

This subject was not listed by the Mega-ton Water System project in 2009. In 2010, the International Desalination Association (IDA) launched the industry's first Environmental Task Force-now called the IDA Energy and Environmental Committee (EEC). Through many discussions on promising candidates, 1) nuclear, 2) wind power and 3) solar power energies were considered.

By 2019, solar power energy had remarkably progressed and for Mega-SWRO, it was considered to be the preferable renewable energy source (Althman, 2019).

3.1.2. Subject 2: Seawater RO System-RO Technology

3.1.2.1 Requirement for Energy-Saving

Energy reduction and improvement of water quality are two major subjects in SWRO desalination. The average energy consumption in SWRO plants had been reduced to 40% as a total plant and one fourth in the case of 1st RO pass consumption over the last 40 years by 2012, as shown in Figure 8 (Sanz, 2013). This is a result of the remarkable technical advances in membranes, pumps and energy recovery devices. Technical progress to reduce energy consumption further, (for example, low-pressure operation membranes and high permeability at low temperature) and efficient energy recovery devices are still required.

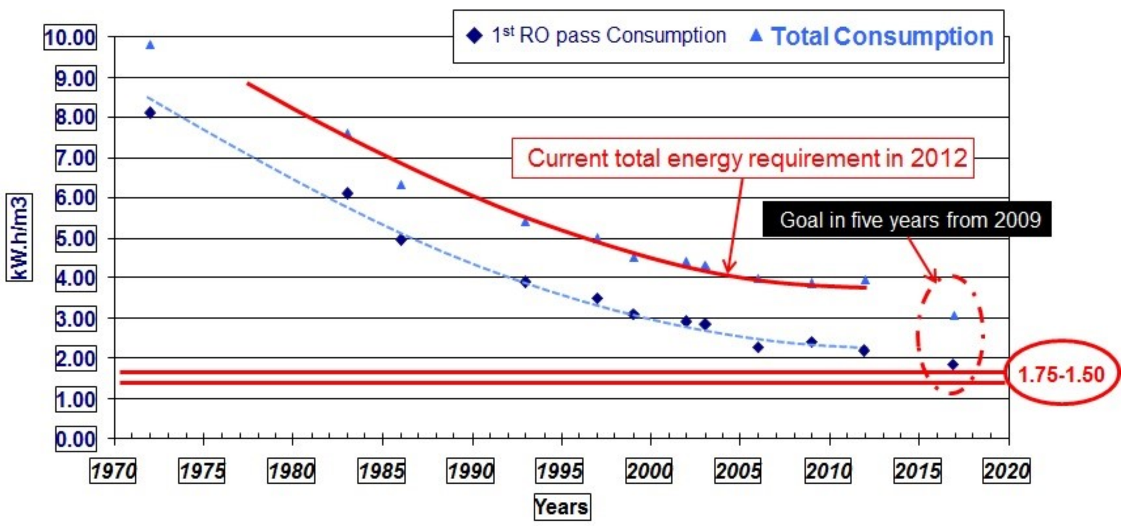

Figure 8. Trends of energy reduction in SWRO (Sanz, 2013)

The Mega-ton water system project achieved a 20% reduction to 2.80 kWh/m^3 as total consumption by 2014 (Kurihara and Takeuchi, 2018).

According to Sommaria, the maximum of 3.5 kWh/m^3 as SEC had been necessary since 2017 (Sommaria, 2020). As for water quality, the regulation value of salt disinfection by-products (DBPs) and boron concentration depend on whether the water is for drinking or irrigation use.

-

-

Bibliography

[1] John F. Kennedy (1961) The American Presidency Project (http://www.presidency.ucsb.edu/) by (/PEOPLE/PRESIDENT/JOHN-F, KENNEDY), The President's News Conference, April 12, 1961 [This presents President Kennedy's speech at News conference].

[2] Tambo, N. (2002) Infrastructure development under decreasing population – A design from expansion to shrink – Japan Society of Civil Engineers, Tokyo, 2002 (Japanese) [This is Tambo's prediction concerning the future water treatment technologies].

[3] Global Water Intelligence; (2020) DesalData, Desalination Projects, December 2020, https://www.desaldata.com/projects [This is created by Toray from GWI/Desal Data in December 2020].

[4] Kurihara, M. Sakai, H. Tanioka, A. and Tomioka, H. (2016) Role of pressure-retarded osmosis (PRO) in the Mega-ton water system project , Desalination and Water Treatment 57 (2016) 26518–26528, doi:10.1080/19443994.2016.1168582 [This shows the roles and results of PRO in the Mega-ton Water System].

[5] Weaver, R. (2018) Desalination Market Update/ Second Quarter Assessment, Global Water Intelligence, *Desal Data*, 14 June 2018.

[6] Water Desalination Report, (2018) Research/RFP issued $100 million R&D Hub, Vol. 54, No. 47, page-1, 18 December.

[7] Kurihara, M., and Hanakawa, M., (2013) Mega-ton Water System: Japanese national research and development project on seawater desalination and wastewater reclamation. *Desalination* 308 131–137.[This presents the contents of Mega-ton Water System : Japanese National Research & Development Project on seawater desalination and wastewater reclamation. This also presents the market growth prediction in the large SWRO plants].

[8] Althman, T.(2019) Saudi Water Forum, Accelerating Innovation in Desalination 19 March 2019 [This presents Mega-SWRO project at Saudi Water Forum].

[9] Kurihara, M., and Ito, Y. (2020) Sustainable Seawater Reverse Osmosis Desalination as Green Desalination in the 21st Century, *J. Membr. Sci, Res*, 2020, 20-29 https://issuu.com/idadesal/docs/ida_global connections_winter19 [This shows the latest sustainable SWRO as green desalination].

[10] Gasson, C. (2019) Is 40₵ Desalination in sight?, IDA Global Connections, Winter 2019, pp.27-29. https://issuu.com/idadesal/docs/ida_global_connections_winter19 [This shows the rapid price change of desalinated water since 2000].

[11] Water Desalination Report (2020), Volume 56, Number 44, 30 November 2020 [This presents the lowest price of desalinated water reported in November 2020].

[12] Sanz, M.A. (2013) Energy as motor of seawater reverse osmosis desalination development, Mega-ton water system international symposium, Tokyo, Japan, 21-22 November 2013 [This indicates the trend of energy reduction from 1970 to 2013].

[13] Kurihara, M., and Takeuchi, H. (2018) Earth-friendly Seawater Desalination System required in 21st Century, *Chem. Eng. Technol*. 41 401–412.[This presents the target and result of Mega-ton Water System project in terms of energy reduction].

[14] Sommaria, C. (2020) *Water Desalination Report*, Volume 56, 2020 Number 18, 7

[15] Kurihara, M., Sasaki, T, Nakatsuji, K., and Kimura, M., and Henmi, M. Low pressure SWRO membrane for desalination in the Mega-ton Water System. *Desalination* 2015, 368, 135–139. [This presents the schematic diagram of the salt removal and water permeation through the protuberance of RO membrane].

[16] Kurihara, M. (2012) Membrane research for water treatment facing the age of global mega competition & collaboration, Oral Presentation in IUPAC World Polymer Congress Polymer and Polymer-based Membranes for Energy and Environmental Applications II. In Proceedings of the 2012 World Polymer Congress (WPC) of the International Union of Pure and Applied Chemistry (IUPAC), Blacksburg, VA, USA, 24–29 June 2012. [This indicates the precise structure of the protuberance done by Mega-ton Water Syetem project].

[17] Kurihara, M, and Sasaki, T. (2017a) The most advanced membrane analysis and the save-energy type: Low Pressure Seawater Reverse Osmosis Membrane developed by Mega-ton Water System Project. In *Comprehensive Membrane Science and Engineering,* 2nd ed.; Elsevier: Amsterdam, The Netherlands, Volume 4, pp. 131–149. [This is the low pressure seawater RO membrane developed by Mega-ton Water System project].

[18] Kurihara, M, and Sasaki, T. (2017b) The Pursuits of Ultimate Membrane Technology including Low Pressure Seawater Reverse Osmosis Membrane developed by Mega-ton Water System Project. *J. Membr. Sci. Res.*, 3,157–173. [This explains the history of high performance SWRO membrane and the comparison between conventional SWRO membrane and new advanced low pressure SWRO membrane].

[19] Quoted from *Desalination* 125 (1999) 9-15, Presented at the Conference on Desalination and Environment, Las Palmas, November 9-12, 1999, European Desalination Society and International Water Services Association.

Original: Kurihara, M., Yamamura, H., and Nakanishi, T. (1999) High recovery/high pressure membranes for brine conversion SWRO process development and its performance data. *Desalination*, 125, 9–15. [This is the low-cost desalination system referred to as Brine Conversion System (BCS)].

[20] Wei, Q, McGovern, R, and Lienhard, J.H.V. (2017a) Saving energy with an optimized two-stage reverse osmosis system. *Environ. Sci. Water Res. Technol*., 3, 659–670.

[21] Wei, Q, McGovern, R, and Lienhard, J. (2017b) Two-stage reverse osmosis: Optimal element configuration and energy savings. In Proceedings of the IDA World Congress, World Trade Center, Sao Paulo, Brazil, 19 October 2017.

[22] Kurihara, M., and Takeuchi, H. (2018) SWRO-PRO System in Mega-ton Water System for Energy Reduction and Low Environmental Impact, *Water* 10 48. Doi.org/10.3390/w10010048.[This presents the energy reduction and low environmental impact done by Mega-ton Water System project].

[23] Kishizawa, N, Tsuzuki, K, and Hayatsu, M. (2015) Low pressure multi-stage RO system developed in Mega-ton Water System for large-scaled SWRO plant. *Desalination* 2015, 368, 81–88. [This is low pressure multi-stage RO system (LMS) developed in Mega-ton Water System project for large-scaled SWRO plant].

[24] Takahashi, T, Shinoda, M, Takita, S. and Goto, A. (2013) A Next-Generation Isobaric Energy Recovery Device with Piston-less and No-Leakage Concepts for SWRO Desalination, IDAWC/TIAN13-008. In Proceedings of the International Desalination Association World Congress, Tianjin, China, 20–25 October 2013.

[25] Kurihara, M, H. Takeuchi, and Ito, Y. (2018) Reliable Seawater Desalination System based on the membrane technology and the biotechnology considering Environmental Impacts, *Environments* 5, 127. DOI: 10.3390/environments 5120127 [This shows the countermeasures against biofouling of SWRO plants by the biofouling monitoring system].

[26] Vauch, Nikolay. (2019) Saudi Water Forum, workshop, State of the art of design and operation of membrane desalination plants, 17 March 2019

[27] Kurihara, M. (2019) Further progress of “Mega-ton water system” technology for green desalination, Saudi Water Forum, 10 March 2019 [This is the comparison between conventional technologies and Mega-ton technologies on the SEC (kWh/m^3) consumption].

[28] Kurihara, M, and Kurokawa, H. (2018) Further progress of “Mega-ton water system” 12th, SWA-APDA Joint Conference, Singapore, 11 July, 2018.

[29] Loeb, S. (1975) Method and Apparatus for Generation Power Utilizing Pressure-Retarded Osmosis. U.S. Patent 3906250, 16 September. [This is the method and apparatus for generation power utility pressure treated osmosis].

[30] Loeb, S. (1976) Production of energy from concentrated brines by pressure-retarded osmosis. *J. Membr. Sci.*, 1, 49–63.

[31] Loeb, S. Van Hessen, F, and Shahaf, D.(1976) Production of energy from concentrated brines by pressure-retarded osmosis: II. Experimental results and projected energy costs. *J. Membr. Sci.*, 1, 249–269.

[32] Loeb, S. (1980) Method and Apparatus Generating Power Utilizing Pressure-Retarded Osmosis. U.S. Patent 4193267, 18 May 1980.

[33] Sarp, S. (2015) Pressure Retarded Osmosis (PRO): Current Statue and prospects. In Proceedings of the 2nd International Conference on Desalination using Membrane Technology, Singapore, 26 -29 July 2015. [This is the summary of the current status and prospect of PRO].

[34] Skilhagen, S.E., and Dugstad, J.E., and Aaberg, R.J. (2008) Osmotic power—Power production based on the osmotic pressure difference between waters with varying salt gradients. *Desalination*, 220, 476–482.

[35] Tanioka, A., Higa, M., and Sakai, H. (2015) Energy Recovery by Pressure Retarded Osmosis System. *J. Membr. Sci.*, 40, 67–72.

[36] Saito, K. (2012) Power generation with salinity gradient by pressure retarded osmosis using concentrated brine from SWRO system and treated sewage as pure water. *Desalin. Water Treat.*, 41, 114–121. [This is successful in pilot using power generation by pressure retarded osmosis using concentrated brine from SWRO system and treated sewage as pure water].

[37] Hong, S., Kim, J., Cha, G., and Kim, J. (2017) Low-energy seawater reverse osmosis (SWRO) desalination plant optimized for the Middle East. In Proceedings of the IDA World Congress, World Trade Center, Sao Paulo, Brazil, 18 October 2017. [This is a case study using SWRO-PRO system to reduce the energy consumption of SWRO plants].

[38] Lattemann, S., and Höpner, T. (2008) Environmental impact and impact assessment of seawater desalination. *Desalination* 220, 1–15. [This presents the greater awareness of the need for the environment preservation and there have been efforts made to reduce the amount of chemically treated seawater discharged from desalination plants to lessen the ecological impact].

[39] Jones, E., Qadir, M., van Vliet, T.H., Smakhtin, V., and Kang, S. (2019). The state of desalination and brine production: A global outlook, *Sci. Tot. Environ*. 657 , 1343-1356. [This is the start of green desalination by the publication of the state of desalination and brine production into science and the total environment].

[40] Hayward,K. (2019) Desalination and the drive for progress with unconventional resources, The Source, March 2019, https://www.thesourcemagazine.org/desalination-and-thedrive-for-progress-with-unconventional-resources/

[41] Al-Hazmi, A. (2019) SWCC Provides stewardship to the aquatic environment by applying advanced technology and science, IDA Global Connections, Spring 2019, pp.15-16, https://issuu.com/idadesal/docs/ida_global_connections_spring19 [This is the SWCC governor’s commitment to discharge no toxic brine from SWRO pants].

[42] Views from the Experts (2019) The State of Desalination, Water Reuse and Environmental Stewardship., IDA Global Connections, Spring 2019, pp.26-41. https://issuu.com/idadesal/docs/ida_global_connections_spring19

[43] Kimura, T., Ito, Y., and Nakaoki, Y. (2001) *Innovative Biofouling Prevention on Seawater Desalination Reverse Osmosis Membrane*; International Desalination Association: Oxford, UK.

[44] Ito, Y., Hanada, S., Kitada, T. Tanaka, Y., and Kurihara, M. (2013) Clarification of impact of biofouling triggered by chemical addition for designing a mega-ton SWRO plant, IDA World Congress on Desalination and Water Reuse 2013/Tianjin, China, IDAWC/TIAN13-062 [This is the first report to

present that chlorine sterilization has no effect on marine bacteria and propose the no chlorine dosing to SWRO plant to the reliable plant operations and less chemical cleaning of the plants].

[45] Ito, Y., Kantani, S., Maeda, T., Okubo, K., and Taniguchi, M. (2015) Innovative biofouling monitoring device and its criteria for reverse osmosis plant operation and optimization, IDA World Congress and Water Reuse 2015/San Diego, CA, U.S.A. IDAWC15 [This shows the mBFR is an excellent way to monitor the evaluation of RO chemical cleaning interval due to biofouling].

[46] Abushaben, A., Salinas-Rodriguez, S.G., Kapala, M., Pastorelli, D., Schippers, J.C., S., Mondal, S., Gaueli and Kennedy, M.D. (2020) Monitoring biofouling potential using ATP-based bacterial growth potential in SWRO pre-treatment of a full-scale plant, *Membranes* 10, 360.

[47] Ayumantakath, M.F., Al Shaiae, M.M., Green,T.N., Miyakawa, H., Ito, Y., Kurokawa, H., Fusaoka, Y., and Al Amomudi, A.S. (2019) Reliable seawater RO operation with high water recovery and no-chlorine/no-SBS dosing in Arabian gulf, Saudi Arabia, IDA WC 2019, Dubai, UAE.

[48] H.E. Eng. Abdullah Bin Ibrahim Al-Abdul Kareem (2020a), SWCC Governor Interview, IDA Global Connection SUMMER 2020a

[49] IDA Webinar (2020b) Innovation in Desalination Brine Mining held under the patronage of the SWCC Governor, HE Abdullah Bin Ibrahim Al-Abdul Kareem, July 29, 2020b [This shows the innovative dual brine concentrator to apply to new brine mining technology].

[50] *Water Desalination Report* (2020), volume 56, Number 33, 7, September 2020

[51] Global Water Intelligence Magazine (2020a), 5 July 2020a [This shows the latest desalination technology trend].

[52] Global Water Intelligence Magazine (2020b), 44, July 2020b [This is the Neom project in Saudi Arabia, which shows the green hydrogen production by using the water from desalination of SWRO plant and power from wind/solar renewable energy].

Biographical Sketches

Masaru Kurihara, Senior Executive Adviser at Toray Industries, Inc. Senior Scientific Director, Mega-ton Water System in Funding program for World-Leading Innovative R&D on Science and Technology during FY 2009-FY2013. He is now promoting the verifications of the technology collaboration with Saline Water Conversion Corporation in Saudi Arabia, 1) Pilot plant verification at Al Jubail, the Arabian Gulf during 2016-2018 and 2) Full plant verification of NEDO-SWCC Demonstration Project at Duba, the Rea Sea during 2018-2022.

He received the B.S. in 1963 at Gunma University, Japan and Dr. Engineering 1970 at the University of Tokyo, Japan. He studied the membrane under the fund of the Office Saline Water Conversion (OSW) at University of Iowa as post doctorate.

He joined Toray in 1963. Over 50 years, his research activities have primarily focused on membrane based desalination and water reuse by RO/NF/UF/MF and MBR membranes. He has published more than 100 articles and 300 patents on the membranes and membrane processes. He has received numerous awards from national and international academic societies and foundations: Technical Award Development of Cross-linked Aromatic Polyamide Composite Reverse Osmosis Membrane from the Chemical Society of Japan, Production Award from Okouchi Memorial Foundation, Lifetime Achievement Award , Outstanding Professional in Water Reuse and Conservation Award from International Desalination Association (IDA), Award for International Communication and Cooperation in Membrane Technology from Membrane Industrial Association of China (MIAC), and others. He is a Board Member of IDA, a member of IDA Honorary Council, President of Asia Pacific Desalination Association (APDA), Fellow of The Chemical Society of Japan and The Society of Polymer Science, Japan with Lifetime Achievement Award.