TECHNOLOGY SCAN: ENERGY-EFFICIENT DESALINATION TECHNOLOGIES

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METHODOLOGY

1. Dataset used for the report

The patent dataset was retrieved on 8 May 2019 and comprises worldwide patent applications relating to energy-efficient desalination technologies published in 2009-2018.

Relevant business information, market data, and national policies that are available from commercial databases or on the web are also used to support the findings of the report.

2. Counting the number of inventions

This report counts the number of inventions by the number of unique patent families. Counting individual patent applications will result in double counting as each patent family may contain several patent publications if the applicant files the same invention for patent protection in multiple destinations. As a patent family is a group of patent applications relating to the same invention, analyses based on counting one invention per unique patent family can reflect innovation activity more accurately.

3. Formulation of search strings

To ensure optimal recall and accuracy of the data sets retrieved, the search strings used in this study were formulated by incorporating keywords (and their variants), as well as relevant patent classification codes and indexing, e.g. International Patent Classification (IPC) and Cooperative Patent Classification (CPC).

4. Grouping of technology domains

Grouping of individual patent documents into the respective technology domains was carried out based on patent classifications codes, text-mining and semantic analysis of the patent specifications in particular claims, titles, abstracts, as well as a manual review of the individual patent applications.

5. Growth rate calculation

Annual average growth rate was derived by calculating the average year-on-year growth rate over a defined time period.

CONTENTS

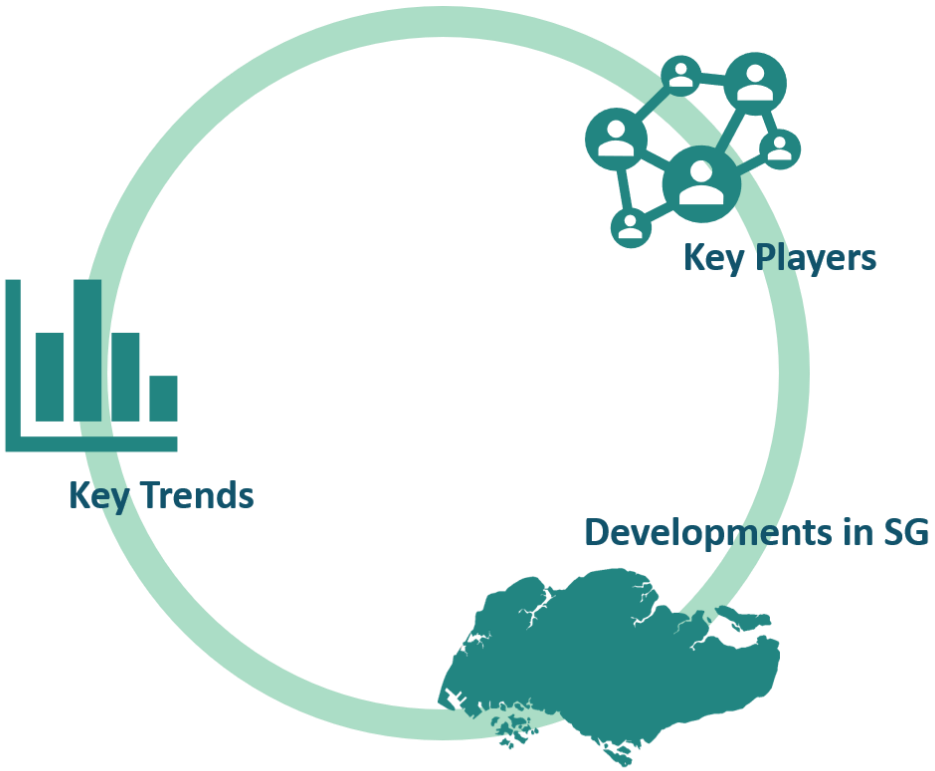
INTRODUCTION

Population growth, rapid urbanisation and the effects of climate change have greatly increased the pressure on potable water supplies and threatened its security[1]. To relieve this pressure, countries are increasingly turning to desalination to provide an alternative source of potable water, driving firm demand for the industry. The global desalination market is expected to grow at a compound annual growth rate (CAGR) of 7.8% up to 2025 to surpass USD 27 billion in value and 150 million m^3 per day in capacity[2,3].

As demand for desalination capacity grows, the need for more energy-efficient technologies in this traditionally power-intensive (and hence, costly) industry has grown in tandem. Power-intensive thermal desalination technologies are increasingly displaced by more energy-efficient membrane technologies such as reverse osmosis ("RO") technologies, as well as newer electrochemical ("EC") approaches[3,4]. Within membrane technologies, active research on ultra-permeable membranes for low-energy desalination is also ongoing.

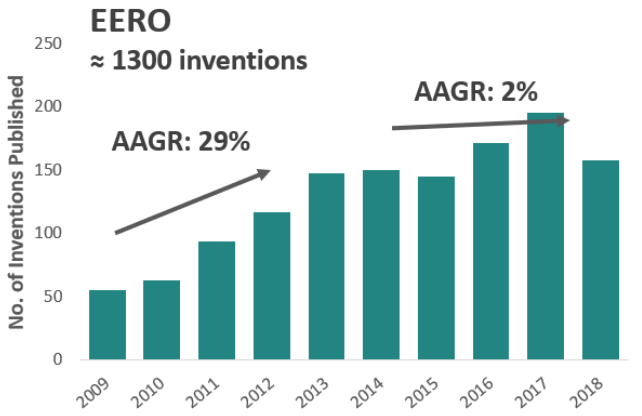
This report reviews these trends from the lens of patent data as a leading indicator of market implementation. It provides a high-level comparison of worldwide patent applications relating to energy-efficient and energy-saving RO ("EERO") technologies to EC ("EEEC") technologies, before diving into a deeper analysis within the emerging technology area of ultra-permeable biomimetic membranes ("BM") to answer three key questions:

1. What are the key trends and new technologies?
2. Who are the key players?
3. What are the related technology developments in Singapore?

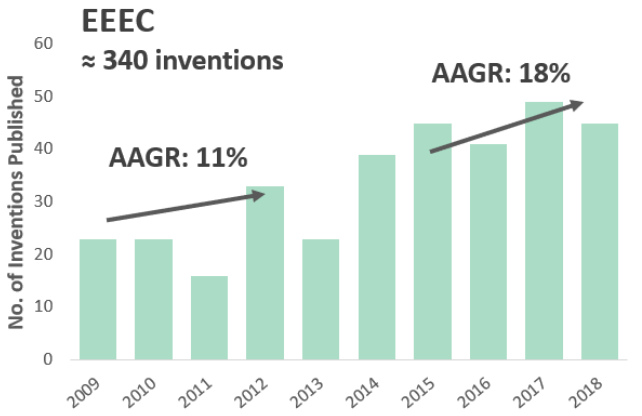


ENERGY-EFFICIENT REVERSE OSMOSIS AND ELECTROCHEMICAL DESALINATION TECHNOLOGIES

PUBLICATION TREND - WORLDWIDE AND TOP 10 MARKETS



	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	Total
China	14	26	44	64	73	85	105	124	135	134	804
US	8	15	34	21	23	32	30	28	36	22	249
Japan	8	12	26	30	40	36	28	24	23	16	243
Korea	7	13	13	23	27	28	34	20	30	18	213
Europe	1	8	10	18	10	11	26	10	9	12	115
Australia	9	1	13	13	13	8	14	6	2	5	84
India	0	5	4	1	6	10	14	25	11	3	79
Spain	1	1	3	5	6	3	5	1	5	11	41
Singapore	0	0	1	8	9	10	3	4	4	2	41
Canada	2	4	7	6	2	7	3	0	5	0	36



	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	Total
China	11	7	10	17	15	17	26	29	37	34	203
US	2	4	7	3	8	13	17	5	11	9	79
Korea	2	6	1	10	4	10	17	5	8	4	67
Japan	3	9	4	9	4	12	7	4	3	0	55
Europe	0	4	3	5	4	8	7	3	1	3	38
Australia	3	0	1	3	3	4	3	2	0	3	22
Canada	2	1	2	2	4	4	2	0	3	1	21
India	0	3	1	1	2	1	4	7	0	1	20
Taiwan	3	2	2	3	2	0	0	0	3	2	17
Singapore	0	0	2	3	4	3	2	3	2	1	20

As the more established technology, more EERO inventions were published than EEEC technologies in the period from 2009 to 2018. However, the growth of EERO inventions had stagnated in the most recent five years, registering a mere 2% increase per annum that is significantly lower than the annual growth of 29% observed in 2009 to 2013. This is typical of a maturing technology. In contrast, EEEC inventions had been increasing at 18% per annum from 2014 to 2018 as compared to 11% in the preceding five years. The greater interest in this technology area was driven by the potential of EC technologies to achieve higher energy efficiency than RO technologies.

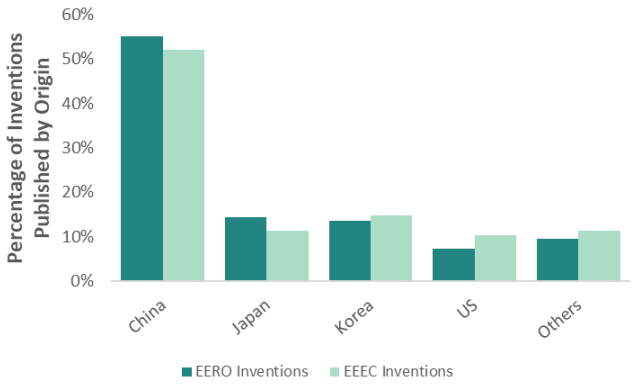
Large economies received the most patent applications relating to EERO and EEEC technologies, a mixed indicator of market interest and technology origin[5,6]. China dominated both technology areas, receiving more patent applications than the next three countries combined (US, Japan and Korea). Beyond the large economies, Australia, Canada, India and Singapore also received a relatively higher number of patent applications across both technologies despite the lower number of inventions originating from these countries. This strong market interest corresponds well with market revenue forecasts and the number of desalination projects in these countries[1]. This is especially true for Singapore, which typically receives fewer patent applications due to its smaller economy, and points to Singapore's use of desalination as one of its four national taps and the more than 200 water companies in Singapore[7].

TECHNOLOGY ORIGIN AND KEY PLAYERS

Rank	EERO Applicant	No. of Inventions
1	Hitachi	33
2	Toray Industries	29
3	Toshiba	28
4	Institute Of Seawater Desalination & Multipurpose Utilization	23
5	Ebara	22
6	China Sinopec Group	19
7	LG	14
8	Beijing University Of Technology	13
9	General Electric	13
10	Quanzhou Taiwanese Investment Zone Tiangong Dynamo Electric Design	13

Rank	EEEC Applicant	No. of Inventions
1	Organo	14
2	Evoqua Water Technologies	10
3	Miura Kogyo	9
4	Korea Institute Of Energy Research	8
5	General Electric	7
6	Hohai University	7
7	Beijing University Of Chemical Technology	6
8	Idropan Dell Orto Depuratori	6
9	Jiangsu University Of Science &Technology	4
10	Korea Institute Of Geoscience & Mineral Resources	4
11	Kurita Water Industries	4

The number of patent applications made by the top applicants in both technology areas was small compared to the industry total, indicating a fragmented market with no single player that had gained dominance in energy-efficient desalination technologies. EEEC technologies also appeared less mature, where almost half of all top applicants were universities and research institutes. These universities and research institutions could be potential collaborators for companies which are looking at entering the space but do not possess the relevant technology know-how. Companies within the top applicants may also be open to collaboration to achieve technological breakthroughs that will enable them to gain market dominance.



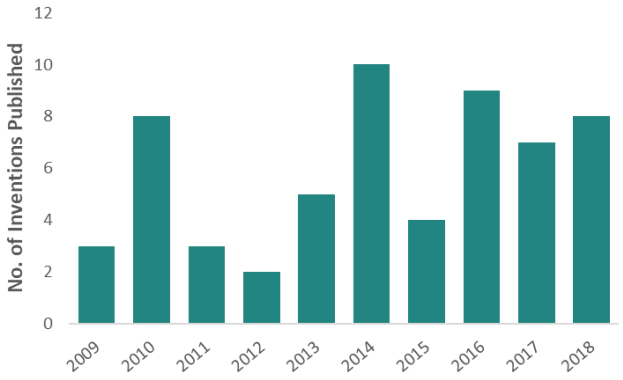
Although more than half of all EERO and EEEC technologies originated from China, the top three applicants across both technology fields were Japanese companies (except for Evoqua Water Technologies). Patent applications by the top Chinese applicants were generally more recent, and were filed exclusively in China only (data not shown), which reflected the more domestic focus of these Chinese applicants. General Electric stands out as the only company among the top applicants that was active across both technology areas, and this is reflected in their R&D activities and patent applications in Singapore[8]. (Note: GE Water & Process Technologies was acquired by SUEZ in 2017)[9].

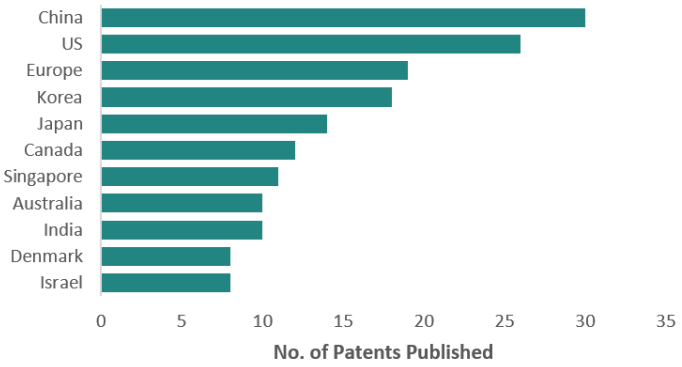
In addition to GE, other key players across EERO and EEEC technologies including Hitachi, Toray Industries, and Evoqua Water Technologies have also made patent applications in the island city-state to support their business operations and collaborations. Taken together with the relatively higher number of patent filings that Singapore received in both technology areas, the overall patenting activity reveals the interest to develop, test and deploy RO and EC technologies in Singapore despite its smaller economy[10,11].

BIOMIMETIC MEMBRANES

Biomimetic membranes ("BM") form one class of ultra-permeable membranes that can be used to lower the energy requirements of the desalination process. Amongst the different definitions of biomimetic membranes, this report focuses on membranes with transmembrane biological channels applied for use in desalination.

PUBLICATION TREND - WORLDWIDE AND TOP 10 MARKETS



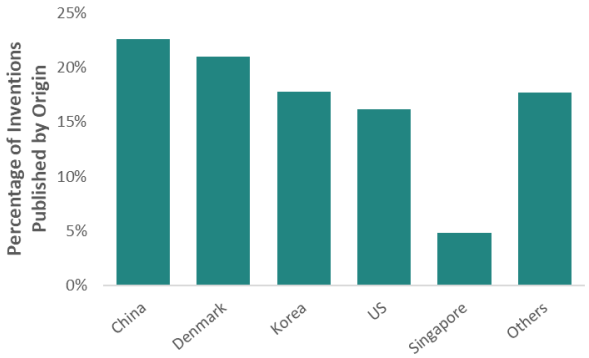


Typical of emerging technologies, the overall number of patent applications for BM technologies was low and growth was erratic. Half of the top thirty applicants comprised universities and research institutes (data not shown). Similar to EERO and EEEC technologies, China received the most patent applications, but its lead in this emerging technology area was much smaller. Other markets of interest included Australia, Canada, India and Singapore, similar to that of EERO and EEEC technologies.

TECHNOLOGY ORIGIN AND KEY PLAYERS

Rank	Applicant	No. of Inventions
1	Aquaporin A/S*	10
2	Applied Biomimetic	6
3	LG	6
4	Ningbo RXHL Technologies	5
5	Aquapoten	4
6	Ocean University of China	3
7	Inha-Industry Partnership Institute	3
8	Penn State Research Foundation	3

**Filings from Aquaporin Asia are consolidated under Aquaporin A/S*



In terms of technology origin, Denmark and Singapore were ranked 2nd and 5th respectively, and their innovation output was significantly outsized compared to the size of their economies. Japan appeared to have less activity in this area as compared to EERO and EEEC technologies. Filings from Denmark were led by top applicants Aquaporin A/S and Applied Biomimetic, while applications in Singapore were led by the National University of Singapore (NUS) and Nanyang Technological University (NTU). Aquaporin A/S and Aquapoten, Aquaporin A/S' joint venture in China, led the industry for BM technologies, and has known collaborations with NTU. LG, a strong player in EERO technologies, was also active in BM technologies. Of note as well is Ningbo RXHL Technologies which was only founded in 2016 but was among the top five applicants for BM technologies[12].

BM TECHNOLOGY DOMAINS

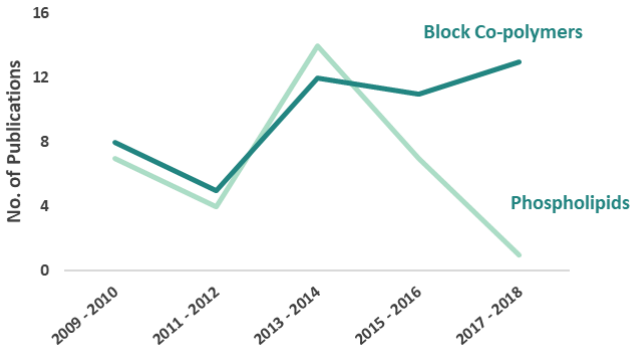
Upstream → Downstream

	Membrane Formation	Membrane Fixation & Support	Desalination Apparatus	Plant Processes
Aquaporin A/S	9	3	4	0
Applied Biomimetic	5	1	0	0
LG	1	5	3	0
Ningbo RXHL Technologies	5	2	0	0
Aquapoten	2	3	0	0
Ocean University of China	3	2	0	0
Inha-Industry Partnership Institute	3	2	0	0
Penn State Research Foundation	2	1	0	0
NTU	2	0	0	0
NUS	2	2	0	0
Total	34	21	7	0

	Phospholipids	Block-copolymers	Aquaporins	Other Biological Channels
Aquaporin A/S	6	8	11	1
Applied Biomimetic	1	4	4	0
LG	6	6	6	0
Ningbo RXHL Technologies	1	4	5	0
Aquapoten	1	1	4	0
Ocean University of China	3	0	3	0
Inha-Industry Partnership Institute	1	2	2	0
Penn State Research Foundation	1	3	2	0
NTU	1	2	2	0
NUS	1	2	2	0
Total	22	32	41	1

The time-to-market for BM technologies is likely to be long as innovation activity was still more focused on upstream technologies to form membranes with functional transmembrane protein channels. Aquaporin A/S has technologies across the value chain and may be the frontrunner to fully commercialise BM technologies. In contrast, LG focused on more downstream technologies to fix and stabilise membranes in desalination apparatus, and is a potential partner for companies who require such technologies to commercialise their own upstream BM technologies.

On the membrane itself, there appeared to be a shift towards the use of block co-polymers instead of phospholipids, though the number of inventions published were small. Co-polymers as the preferred material of choice for biomimetic membranes could stem from its greater stability. This shift was seen across the key industry players



as well as the industry as a whole. Aquaporin remained the predominant transmembrane protein channel used in biomimetic membranes although a small number of innovations by the universities and research institutes utilised potassium and sodium ion channels, such as Fraunhofer, RWTH Aachen, Joseph Fourier University and Yantai Institute of Coastal Zone Research.

CONCLUSION

This report has identified the key trends, key players and related technology developments worldwide and in Singapore for EERO, EEEC and BM technologies. EERO technologies are more mature but EEEC technologies are receiving more interest. Commercial applications of BM technologies in desalination are still in its infancy stage, with innovation activity focusing on upstream processes. There appears to be strong market interest in Singapore across all three technology areas, where key players in each field were testing their technologies or have collaborated with universities in Singapore, placing Singapore in a strong position to continue exploit the newest technologies for our water security.

REFERENCES

1. Frost and Sullivan: *Analysis of Global Desalination Market*.
2. Water Technology Online: *Growth expected for global water desalination market from 2018 to 2025*.
3. International Desalination Association: *Trends in Desalination & Water Reuse; Desalination and Water Reuse Business Forum*.
4. For the purposes of this report, EC technologies include but are not limited to electrodialysis, electrodialysis reversal, continuous electrochemical deionisation, and capacitive deionization.
5. This includes China, the EU, Japan, Korea, and the US, which traditionally receives the most patent applications globally.
6. To obtain an accurate count of patent publications in each jurisdiction, one representative patent family per jurisdiction was used instead of one representative from each patent family.
7. Channel News Asia: *Singapore water industry contributes S$2.5b in value added to economy annually, creates 14,400 jobs to date.*
8. Public Utilities Board: *Innovation in Water Singapore*, July 2017, Volume 9.
9. SUEZ: *SUEZ finalizes the acquisition of GE Water & Process Technologies.*
10. Toray Group: *Inauguration of Toray Singapore Water Research Center - Toray's Water Treatment R&D Base in Singapore*.
11. Public Utilities Board: *Innovation in Water Singapore*, June 2016, Volume 8.
12. http://www.rtlwater.com/about.asp

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