**JACI Textbook** Learning from social practice cases that have received the GSC Awards

**G**reen and
**S**ustainable
**C**hemistry

# Introduction to GSC

No.5 Revised Edition

**Received the Minister of Economy, Trade and Industry Award and Minister of the Environment Award of the 15th GSC Awards (2015)**

# Development of High-Performance Reverse Osmosis Membrane Contribution to the Solution of Global Water Issues

## Toray Industries, Inc.

Toray Industries, Inc. has developed a high-performance reverse osmosis membrane with exceptional water permeability, removal performance, and fouling resistance. Membranes that achieve both energy saving and high quality water production are regarded as epoch-making technology that contributes to the solution of water issues worldwide.

### Outline of the GSC Awards and the award-winning company

The GSC Awards are bestowed upon individuals and organizations for their contribution toward the advancement of Green and Sustainable Chemistry (GSC), and several awards are conferred each year. Innovations that contribute toward the development of sustainable industrial technology are awarded the Minister of Economy, Trade and Industry Award; those that contribute toward the development and promotion of science are awarded the Minister of Education, Culture, Sports, Science and Technology Award; those that contribute toward the overall reduction of environmental impact are awarded the Minister of the Environment Award; while small and medium-sized businesses that contribute toward the development of industrial technology are awarded the Small Business Award (established in 2015; renamed to Venture Company Award, Small and Medium-sized Company Award in 2018 and Venture, Small and Medium sized Company Award in 2022). Additionally, innovations that exhibit high potential for future development are awarded the Incentive Award.

Toray Industries, Inc. is a chemical manufacturer (Head Office: Chuo-ku, Tokyo) founded in 1926. Toray's business covers chemical products including synthetic fibers and synthetic resins, and information-related materials

## Objective of the textbook series

Global issues, in areas such as resources and energy, global warming, water and food have increasingly become major and complicated concerns. Innovations for achieving both environmental conservation and economic development are needed in order to resolve these issues and realize the sustainable development of society, and expectations for GSC continue to rise. In this textbook series, technologies and products that have received the GSC Awards given to great achievements contributing to the progress of GSC are explained, so that everyone can understand "what is GSC?" and take responsibility for realizing a sustainable society.

*Please refer to The Statement 2015 at the end of the textbook.

## What is GSC?

**Acronym for Green and Sustainable Chemistry**

## Definition of GSC

**Chemical sciences and technologies which are benign to both human health and the environment, and support the development of a sustainable society**

## Guidelines of GSC activities

- The chemistry community has been addressing future-oriented research and education, and development towards environmentally-benign systems, processes and products for the sustainable development of society.

- Specifically, in response to the Rio Declaration at the Earth Summit in 1992, the chemistry community has been working in a unified manner linking academia, industry and government to start up Green and Sustainable Chemistry and engage in its activities, in order to advance the pursuance of coexistence with the global environment, the satisfaction of society's needs, and economic rationality. These goals should be pursued with consideration for the environment, safety and health across the life cycles of chemical products, their design, selection of raw materials, processing, use, recycling and final disposal.

- Long-term global issues, in areas such as resources and energy, global warming, water and food, and demographics have increasingly become major and complicated concerns in the present century. Therefore, expectations are growing for innovations, based on the chemical sciences, as driving forces to solve such issues and to achieve the sustainable development of society with enhanced quality of life and well-being.

- The chemistry community will live up to these expectations by strongly advancing Green and Sustainable Chemistry through global partnership and collaboration and by bridging the boundaries that separate industries, academia, governments, consumers and nations.

## Examples of GSC

- The general classification is expressed in terms of a combination of the intended social contribution and the means to achieve this goal. With regard to the objectives, the efforts to achieve them have extended in stages from social challenges to difficult long-term challenges, beginning with manufacturing or utilization, and common/basic categories have also been established -

### Minimization of resource consumption and maximization of the efficiency of reaction processes for production with reduced environmental impact

**1.** Chemical technologies and products that lead to reduction in by-product formation and avoid the use of hazardous substances

**2.** Separation, purification and recycling technologies that reduce the generation and emission of greenhouse gases like $CO_2$ or toxic/hazardous substances, thus lowering environmental impact

**3.** Chemical technologies and products that reduce the generation and emission to the environment of greenhouse gases like $CO_2$ or toxic/hazardous substances

**4.** Catalysts and reaction processes that realize the saving of energy and resource and improvement in product yields

### Risk reduction of chemical substances beneficial to safe and secure living environment

**5.** Chemical technologies, products and systems that reduce waste generation

**6.** Chemical technologies, products and systems that inhibit the generation and emission of hazardous substances and pollutants

### Challenges to solve energy, resource, food and water issues

**7.** Chemical technologies, products and systems to utilize low-grade heat sources, non-conventional resources, and other similar alternatives

**8.** Chemical technologies, products and systems whereby un-utilized energy and resources can be converted into available energy, transported and stored

**9.** Chemical technologies, products and systems which decrease the dependence on exhaustible resources such as fossil fuels and scarce minerals and promote the shift to renewable energy and resources, including their storage

**10.** Chemical technologies, products and systems that contribute to the Three R's: Reduce, Reuse and Recycle

**11.** Chemical technologies, products and systems that promote the efficiency of production and supply of food, and utilization of water resources

### Pioneering challenges to long-term issues aiming to realize a safe, secure and sustainable society with enhanced quality of life

**12.** Chemical technologies, new products and new operational systems that contribute to the introduction of new social systems, for instance based on ICT, and aimed at solving social issues such as energy and resource consumption, food and water security, disaster prevention and infrastructure improvements, transportation and logistics, medical and health care, education and welfare, and other mega-trends of society

**13.** Chemical technologies, new products and new operational systems that contribute to the improvement of social and individual comfort whilst reducing and preferably inhibiting environmental impact

### Systematization, dissemination, enlightenment and education of GSC including its metrics to be established

**14.** Systematization of GSC practices and concepts

**15.** Dissemination, enlightenment and education of GSC practices and concepts

**16.** Establishment and dissemination of GSC metrics

(Definition from JACI GSCN Council
https://www.jaci.or.jp/english/gscn/page_01.html)

# Development of High-Performance Reverse Osmosis Membrane Contributing to the solution of global water issues

## Toray Industries, Inc.

At the 15th GSC Awards (2015), Toray Industries, Inc. received the Minister of Economy, Trade and Industry Award and the Minister of the Environment Award for the "Development of High-Performance Reverse Osmosis Membrane". Toray Industries Inc. is the first company to receive two GSC Awards simultaneously. The reverse osmosis membranes developed by this company can be used in different types of water-treatment systems (including seawater, river water, and sewage wastewater) for high-quality water production using low energy.

## 1 The Path to Technology Development

### ~ What were the intentions that started development toward realizing the sustainable progress of society?

Water is an important "resource", not only for sustaining human life but also for facilitating daily life and economic activities. With the rapid population growth and economic development of the world, water problems such as water shortages and water pollution are becoming more serious. With time, these issues are expected to worsen and might even trigger international disputes. The biggest issue is that approximately 900 million people in developing countries, particularly Africa, do not have easy access to safe water. As the Sustainable Development Goals (SDGs) adopted in the 2015 United Nations Summit prioritize the resolution of water issues, "securing a stable supply of safe water" is recognized as an important issue for all of humanity*[1].

The Earth, with approximately 70% of its surface covered with water, is also called the "water planet." However, most of this water is seawater; only 0.01% is freshwater that can be directly consumed by humans. To resolve the global water issue, the utilization of different types of water, including seawater and brackish water*[2] in inland areas, must be explored.

In regions where freshwater is scarce, such as the Middle East, seawater desalination is used to produce fresh water from seawater. "Desalination methods" include "evaporation methods"*[3] (in which fresh water is produced by heating seawater and cooling the water vapor) and "reverse osmosis methods" (in which fresh water is produced by filtering seawater through a special membrane called a reverse osmosis membrane). A reverse osmosis membrane is covered with numerous pores (≤1 nm in diameter) that allows the passage of only water (not impurities such as salts). Therefore, these membranes are used to produce fresh water by removing impurities from seawater (see column 1). Evaporation method requires a large amount of energy, making water production expensive. In contrast, the reverse osmosis method exhibits a relatively high energy efficiency, and is therefore gaining worldwide attention. This method exhibits high potential for use in economically disadvantaged countries.

However, reverse osmosis method involves the application of high pressure onto seawater, which requires some energy. Additionally, seawater contains organic substances (such as plankton and plankton carcasses) and inorganic substances other than salts that clog the membrane. This hinders both the passage of water through the membrane and the removal of salt; therefore, the membrane must be cleaned regularly. Fresh water cannot be obtained while the membrane is being cleaned, and cleaning agents damage the membrane on repeated cleaning, thereby shortening the life of the membrane and increasing the cost of water production.

*1
Introduction to GSC Special Edition : https://www.jaci.or.jp/english/gscn/GSCgs/esp/gsc_esp.php

*2
Water in lakes and rivers containing more salinity than freshwater, but not as much as seawater.

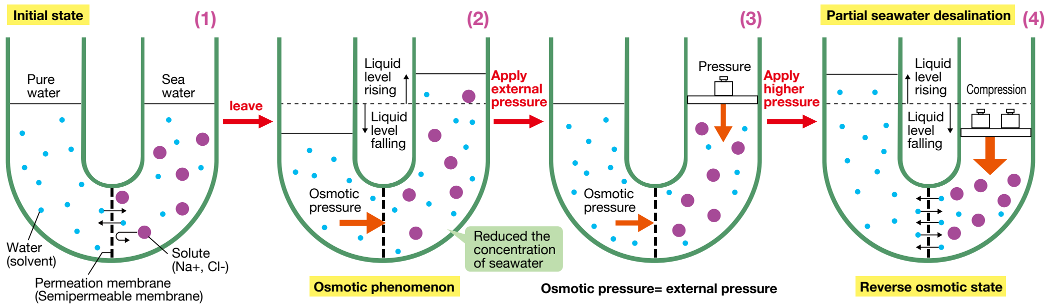
*3
Including the multi-stage flash process that distills under reduced pressure, and the multiple effect method that distills using connected drums, etc.

Toray Industries Inc. has been developing reverse osmosis membranes for more than 40 years. The applications of these membranes have been extended from the production of ultrapure water for the semiconductor industry to the desalination of brackish water and seawater and the reuse of sewage and wastewater. Toray has embarked on the development of a high-performance reverse osmosis membrane with the aim of contributing to water issues through application of the technologies they have accumulated over their long history.

Column 1

## The principle of reverse osmosis

Osmotic membranes, also known as semipermeable membranes, do not allow molecules or ions larger than a certain size to pass through them. The pore size of osmotic membranes is several times larger than the size of water molecules (approximately 0.38 nm); therefore, water molecules freely pass through them. Seawater mainly contains sodium ions (0.12–0.14 nm in size) as the ionic impurity. As hydration causes water molecules to gather around sodium ions, their apparent size increases significantly (from several times to 10 times or more), making their passage through an osmotic membrane challenging.




A membrane that allows some, but not all, substances in a solution to pass through it is referred to as an osmotic membrane (or semipermeable membrane).

Solvent molecules move to the solution side through the osmotic membrane (process of osmosis). The pressure at which the molecules pass through the membrane is referred to as osmotic pressure.

In order to keep the heights of both liquids at the same level, it is necessary to apply an external pressure that is equivalent to the osmotic pressure.

When a pressure higher than the osmotic pressure is applied to the seawater side, only the water molecules in the seawater permeates the osmotic membrane, passing through into the water side. This phenomenon is referred to as reverse osmosis.

**Figure 1: Principles of osmosis, reverse osmosis, and osmotic pressure**

Therefore, osmotic membranes can be used to obtain freshwater from seawater.

Pure water and seawater are separated by an osmotic membrane (1), and if left for while, the water molecules will pass through the membrane to the seawater side, reducing the concentration of the seawater. This process is referred to as the osmotic phenomenon. The difference in liquid levels between the pure water and seawater occurs because the pressure at which water molecules pass through the membrane (osmotic pressure) pushes up the seawater (2). To control the permeation of water molecules and maintain the same height for both the liquids, it is necessary to apply an external pressure equivalent to the osmotic pressure (3). If a pressure higher than the osmotic pressure is applied to the seawater side, only the water molecules move from the high-concentration side to the low-concentration side. This process is labeled reverse osmosis (4).

Reverse osmosis can be used to extract freshwater (containing almost no sodium or chloride ions) from seawater. However, if the salts that do not pass through the membrane are not continuously removed, the salt concentration on the pressurized side increases. This increases the osmotic pressure, preventing water molecules from passing through the membrane, and therefore the supplied seawater cannot be treated entirely. If the discharged water flows continuously along the membrane surface at a certain rate, the adhesion of impurities to the membrane can be reduced.

Therefore, industrial facilities are designed to continuously remove the water containing concentrated salts and impurities (brine). With reverse-osmosis membranes, 1) the higher the salt concentration of raw water, 2) the lower is the salt concentration remaining in the water that has permeated the membrane, and 3) the more the brine needs to be reduced, the higher is the pressure required for filtration. Accordingly, either the thickness of the membranes is increased, or multiple membranes are used in succession. For example, approximately 50–60 atm pressure is required to obtain fresh water with a salt concentration of 0.01% (meeting Japanese drinking water standards) from seawater (which has an average salt concentration of 3.5%) at a recovery ratio of approximately 40%. The seawater remaining after reverse osmosis is discharged into the sea as brine (with a salt concentration of 5.8%); measures are taken to ensure that it exerts low impact on the surrounding sea area.

For detailed information, please refer to an overview of the desalination facilities and the principles of desalination provided by the Okinawa Prefectural Seawater Desalination Center [https://www.eb.pref.okinawa.jp/homepage/1005], etc.

## Column 2

*4
1 μm is 1/1000 of 1 mm
1 nm is 1/1000 of 1 μm

### Water treatment using membranes

Membranes with nanometer to micrometer*4 pores are used in water treatment. These membranes are classified as microfiltration membranes (MF), ultrafiltration membranes (UF), nanofiltration membranes (NF), and reverse osmosis membranes (RO) membranes depending on the pore size (which indicates the size of separable substances). The smaller the pore size, the finer are the impurities that can be removed. Various membrane types have been used for different purposes.

MF membranes contain pores that are several microns to 0.1 μm in size; they remove suspended matter, colloidal particles, and bacterial cells efficiently from liquids. Wastewater treatment utilizes a submerged membrane bioreactor (MBR) comprising an MF membrane submerged in a water tank.

UF membranes with pores sizes of around 0.01–0.1 μm are used as sieves at the molecular level according to the pore size and size of the solute molecules. They are widely used to remove viruses, bacteria, yeast, fine particles, and colloids. RO membranes (with pores that are 1 nm or smaller in size) are used to remove ions and low-molecular-weight organic substances. They are used for the desalination of seawater and production of ultrapure water. NF membranes are a special type of RO membranes. While RO membranes remove all ions from water, NF membranes remove divalent ions from water.

During water treatment, the membrane is incorporated into a unit called a membrane module that is installed in the water-treatment apparatus or plant. Module shapes can be classified into the "pleated type," "tubular type," and "spiral type." The "pleated-type" shape comprises overlapping sheet-like membranes; some MF membranes exhibit this shape. The "tubular type" shape comprises a bundle of hollow fiber membranes; MF, UF, and RO membranes exhibit this shape. The "spiral type" comprises a sheet-like membrane rolled around a pipe; RO membranes are often constructed in this shape.

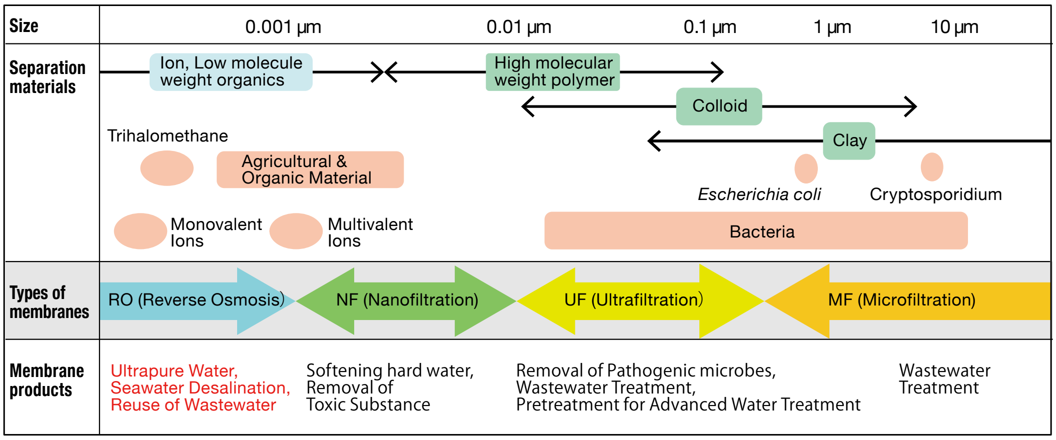



**Figure 2: Types of Membranes**

# 2 Toward Resolution of Issues

## ~ What types of technological challenges did the developers face and how did they resolve them?

### Enhancing the function of reverse osmosis membranes

Toray began their development of reverse osmosis membranes with the aim of utilizing them in the desalination of seawater. Development was extremely difficult and it was difficult to put it to practical use. The reason for this was that it was difficult to achieve both water permeability and increased removal of impurities such as salt.

Enlarging membrane pores increases water permeability, but also allows salt to pass through more easily. Contrarily, membranes with small pores exhibit excellent salt removal and produce high-quality water; however, the efficiency of water treatment declines. Moreover, because pressure is applied, pressure resistance is also necessary. To resolve these tradeoff issues, Toray experimented with various materials and surface structures. One such development is a cross-linked aromatic polyamide*5 composite membrane produced by interfacial

*5
A polyamide that is produced through the polycondensation of amines with acid chlorides and/or carboxylic acids. It is the main material used in reverse osmosis membranes.

*6 A method of polycondensation at the interface between two liquid phases that do not intermix

polycondensation*6 (see "In More Detail" below). The protuberant surface structure of these membranes (Fig. 3) enables an increase in surface area that facilitates the purification of large amounts of seawater. Thus, despite a small pore size, these membranes efficiently remove salt from seawater to produce freshwater.

With the increased use of membranes, improvements in energy efficiency, water quality, and operational stability are required to facilitate water treatment (including the desalination of seawater and treatment of brackish water, river water, and sewage wastewater). Increasing water permeability is imperative for saving energy. This is due to the fact that if the more water flow through the membrane, obtaining the amount of water will require less energy. Furthermore, to improve water quality, it is essential to increase the impurity-removal ratio. If the surface of the membrane is resistant to fouling, not only can the decrease in water permeability be controlled, but also the frequency of membrane cleaning can be reduced. It was for the above reasons that Toray decided to develop a membrane with these numerous functions.

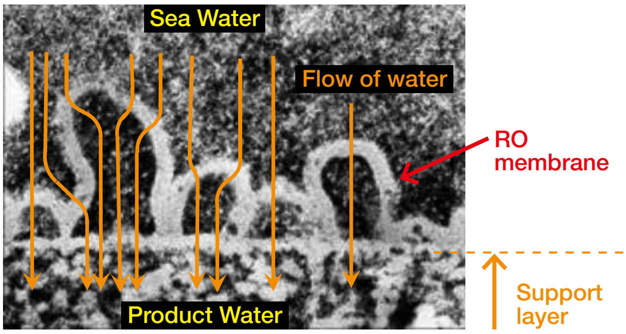



Figure 3: Surface structure of membranes (CS–TEM)

## Analyzing the structure of reverse osmosis membranes

The development team at Toray believed that the performance of reverse osmosis membranes could be improved by precisely controlling the structure of the protuberances and pores of conventional cross-linked aromatic polyamide composite membranes. They therefore decided to analyze thoroughly the surface structure of membranes. However, the analysis of surface structures of 1 nm or less in size was challenging.

An electron microscope was used to analyze the size of the protuberances on the membrane surface. A conventional scanning electron microscope could only provide information on the shape of the protuberances. Moreover, although they could observe finer structures using a transmission electron microscope, they did not have the technology to quantify even finer structures.

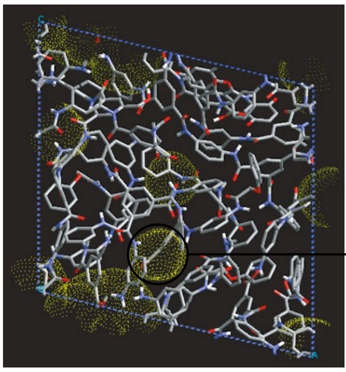
Therefore, to facilitate analysis, Toray developed an original analysis technology through joint research with Toray Research Center, Inc. (TRC). The new technology enabled a detailed analysis of the internal structure and surface area of membrane surface protuberances and the membrane thickness. As a result, they were able to clarify the relationship between the structure of the protuberances and the properties of reverse osmosis membranes. This clarification facilitated their design of the reverse osmosis membrane structure.

Although Toray endeavored to quantify the sizes of the pores in the membrane, they had no means of measuring the structure of the fine pores at that time. After much brainstorming, they hit on the idea of using positron annihilation lifetime measurement, a method used to calculate the time between the injection of positrons into a sample and their annihilation through interaction with electrons. As positrons trapped in small pores are more likely to collide with surrounding electrons and exhibit short lifetimes, these measurements can be used to estimate the pore size of a membrane.

Although small-measurement apparatus are currently available, no such instruments were available in 2015. Toray collaborated with TRC and various other internal and external organizations to develop a small-measurement apparatus. They then combined use of this apparatus with molecular dynamics calculations to establish a method for measuring pore size. They were able to confirm that the size of pores in reverse osmosis membranes is 0.5 to 0.7 nm, and also found a correlation between the pore size and boron removal ratio. (Boron and boron compounds are regulated substances in drinking water.)

Based on these analysis results, Toray designed a three-dimensional model of the membrane's structure utilizing computer simulation technology, and used the model to determine how to control the size of the protuberances and pores in order to attain high permeability, removal performance, and durability. In addition, after experimenting with the interfacial polymerization method and surface control technology, they finally achieved the ideal membrane structure through a process of trial and error. By controlling the surface of the membrane, they were also able to create a surface that is resistant to fouling.

**Pore structure of RO membrane analyzed using molecular dynamics simulation**




**Correlation between pore size and boron removal ratio**

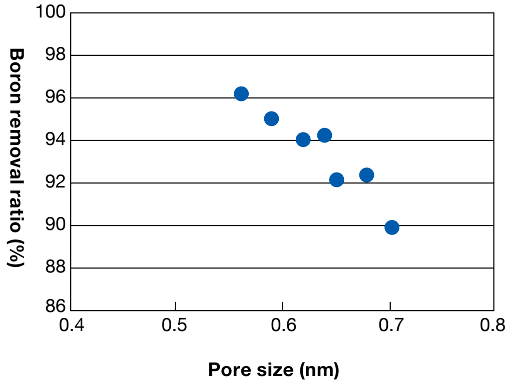



**Figure 4: Pore size analysis of reverse osmosis membranes**
Toray discovered that reverse osmosis membranes contain pores with 0.5–0.7 nm size (left) and correlated the pore size with the boron removal ratio of the membrane (right).

## Energy saving through improved constructional elements

The reverse osmosis membrane is formed into a flat sheet and rolled up like a Swiss roll cake together with the spacer to be used as a spiral-type element. One cross section is the supply side where seawater is introduced, and salt is removed as pressure is applied to permeate the water through the reverse osmosis membrane (Fig. 5).

The salt separated from water by the membrane accumulates on the surface of the membrane, causing a concentration-polarization phenomenon (in which the ion concentration on the surface increases above the ion concentration in the feed seawater). This phenomenon changes the permeation performance of the membrane. Therefore, it is vital to reduce the ion concentration on the surface of the reverse osmosis membrane by increasing the flow velocity of the supplied water. To do so, Toray improved the performance of feed spacers. Using fluid analysis to make the feed spacer thinner and optimize the network structure, Toray developed a technology that doubled the flow velocity of the supplied water, reducing the ion concentration on the membrane surface by 30% or more.

Additionally, the spacer typically comprises a densely structured tricot (a fabric with a mesh connected in the vertical direction) that can withstand the high applied pressure. However, this dense structure impedes the flow of water, reducing the permeation performance of the membrane. Toray therefore applied their fiber processing technology in addition to fluid analysis and structural analysis, and were able to mold the molten resin with ultra-precision into dots and stripes, successfully expanding the flow path while maintaining pressure resistance. Consequently, the flow resistance was reduced by 50% and the water permeation was increased by up to 20%. In this way, Toray improved the structure of the spacer for both the supply water and permeated water in order to maximize the membrane's performance.

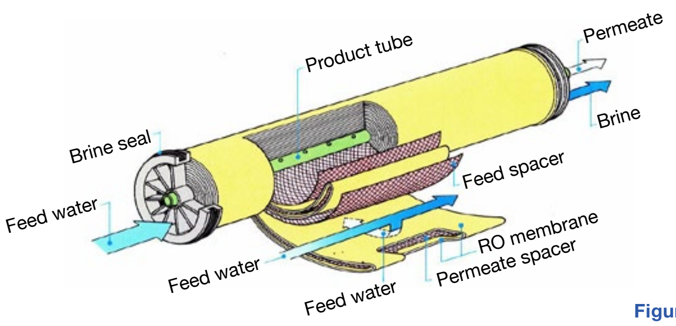



**Figure 5: Structure of the RO Element**

## Column 3 Separation operations in the chemical industry

Separation operation is a fundamental technology of chemical processes. It is an indispensable process in the production of a wide array of products, such as in refining raw materials, removing harmful substances, and recovering unreacted substances.

In recent years, it has also been gaining attention as a means of mitigating the environmental impact of industrial wastewater and waste treatment. Separation operation processes include filtration, distillation, fractional distillation, sublimation, extraction, recrystallization, adsorption, and chromatography. For example, in the petroleum industry, crude oil is distilled and then separated into gasoline, kerosene, etc. The chemical industry consumes large amounts of energy, approximately 70% of which is used in separation processes. In the petrochemical industry in particular, about 40% of energy is used for distillation, and high expectations are held for technologies that improve the efficiency of the distillation process as well as technologies that achieve membrane separation rather than distillation.

# 3 Contribution to Society

## ~What is the contribution of this novel technology to society?

By thoroughly analyzing the chemical structure and physicochemical data of membrane materials and establishing a technology for controlling the membrane-surface structure ( such as optimizing the pore size and protuberance structure), Toray developed reverse osmosis membranes with high permeability and high removal performance. Owing to increased water permeability, the new membranes enabled water treatment at lower pressures than ever before, saving large amounts of energy. Moreover, owing to their fouling- and chemical-resistant properties, these membranes require less frequent cleaning and show a long lifetime. Thus, the reverse osmosis membranes developed by Toray enable the stable removal of harmful substances, such as boron, and provide a long-term high-quality water supply.

As a result, their waste water treatment calculations found that a 60% reduction in water production costs can be expected using reverse osmosis membranes. Moreover, the energy-saving properties of RO membranes are estimated to reduce carbon dioxide emissions by approximately 8 million tons over five years (from 2010 to 2014).

These RO membranes enable the stable and inexpensive production of high-quality water from different types of water (including seawater, brackish water, and sewage).

Furthermore, water purification by RO membranes is estimated to involve a significantly lower energy consumption compared to conventional methods of water purification (such as evaporation). Currently, the RO membrane technology is used in many regions of the world, and is contributing toward the resolution of global water issues through widespread application.

RO membrane applications have expanded into the food and pharmaceutical industries. In the future, RO membranes are expected to be applied in a wide range of fields related to resources and energy, including petroleum and gas mining; the production of lithium, rare metals, and other valuable resources; and biorefining. Additionally, they are attracting attention in the chemical industry as innovative low-energy technologies.

## In more detail

## Structure of cross-linked aromatic polyamide composite membranes

The reverse osmosis membrane (RO membrane) is composed of a separation layer and a support layer. The separation layer (on the surface of the membrane) removes impurities; the support layer (with no impurity-removal properties) comprises a porous structure with numerous pores. An RO membrane is called a composite membrane because it comprises multiple layers and materials.

The RO membranes that are currently being used are mainly cross-linked aromatic polyamide composite membranes that have a polyamide material for the separation layer. The separation layer is formed through the process of interfacial polycondensation, by which a polymer is continuously formed at the interface between the aqueous phase and the organic phase. A porous film composed of polysulfone is formed on non-woven fabric as a support layer, and an aqueous amine solution is applied on top of the polysulfone to create an aqueous phase. An organic solvent solution of acid chloride is added on top of the aqueous phase in the interfacial polycondensation process, which creates a dense polyamide layer with a thickness of 0.2 μm or less.

RO membranes formed via interfacial polycondensation show protuberant surfaces (Fig. 6, left). Water and impurities (such as salts) are separated by membrane protuberances and pores (measuring ≤1 nm in diameter). RO membranes exhibit excellent ion-removal properties; therefore, they are used for seawater desalination.

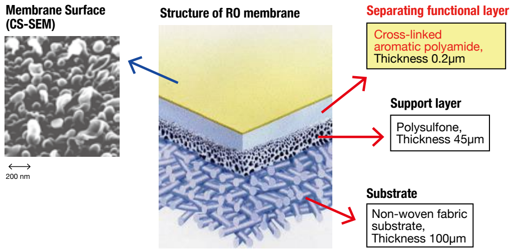



**Fig. 6: Conventional RO membrane**
Structure of reverse osmosis membrane based on crosslinked aromatic polyamide

## Questions

## For deeper understanding

**Through this case study, discuss the following questions from the viewpoint of GSC (Green and Sustainable Chemistry).**

**Q1** Discuss which of the GSC cases best applies to the technologies and products of this teaching material, along with the reasons.

**Q2** Implementation in society is vital for any technology to meet the goals of GSC. This involves the simultaneous fulfillment of coexistence with the global environment, the satisfaction of society's needs, and economic rationality.
In the examples of technologies and products in this teaching material, summarize what measures have been taken to meet not only environmental and social satisfaction but also economic rationality.

**Q3** Life on earth depends on water.
1) Draw the Lewis Structure of water and explain why this molecule is bent.
2) Research and make a presentation on the kinds of water-related problems that are currently occurring.
3) Compare the “evaporation method” and “reverse osmosis method” used to obtain drinking water.

**Q4** Using “Introduction to GSC” special edition[*7] as a reference, explain the relationship between this case example and SDGs.

*7 Introduction to GSC Special Edition https://www.jaci.or.jp/english/gscn/GSCgs/esp/gsc_esp.php

**Q5** Evaluate this technology in accordance with the GSC 4-axes method.

**Q6** Reverse osmosis occurs when a pressure higher than the osmotic pressure is applied to the osmotic (or semipermeable) membrane. Osmotic pressure can be calculated using Van’t Hoff’s Law, which is represented as $\pi = cRT$.
$\pi$ : Osmotic pressure; c : Molar concentration; R : Gas constant; T : Absolute temperature
For simulated seawater, a 3.5 wt% NaCl aqueous solution with a molar ion concentration of approx. 1.2 mol/L is used. Calculate the osmotic pressure at a temperature of 27 °C (= 300 K).

## Introduction of literature

## Helpful materials

1) *Environment and Chemistry, Introduction to Green Chemistry*, 3rd Ed. (in Japanese), ed. by K. Ogino, S. Takeuchi and H. Tsuge, Tokyo Kagaku Dojin, Tokyo, 2018
2) *Basics of separation process engineering*, (in Japanese) ed. by Chemical Engineering Society Separation Process Subcommittee, Asakura Shoten, Tokyo, 2009.
3) A. Ito, *Tokoton yasashii maku bunri no hon*,(in Japanese), Nikkan Kogyo Shimbun, Tokyo, 2010.
4) M. Fujiwara, Y. Aoshima, *Mechanisms for the Long-term Innovation, A History of the RO Membrane’s Technological Development* (in Japanese), Toyo Keizai, Tokyo, 2019.

# The Statement 2015

We, the participants of the 7th International GSC Conference Tokyo（GSC-7）and 4th JACI/ GSC Symposium make the following declaration to promote "Green and Sustainable Chemistry（GSC）" as a key initiative in the ongoing efforts to achieve global sustainable development.

The global chemistry community has been addressing future-oriented research, innovation, education, and development towards environmentally-benign systems, processes, and products for the sustainable development of society.

In response to the Rio Declaration at the Earth Summit in 1992 and subsequent global Declarations, the global chemistry community has been working on challenges in a unified manner linking academia, industry, and government with a common focus to advance the adoption and uptake of Green and Sustainable Chemistry. The outcomes include the pursuance of co-existence with the global environment, the satisfaction of society's needs, and economic rationality. These goals should be pursued with consideration for improved quality, performance, and job creation as well as health, safety, the environment across the life cycles of chemical products, their design, selection of raw materials, processing, use, recycling, and final disposal towards a Circular Economy.

Long-term global issues, in areas such as food and water security of supply, energy generation and consumption, resource efficiency, emerging markets, and technological advances and responsible industrial practices have increasingly become major and complicated societal concerns requiring serious attention and innovative solutions within a tight timeline. Therefore, expectations are growing for innovations, based on the chemical sciences and technologies, as driving forces to solve such issues and to achieve the sustainable development of society with enhanced quality of life and well-being.

These significant global issues will best be addressed through promotion of the interdisciplinary understanding of Green and Sustainable Chemistry throughout the discussion of " Toward New Developments in GSC. "

The global chemistry community will advance Green and Sustainable Chemistry through global partnership and collaboration and by bridging the boundaries that traditionally separate disciplines, academia, industries, consumers, governments, and nations.

July 8, 2015<br>
Kyohei Takahashi<br>
on behalf of Organizing Committee<br>
Milton Hearn AM, David Constable,<br>
Sir Martyn Poliakoff, Masahiko Matsukata<br>
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# GSC : Green and Sustainable Chemistry

Chemical sciences and technologies
which are benign to both human health and the environment,
and support the development of a sustainable society.

# Introduction to GSC

## Learning from social practice cases that received the GSC Awards

Global issues, in areas such as resources and energy, global warming, water and food have increasingly become major and complicated concerns. Innovations for achieving both environmental conservation and economic development are needed in order to resolve these issues and realize the sustainable development of society, and expectations for GSC continue to rise. In this textbook series, technologies and products that have received the GSC Awards given to great achievements contributing to the progress of GSC are explained, so that everyone can understand “what is GSC?” and take responsibility for realizing a sustainable society.

**Special Edition**

### “Introduction to SDGs” Sustainable Development Goals GSC plays a driving role in SDGs

Let's change the world towards a sustainable future!

The SDGs are global goals adopted by the United Nations, and it is essential to harmonize the three elements of economy, society, and the environment in order to achieve sustainable development. This way of thinking is shared with the GSC, which aims to achieve both environmental conservation and economic development for the sustainable development of society. As a special issue, this text aims to explain the SDGs from the perspective of the GSC and encourage everyone to think about and put them into practice.

No.1

### New laundry proposal for pioneering a sustainable society

Kao Corporation

The "new laundry proposal for pioneering a sustainable society" of Kao Corporation, which received the Minister of Economy, Trade and Industry Award of the 12th GSC Awards (2012), is characterized by the introduction of Life Cycle Assessment (LCA) into the development of laundry detergents, and the proposal to reduce laundry-related environmental impacts together with consumers by using just one rinse cycle in laundry. How was this innovation generated that simultaneously satisfies environmental friendliness, social contribution and economic rationality?

No.2

### Novel Non-phosgene Polycarbonate Production Process Using By-product $CO_2$ as Starting Material

Asahi Kasei Corporation

The great success of this technology is that unlike the conventional polycarbonate production process, it does not use toxic phosgene as a starting material. At the same time, the technology was revolutionary because it achieved saving of both resources and energy. More than 10 years have passed, and the technology has been widely commercialized all over the world. This worldwide use was highly regarded, and the process became the first technology by a Japanese company to receive the Heroes of Chemistry Award from the American Chemical Society in 2014. What kind of technology is involved in this world-renowned polycarbonate production process?

No.3

### Development of Carbon Fiber Composite Materials for Lightweight Commercial Airplanes

Toray Industries, Inc.

TORAY's carbon fiber reinforced plastic developed through over 40 years of research and development has features of high toughness (material tenacity) in combination with light weight and flexibility. The high toughness carbon fiber reinforced plastic (high toughness CFRP) realizes weight reduction of airplanes which is effective in improving fuel consumption, and makes a substantial contribution to reducing environmental impact.

No.4

### Development and Commercialization of High Performance Transparent Plastics Derived from Plant-Based Raw Material

Mitsubishi Chemical Corporation

"DURABIOTM", the transparent engineering plastic made from renewable resources developed by the company, not only contributes to the reduction of environmental impact, but also realizes performance exceeding that of conventional engineering plastics in terms of optical characteristics, weathering resistance, etc.

No.5

### Development of High-Performance Reverse Osmosis Membrane Contribution to the solution of global water issues

Toray Industries, Inc.

This reverse osmosis membrane can be used in not only seawater but also river water, sewage wastewater, and various other water treatment systems, providing high quality water while saving energy.

No.6

### Development of Low Environmental Load Battery for Idling-Stop System Vehicle with High Charge Acceptance and High Durability

Hitachi Chemical Co., Ltd.
(Currently Energywith Co., Ltd.)
Hitachi, Ltd.

Idling-stop systems heavily burden on the battery, causing existing batteries to rapidly degrade, with short battery lifetimes. This technology resolves this problem and contributes to the reduction in $CO_2$ emissions.

No.7

### Development of Water-based Inkjet Ink for Food Package

Kao Corporation

Kao Corporation developed a “water-based inkjet ink” for printing on the plastic films used for packaging daily commodities and food.
The ink maintains a high image quality and has lower volatile organic compound emissions, thereby reducing its environmental impact.

No.8

### Development and Commercialization of a New Manufacturing Process for Propylene Oxide Utilizing Cumene Recycling

Sumitomo Chemical Co., Ltd.

Sumitomo Chemical Co., Ltd. developed a new manufacturing process for propylene oxide, which is used as a raw material for polyurethane and other materials.
The new process enables high yields of propylene oxide while reducing its environmental impact.

**You can read them in “PDF” and “HTML” that is easy to read on mobile phones.**

**Please take a look!**

https://www.jaci.or.jp/english/gscn/GSCgs/spmenu/page_19_01_sp.php

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