'TORAY'
Innovation by Chemistry

TORAY IR Seminar

R&D of Toray Group's Water Treatment Business and Separation Membrane

March 28, 2025

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General Manager of Research Division,
Toray Industries, Inc.

Contents

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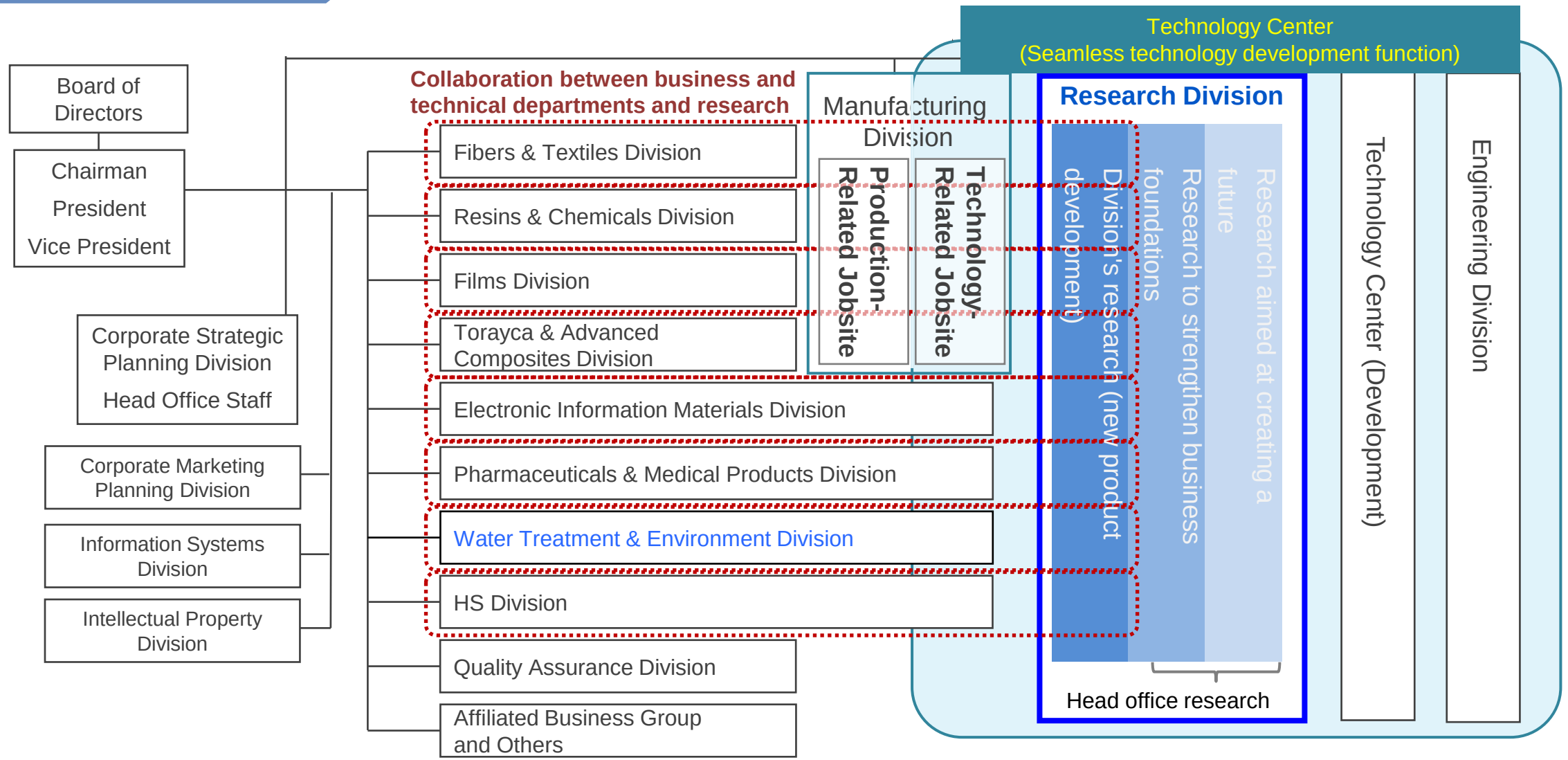
I

R&D Efforts in Water Treatment Business

R&D Structure



Promote divisional research that is integrated with each business division, as well as head office research that looks ahead to the future from a business and company-wide perspective

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Toray's separation membrane-related products and technologies

Medical products

Artificial kidneys

Adsorption column

Biopharmaceutical separation membrane

Water treatment

Seawater desalination

Brackish water desalination

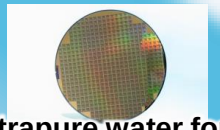
RO membrane

MBR

Torayvino™

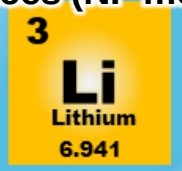
UF membrane

Ultrapure water for semiconductors



Reuse

Recovery of valuable substances (NF membrane)



Wastewater reuse

Food applications

New businesses

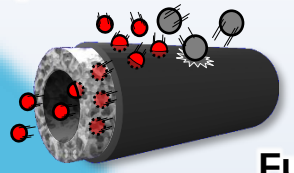
Membrane-based bio-materials

Biomass

Monomer

Polymer

All-carbon CO_2 separation membrane



Fuel cell humidifying membrane

H_2 separation membrane

Gas separator for semiconductors

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Toray's Membrane-Related Business

Water Treatment Business

Products that provides clean water, and reducing environmental impact

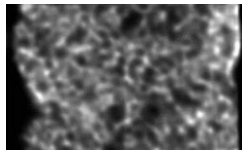
Size separation (μm)

0.001 — 0.01 — 0.1 — 1 — 10

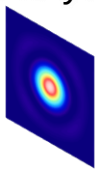
	RO	NF	UF	MBR
Target of removal	Monovalent ion Small molecule	Multivalent ion Agrochemicals and organic substances	High polymer Virus Colloid	Microorganism Turbidity component

Advanced analysis

RO pore structure

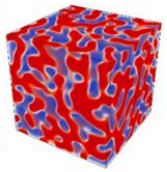


Radiant light analysis



Sub-nanoscale pore analysis

DX Control



DX Simulation to control structural factors

Module Structural Design

Hollow fiber membrane

Module design which utilizes membrane performance

Medical Products

For better medical care and hygiene for people worldwide

Innovative blood purification column

TORAYLIGHT™

FILTRYZER™

- Non-fouling artificial kidneys

FILTOREL™

- β2-MG high adsorption technology

New Businesses

Highly functional separating membranes by deepening and fusing Toray's technology

(1) Biopharmaceutical separation membrane

Water treatment × Medical products

- Inhibition of clogging
- Improving drug yield

(2) All-carbon CO_2 separation membrane

Water treatment × Carbon fiber

- High selective separation property
- High durability

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R&D Strategies of RO Membranes

1. Promote steady technological development to realize a stable water supply

(1) Expand market share of seawater desalination

Currently No.1 in Global Share

(2) Expand RO membrane business for brackish water

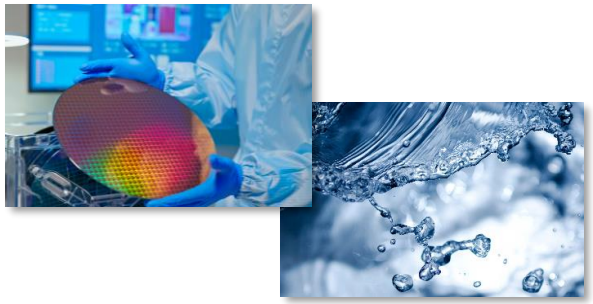
R&D Strategy

Total cost reduction through durability and water permeability improvement

Develop new products that contribute to the reduction of the use of chemicals and electricity

2. Promote upfront development, aiming for expansion in growth areas

(1) Ultrapure water for semiconductors



(2) Wastewater reuse

R&D Strategy

Improve separation property in line with client requirements

Pursue extreme removal of neutral molecules

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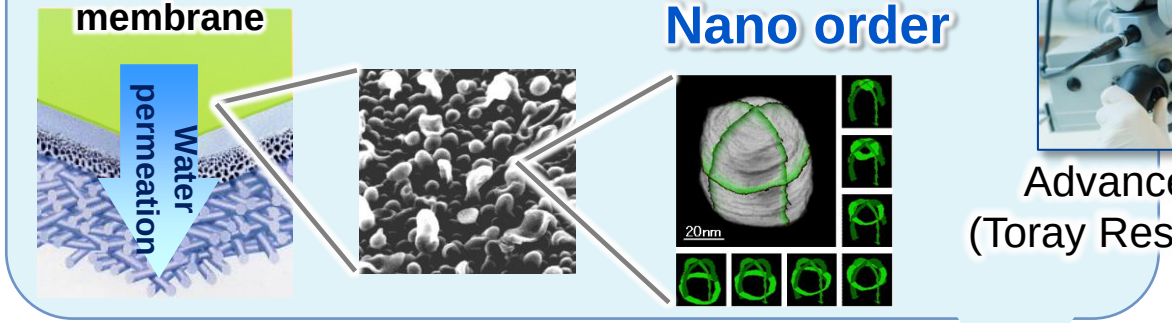
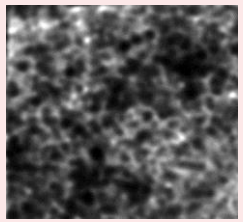
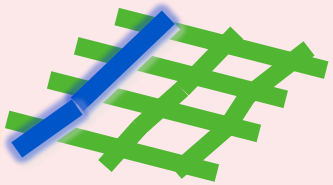
Progress of RO Membrane: Strengths of Our Membrane



Advanced analysis
(Toray Research Center)

Analysis / control of micropore structure
Sub-nano order
(World's First)

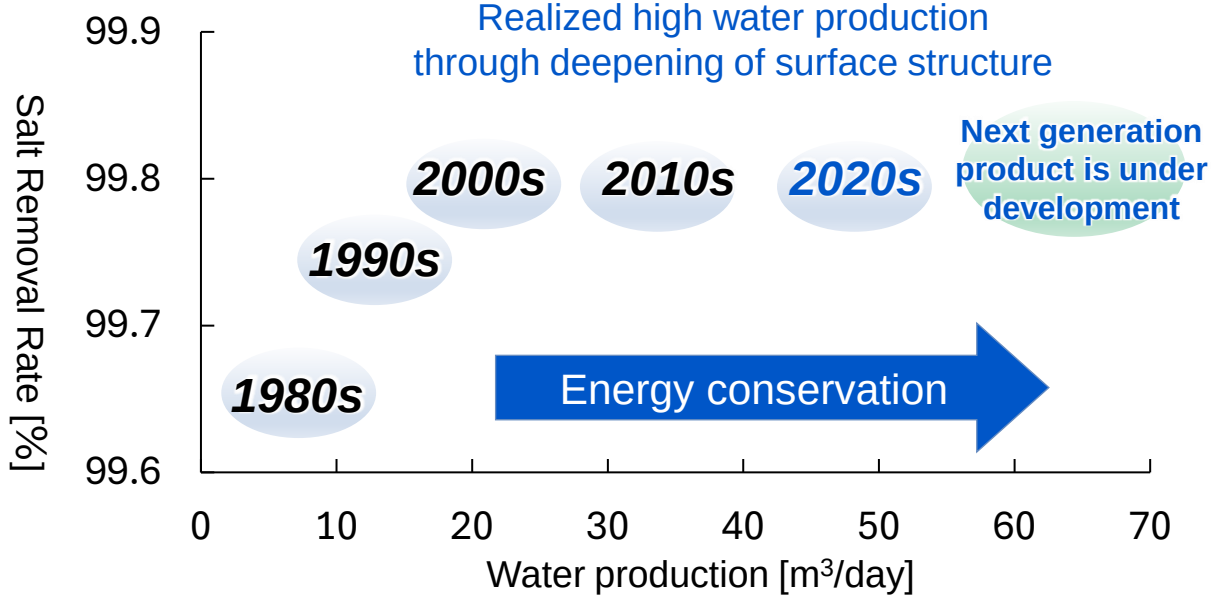




Formation of strong membrane structure (Difficult to dissolve by chemicals)

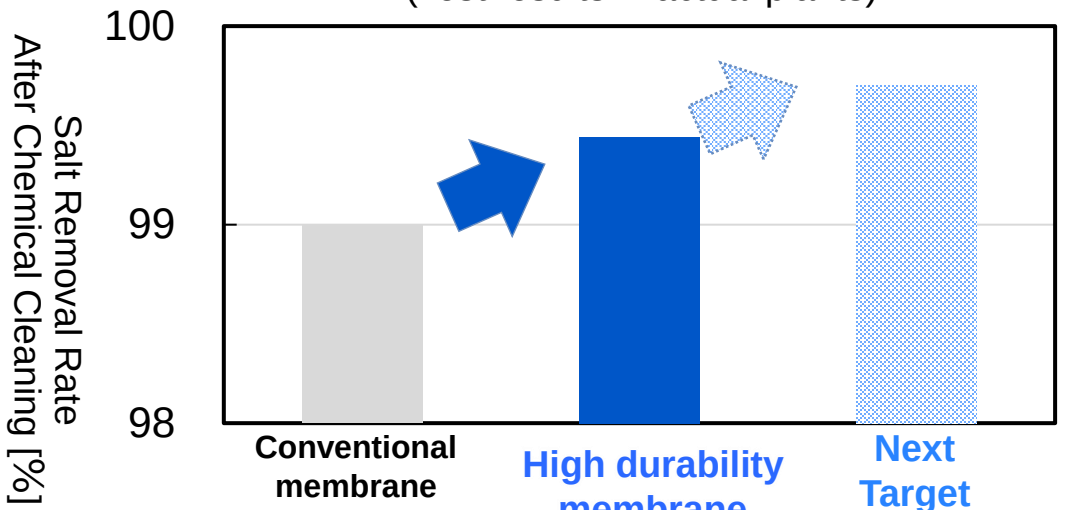
Water production

Realized high water production through deepening of surface structure



Durability

Comparison of performance after repeated cleaning using acid and alkali (Test results in actual plants)



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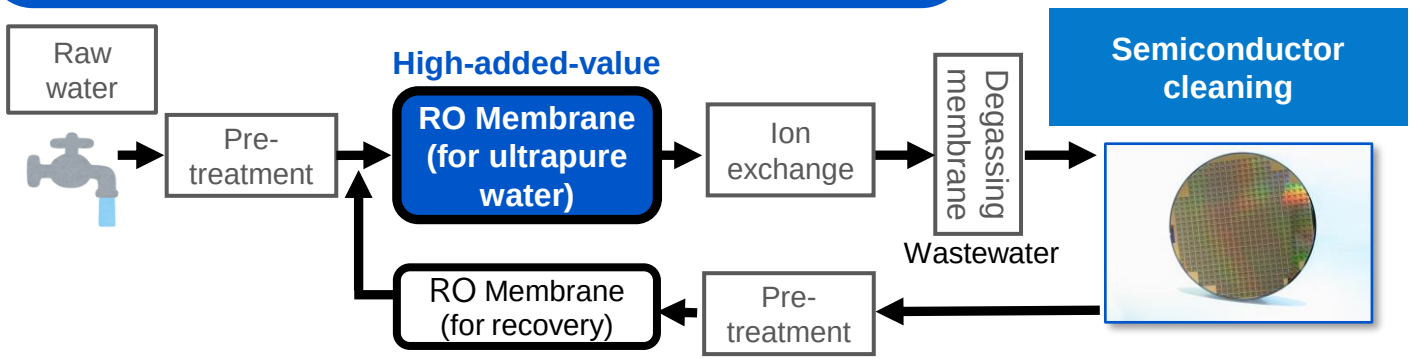
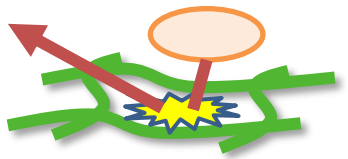
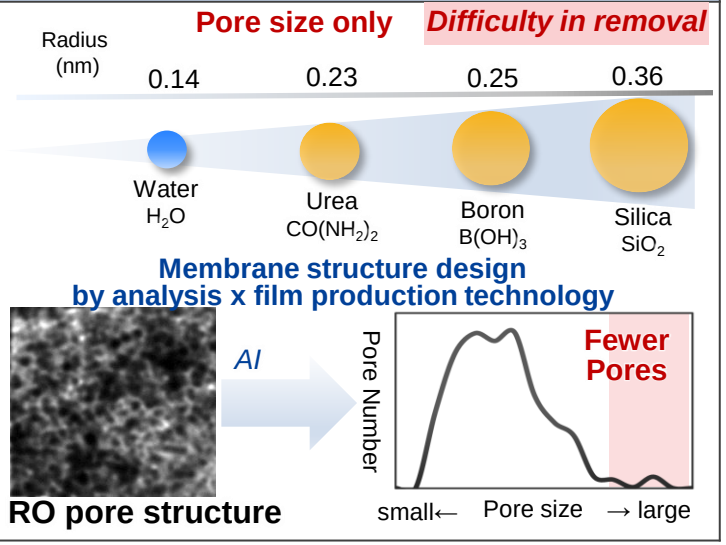
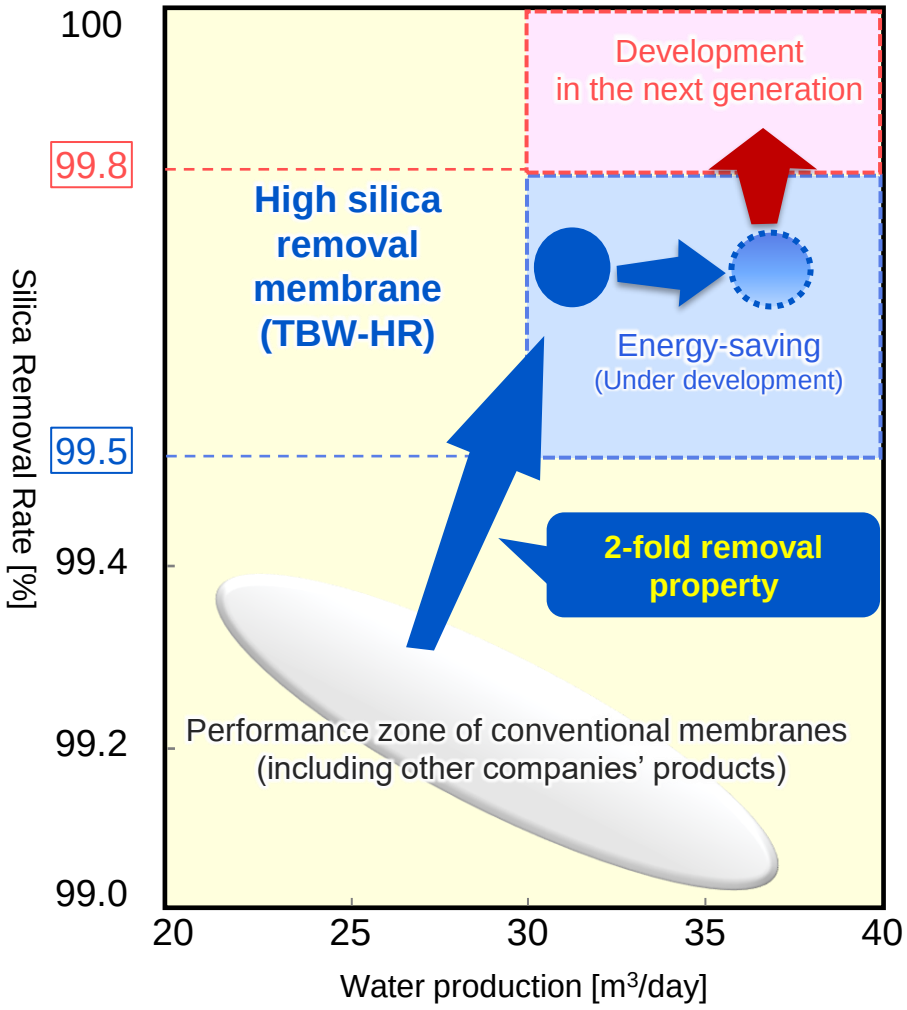
Progress of RO Membrane: High-function Products for the Semiconductor Field

Ultrapure water production process for semiconductors



Impurities	Ion (Na^+, SO_4^{2-}, etc.)	Neutral molecule (silica, boron, urea)
Removal Mechanism	 **Separating functional layer (polyamide)** Charge repulsion + pore size	

High silica removal membrane



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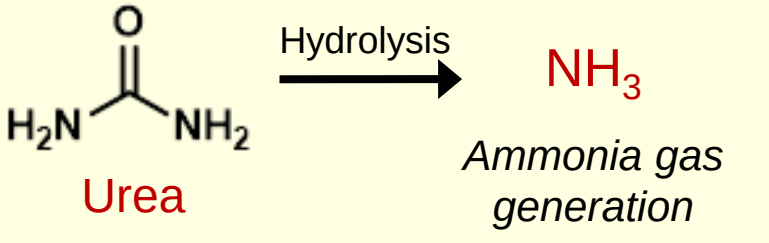
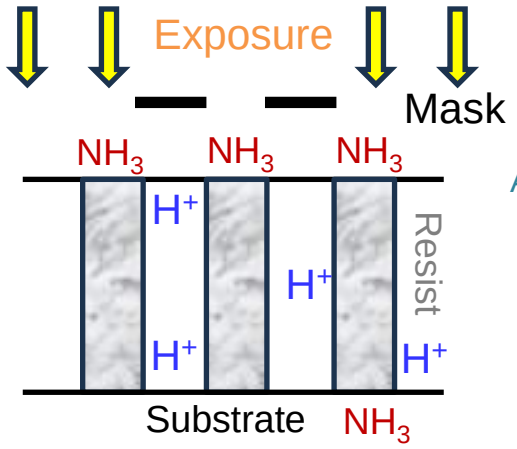
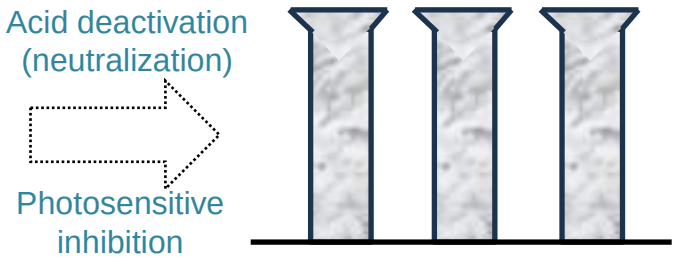
Progress of RO Membrane: New Development for the Semiconductor Field

Ultrapure water for semiconductors

- Consideration for utilization of recycled wastewater is proceeded in response to water source shortage
- **Sewage-derived urea generates ammonia by hydrolysis**



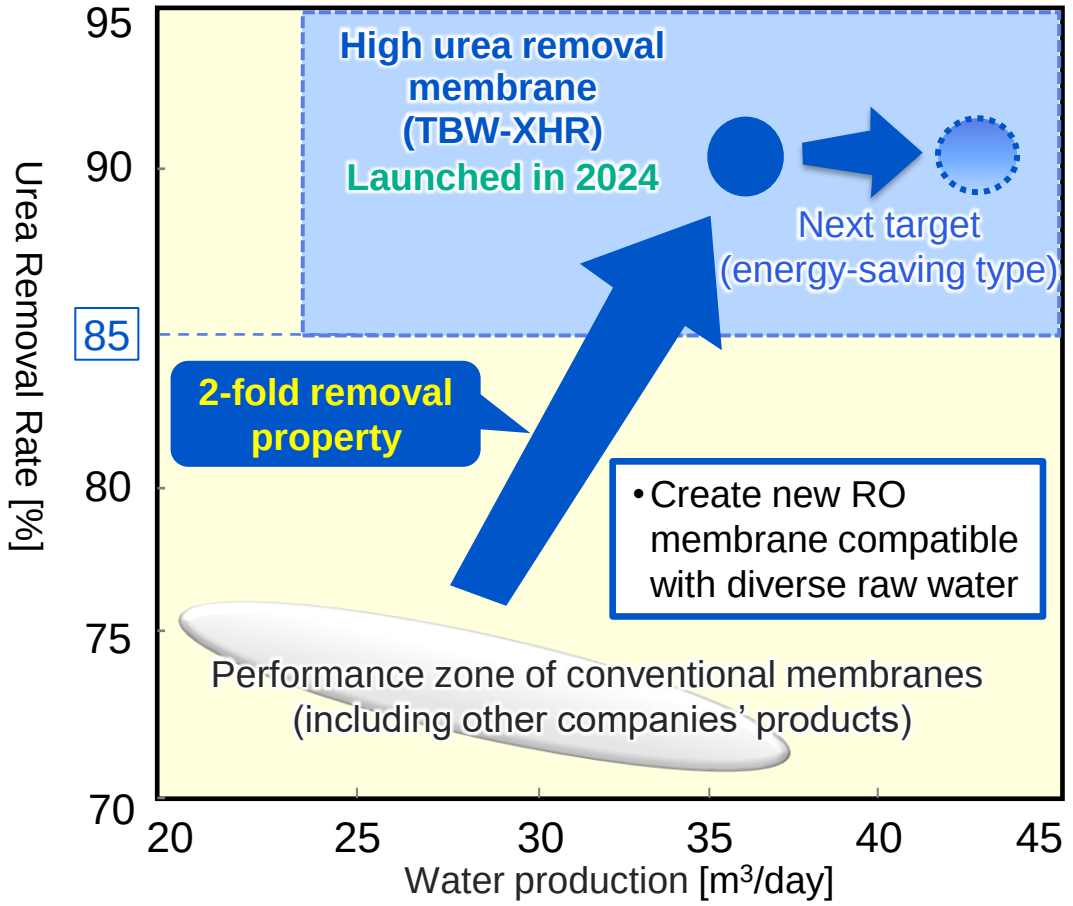




- **Adversely affect resist performance**

e.g., Pattern defect

High urea removal membrane



Launch of high urea removal membrane to contribute to the issue of water source shortage in the semiconductor field

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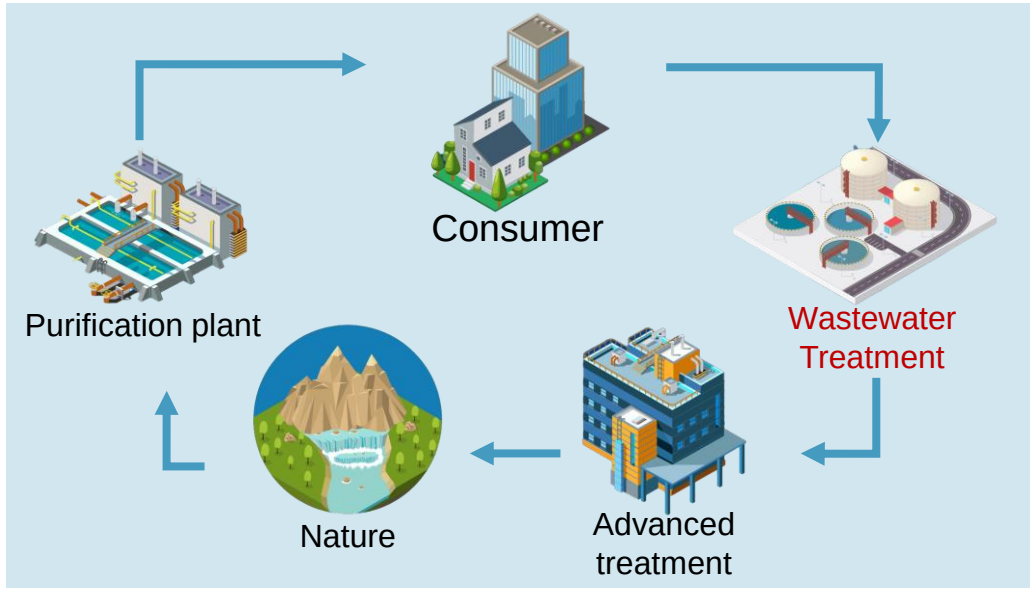
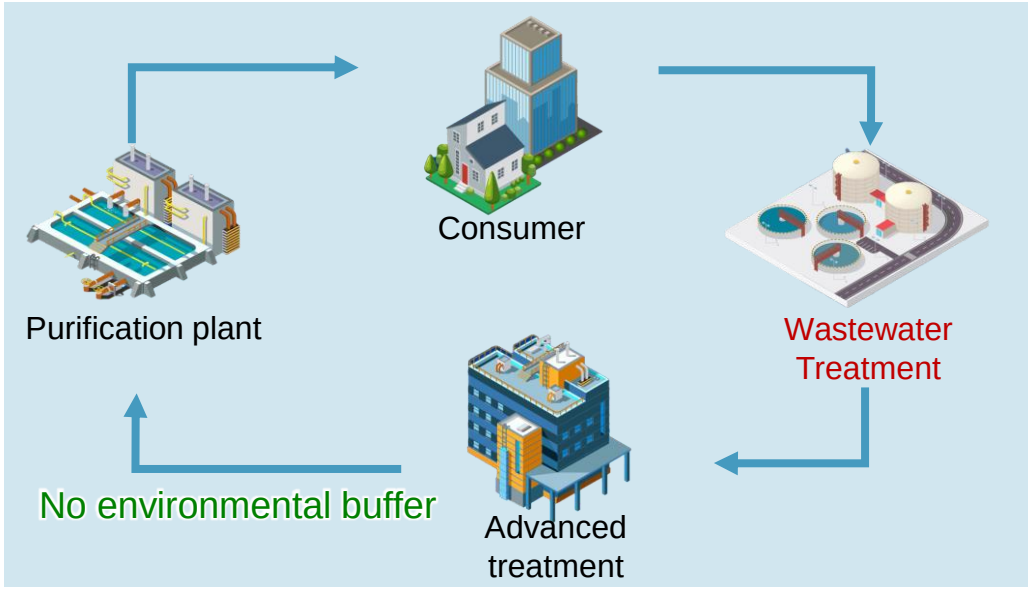
Progress of RO Membrane: Recycled Wastewater Applications

IPR: Indirect Potable Reuse



Trend in USA

DPR: Direct Potable Reuse



✓ Consumer psychology to improve safety

Contribution of Toray's membrane

San Diego Pure Water [California]

Toray's membrane is used in the project aimed for DPR

Toray RO membrane

Low water production cost, safety, and security realized by using Toray RO membrane

Toray's membrane is increasingly being used in wastewater reuse due to its high durability and high neutral molecule removal property

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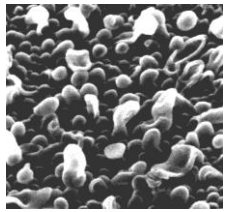
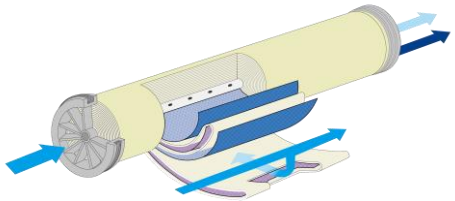
Efforts to Reduce CO_2 Through Progress in Membrane Technologies

1. Reduction of energy for operation through higher water production



Membrane structure control

×



Element structural design

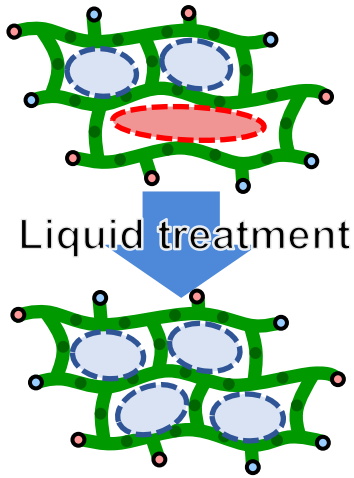
High water-making membrane element reduces pump power

Contributing to reduction of CO_2 emissions from plants

2. Reuse of RO membrane elements

Conventional membrane element flow

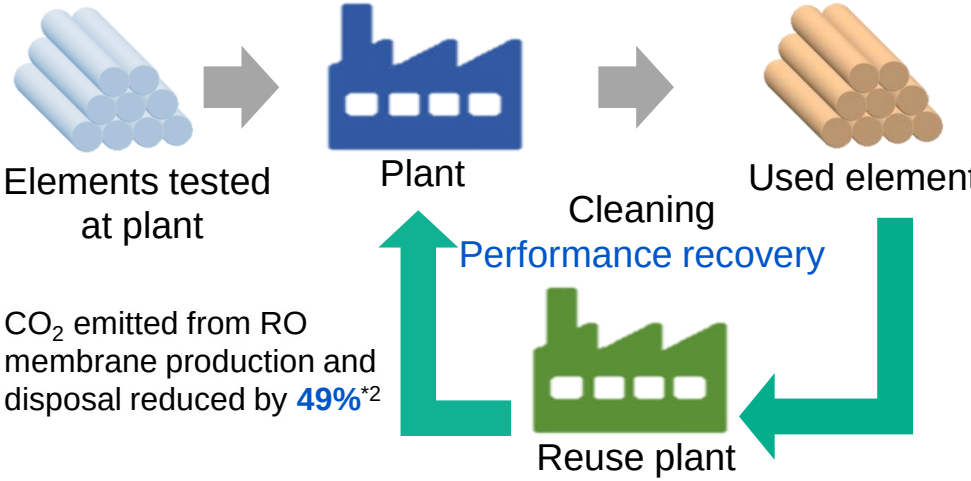
- Conventionally discarded (incinerated and reclaimed)
- Some materials are recycled



Performance recovery technology (reformation of membrane)

Toray's proprietary technology

Flow using Toray's development technology (Promoted by NEDO*1: testing at the plant)



CO_2 emitted from RO membrane production and disposal reduced by **49%***2

*1. New Energy and Industrial Technology Development Organization: an official Japanese nonprofit research and development agency that creates innovation by promoting technological development.

*2. Estimated by Toray

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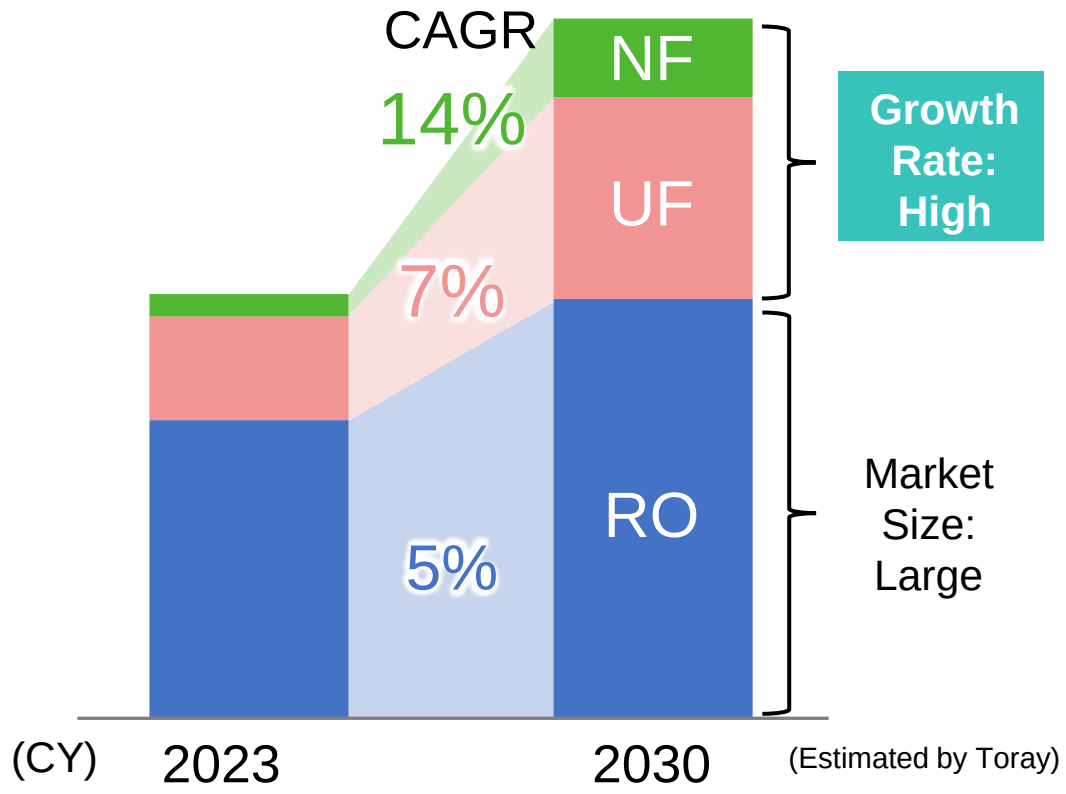
Market Growth Estimate for NF and UF Membrane Modules

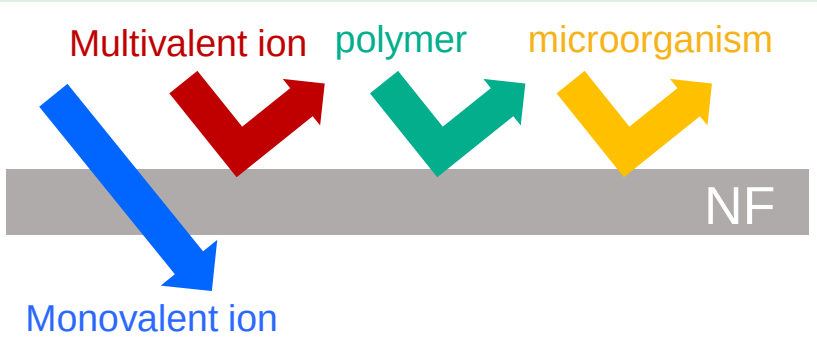
Relative market size

NF : Growing demand for valuable metals due to expansion of LIB market

UF : Potential market for which existing membrane does not work

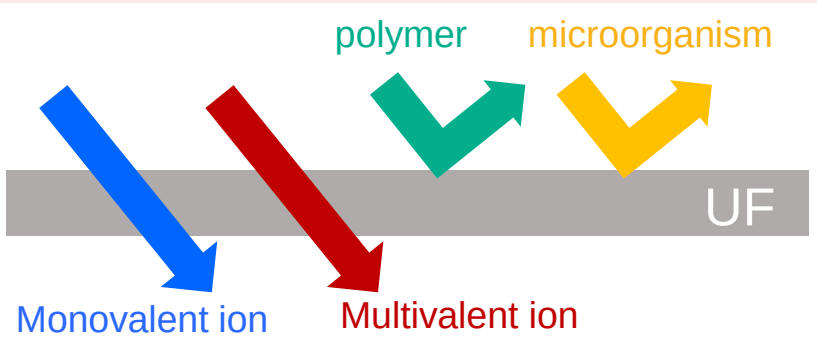


NF membrane



Application: Softening water, removal of organic matter

UF membrane



Applications: Potable water, industrial water

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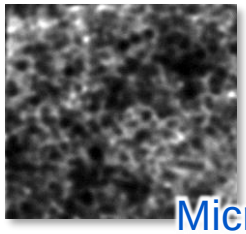
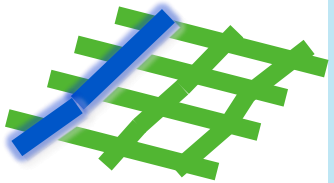
R&D Strategies for NF and UF Membrane Modules

NF membrane

Fusion of RO technologies





Micropores,
molecular structure control

New NF membrane

Compared with conventional membrane

- 1.5 times greater selectivity
- 2 times greater pressure resistance
- 5 times greater acid resistance

Higher added value

Growth Field

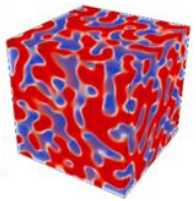
Recovery of valuable metals

From hypersaline lakes

From waste batteries

UF Membrane

Progress of characteristics



Phase separation control
Module structure design

New UF membrane

- High strength and long life
- High permeability x high removal
- High heat resistance: 125˚C

Higher added value

Growth Field

Wastewater reuse

Creation of high removal UF membrane

Food applications

Technology for high turbidity and viscosity, high heat resistance

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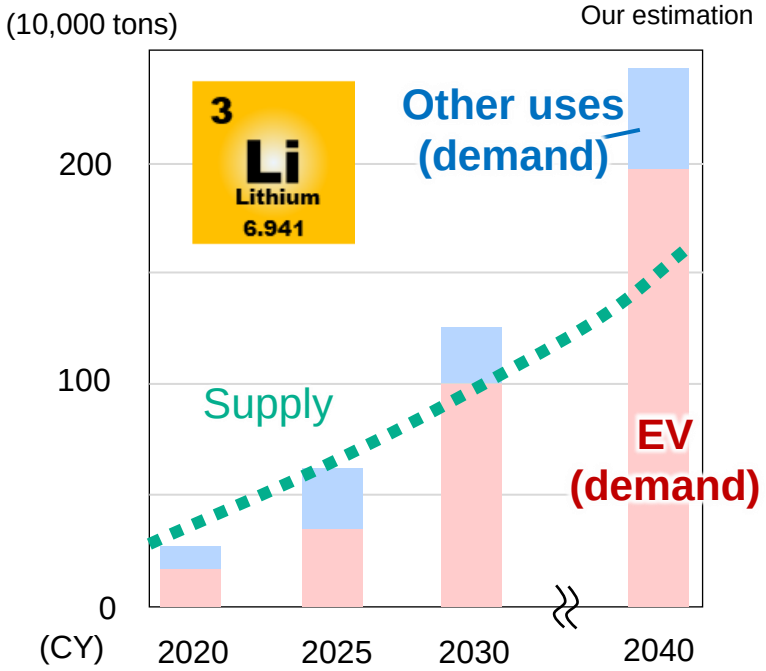
New Development of NF Membrane: Recovery of Valuable Metals

■ **Developed lithium-recovery technology using separation membranes in response to the increasing demand for electric vehicles (EV) and accumulators**

Demand and supply outlook for lithium

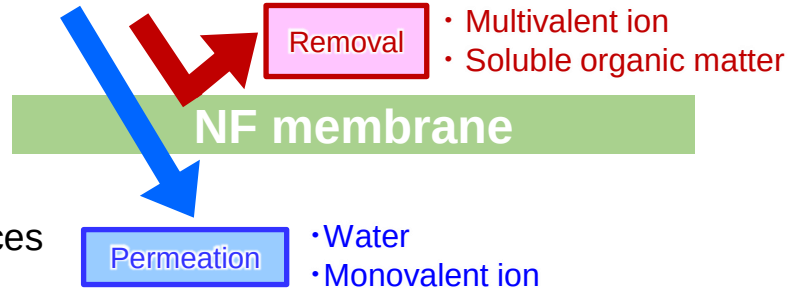


- Rapid expansion of LIB market in line with the spread of EV
- In the long-term, demand is expected to exceed supply

Lithium-recovery technology with NF membranes

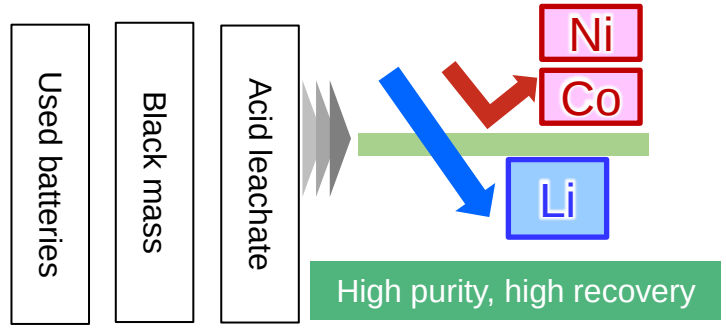
NF characteristics

- Monovalent and polyvalent ion selective separation property
- Low energy consumption



Conventional use

- Softening water
- Removal of hazardous substances

	Salt lake	Waste batteries
Conventional	Concentration by solar evaporation ⇒ **Low productivity**	Multi-step purification process ⇒ **Low recovery rate**
Membrane application	Extraction of lithium from salt lake water	Lithium extracted from acid leachate
Image	 Salt lake	
	High productivity (Several days)	High purity, high recovery

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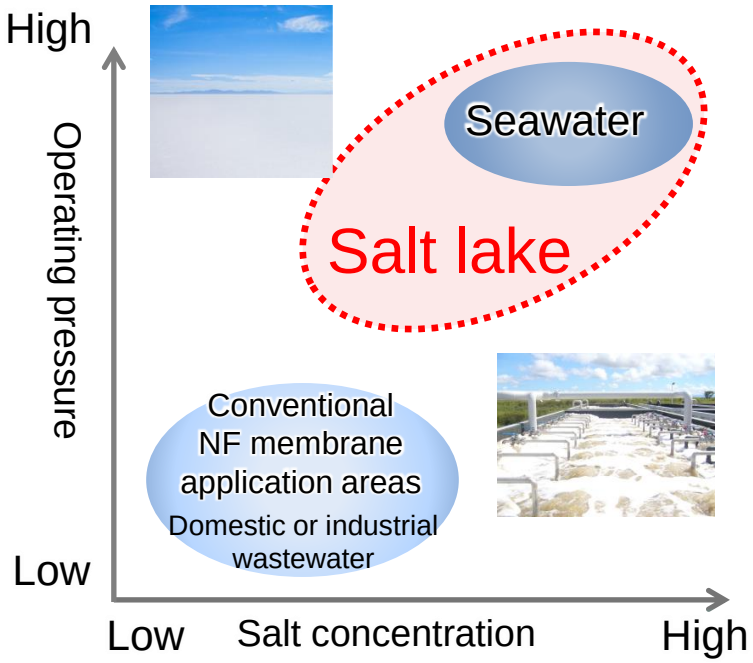
New Development of NF Membrane: Lithium Recovery from Salt Lakes

■ Developed a pressure-resistant NF membrane suitable for lithium-recovery process from salt lakes which requires high-pressure operation

Characteristics of salt lakes

- High salt levels of the total concentration 0.5g/L or higher
- Water quality varies from salt lake origin (e.g. sea salt and geology)



Required characteristics

- High-pressure operation at seawater level
- Lithium selection property from impurities

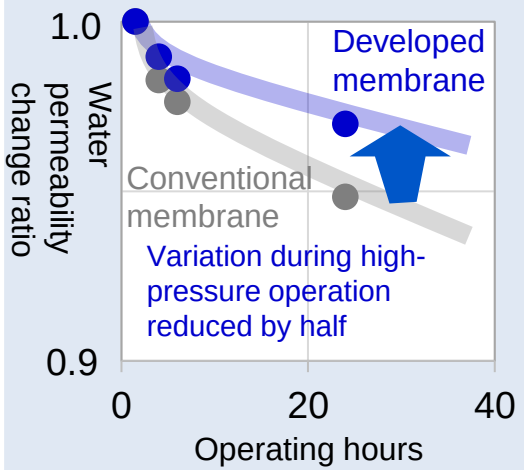
Enhanced function of NF membrane for salt lakes

Development technology

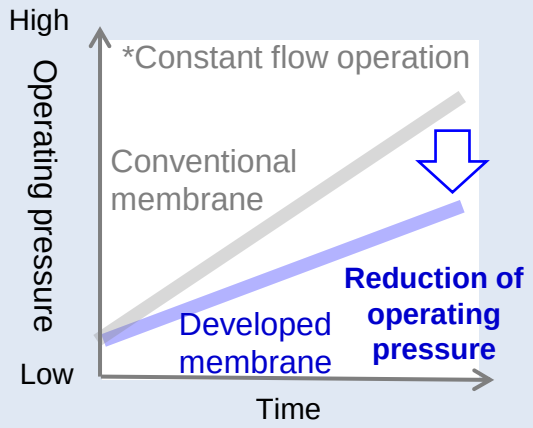
Development of seawater desalination technology

Membrane and element designs operable in high-pressure + Pore structure control for selective permeation of lithium

Improvement in performance



Value to be realized



Contribute to energy conservation

- Mitigate reduction of water production in high-pressure operation
- Sales started in 2024 by establishing mass production technology

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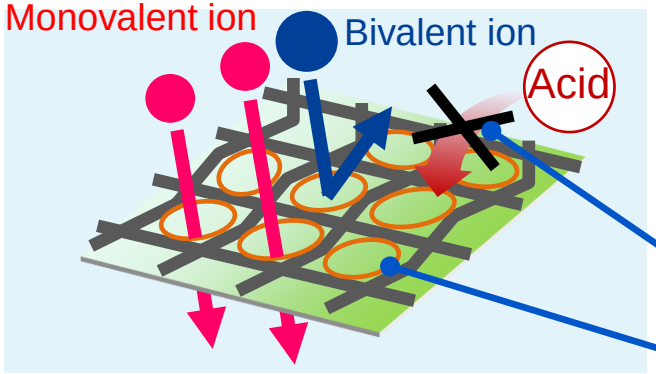
New Development of NF Membranes: Lithium Recovery from Waste Cells

■ **Creation of new NF membranes with improved acid resistance and selective separation property**
Lithium recovery from waste cells using membrane technology

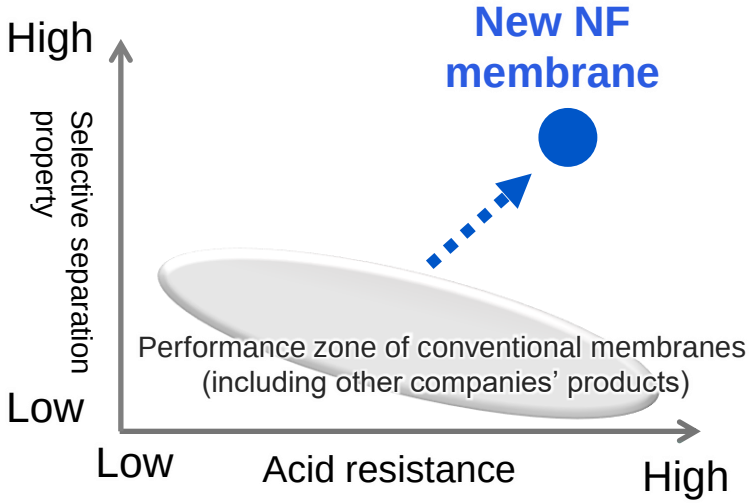
New NF membrane



Precise design based on molecular dynamics calculations

Inhibition of reaction with acid

Uniform pore size



Recovery of high-purity lithium from acid leachate containing metal (membrane life: approx. 1 year) *

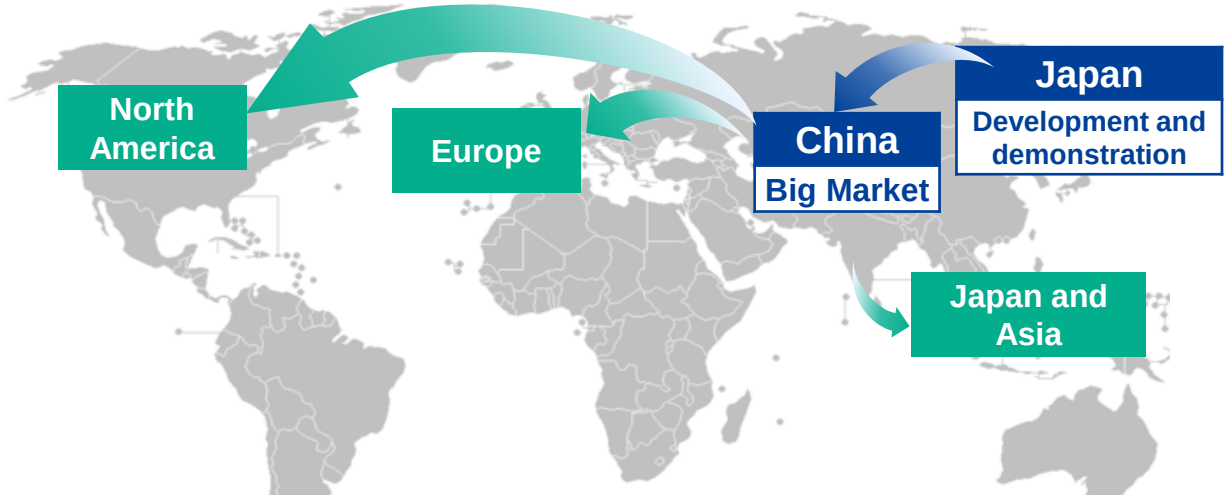
*Estimated by Toray

Business strategy

Current A new membrane and process are being developed and demonstrated using actual liquid
(Commissioned by Ministry of the Environment: Low-carbon 3R technology and system demonstration project)

Future Expansion to China, where waste cells are expected to be generated at an early stage. In the next step, expansion to North America, Europe, as well as Japan and Asia

(2) Expand business based on results in China **(1) Early business development**



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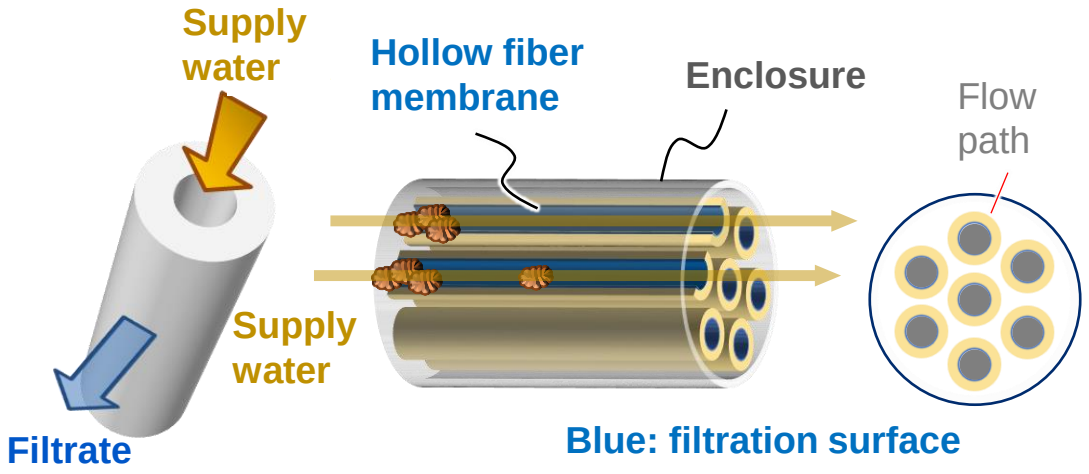
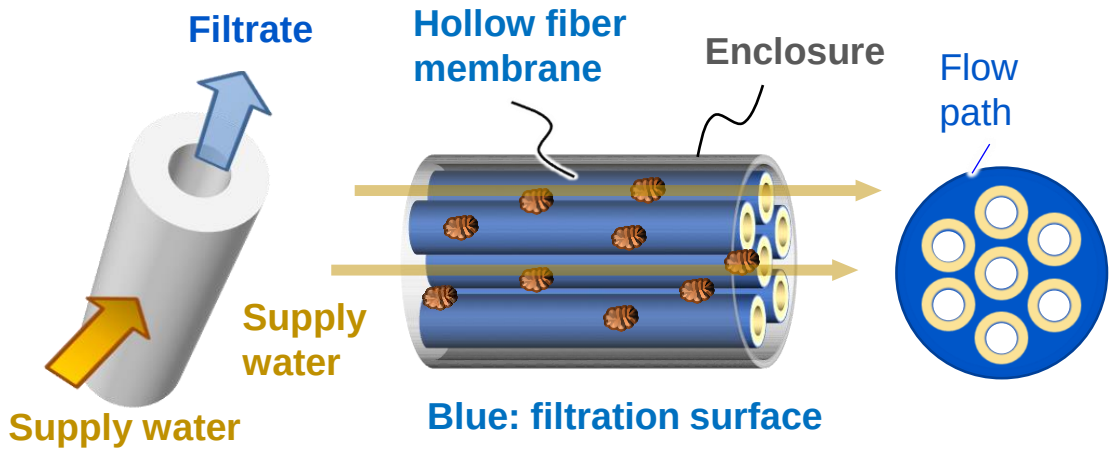
Characteristics and New Development of Toray's UF Membrane Module

Common hollow-fiber UF membrane: Internal Pressure Type



Narrow flow path unsuitable for high turbidity and high viscosity liquid

Toray's UF membrane: External Pressure Type



Wide flow path: Advantage for high turbidity and viscosity liquid

Conventional use:

Potable and industrial water production

Creation of high-value-added products

Expansion into growth business fields

(1) High removal UF membrane (for wastewater reuse)

- Technology for pore size refinement + increasing number of pores
- Reduction of membrane replacement costs and CO_2

(2) Food separation membrane module

- Excellent in high viscosity and turbidity filtration
- Our method: filtration is carried out using heat-sterilized membrane. CO_2 emissions are reduced compared with the conventional constant heat sterilization

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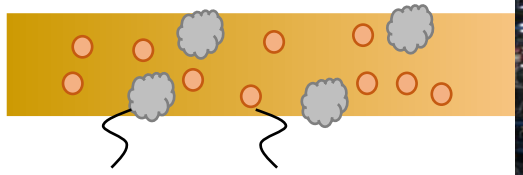
New Development of UF Membrane Modules (1) : High Removal UF

■ **Control of fine pores to remove pollutants**
Reduce CO_2 emissions associated with RO membrane replacement and disposal by 30% or more

Wastewater



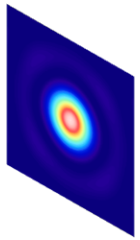
Suspended Solids　Bio polymers

UF Membranes

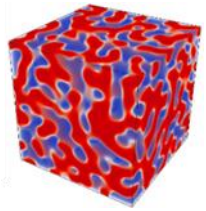
RO Membranes

Potable, industrial and agricultural water, etc.

Analysis and design of pore formation process



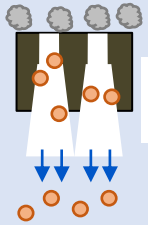
Direct observations on SPring-8*.



Simulation by computational science

Precise control of materials and processes

Conventional

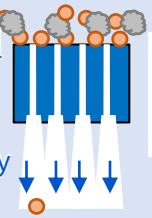


Removal rate 50-75%

Pore size refinement + increase in pore number

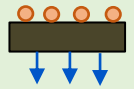
High removal UF

High removal
High permeability

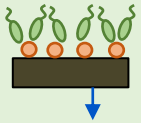


Removal rate 90%

Biopolymer Adherence



Biofouling

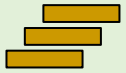


Decreased water permeability

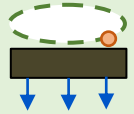
Acid and alkali cleaning

e.g. 350 ton/ year

Membrane replacement



e.g. 20 million yen/year



Maintaining permeability

Acids and alkalis can be reduced 60% or more

30% reduction in membrane replacement

* Large synchrotron radiation facility with the highest performance in the world

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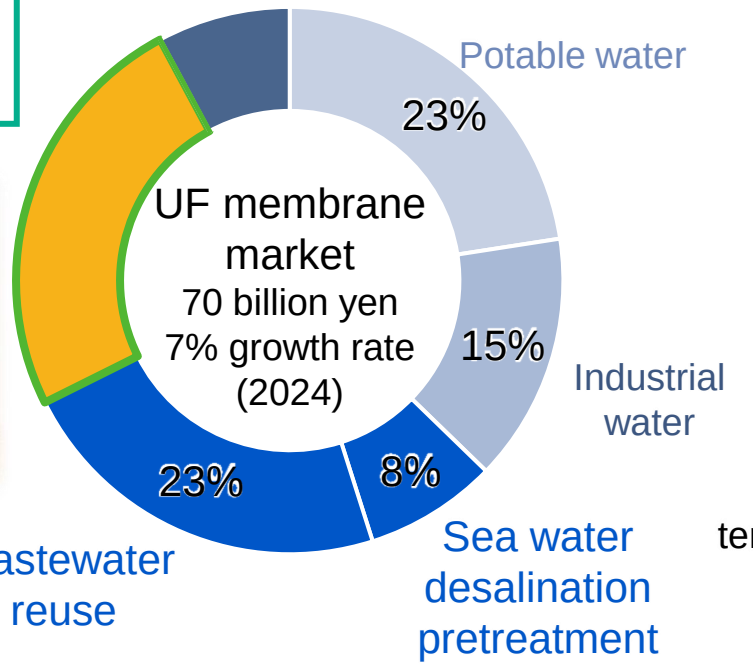
New Development of UF Membrane Modules (2) :Separation Membrane for Food

■ **Marketing of external pressure type separation membrane for food products excellent in high turbidity and high viscosity liquid filtration. Deployment in new fields to help reduce CO_2**

Share of hollow fiber UF membranes by application

- Food manufacturing:
  High-value-added application, large potential markets

Food 25%

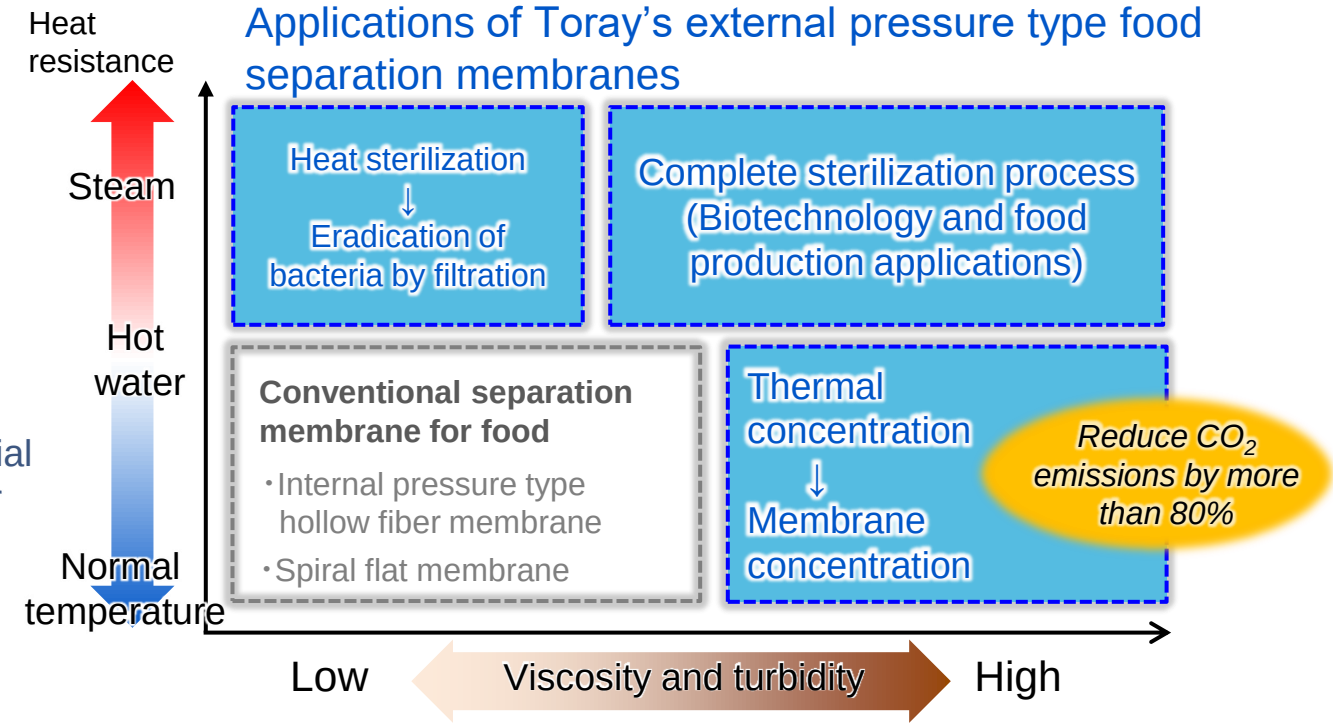


External pressure type food separation membranes

Expand into new market for which existing membrane does not work


Health foods, etc.

Applications of Toray's external pressure type food separation membranes



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II

New Development of Separation Membrane Technology

Toray's Membrane-Related Business

Water Treatment Business

Products that provides clean water, and reducing environmental impact

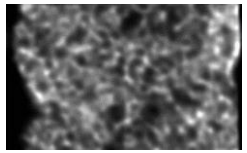
Size separation (μm)

0.001 — 0.01 — 0.1 — 1 — 10

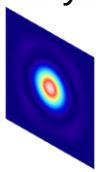
	RO	NF	UF	MBR
Target of removal	Monovalent ion Small molecule	Multivalent ion Agrochemicals and organic substances	High polymer Virus Colloid	Microorganism Turbidity component

Advanced analysis

RO pore structure

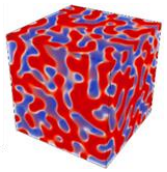


Radiant light analysis



Sub-nanoscale pore analysis

DX Control



DX Simulation to control structural factors

Module Structural Design

Hollow fiber membrane

Module design which utilizes membrane performance

Medical Products

For better medical care and hygiene for people worldwide

Innovative blood purification column

TORAYLIGHT™

FILTRYZER™

- Non-fouling artificial kidneys

FILTOREL™

- β2-MG high adsorption technology

New Businesses

Highly functional separating membranes by deepening and fusing Toray's technology

(1) Biopharmaceutical separation membrane

Water treatment × Medical products

- Inhibition of clogging
- Improving drug yield

(2) All-carbon CO_2 separation membrane

Water treatment × Carbon fiber

- High selective separation property
- High durability

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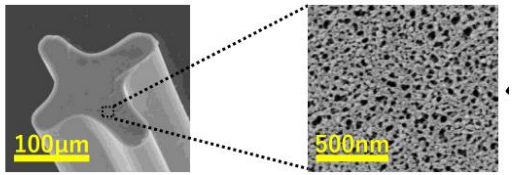
Development of Separation Membrane Products in the Medical Products Market

PMMA Artificial kidneys

(1) High-efficiency protein adsorption



Stereocomplex formation
Proprietary nanopore fiber

FILTRYZER™ (1977-)

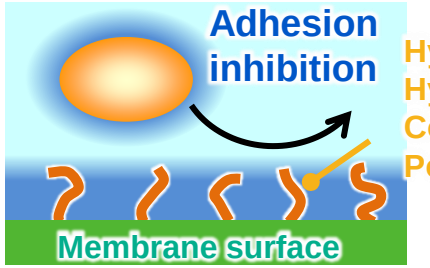
Adsorption removal of uremic toxins

FILTOREL™ (Full-scale sale 2023-)

Nanopore fiber
Pathogenesis protein adsorption

Polysulfone Artificial kidneys

(2) Nonfouling technology (Blockage inhibition)



Hydrophilic/ Hydrophobic Control Polymers

TORAYLIGHT™ NV (2011-)

Constraining reduction of blood pressure during dialysis

Adsorption column

(3) Innovative composite spinning

Sea-island composite fiber using NANODESIGN™ techniques

TORAYMYXIN™ (1994-)

Elimination of endotoxin in the blood
Treatment of sepsis

Next-generation high-value-added products (under development)

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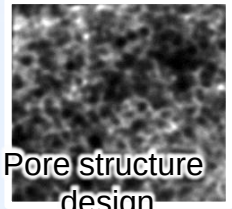
Initiatives in New Areas

■ **Developing new innovative separation membrane through the integration of Toray's specific technology based on water treatment**

Water treatment

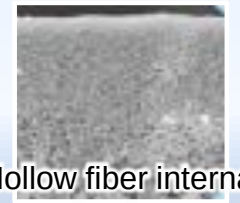
- **Precise control of pore size**



Pore structure design

Advanced analysis (Toray Research Center)

- **Phase separation control**

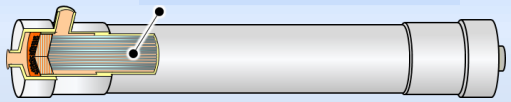


Hollow fiber internal structure

DX

- **Modular technology**

Hollow fiber



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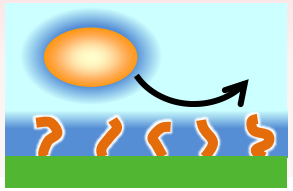
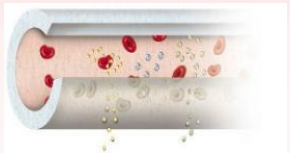
Medical Products

Nonfouling technology

Control of membrane surface hydrophilicity / hydrophobicity using computational science





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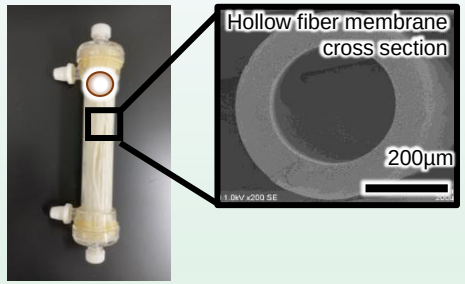
Carbon fiber

Toray's original carbon fiber molding technology

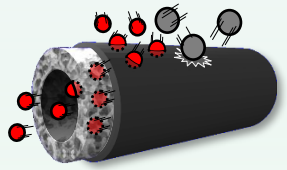
(1) Biopharmaceutical separation membrane

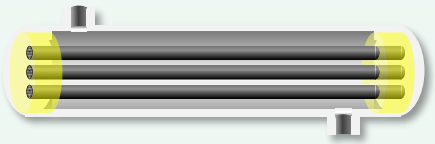


By controlling pore size and reforming the surface, reduce clogging and recovery loss of active ingredients

(2) All-carbon CO_2 separation membrane

World's first porous carbon fiber





Achieves both high selective separation property and high durability

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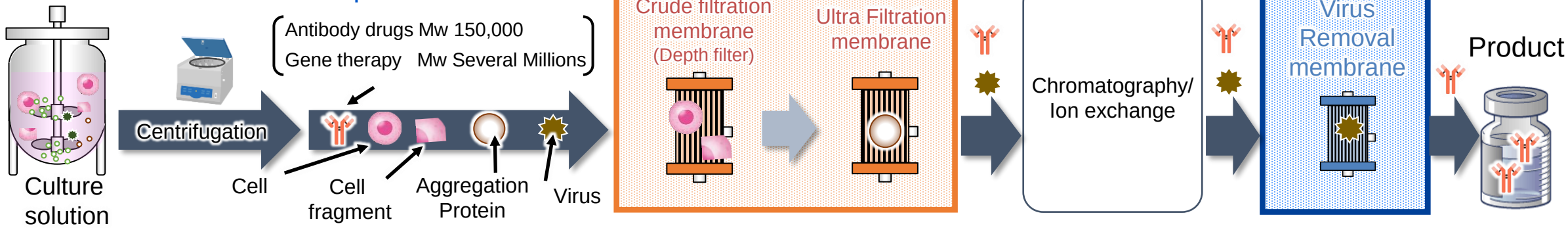
Initiatives in New Areas (1): Biopharmaceutical Separation Membranes / Background and Characteristics of Technology

■ **Issue in biopharmaceuticals* : Loss caused by clogging of separation membranes during the purification process**
⇨ **High price of drugs**

* Antibody drugs, gene therapy

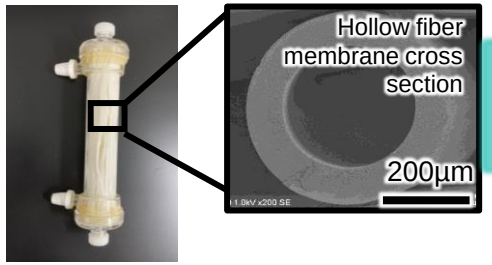
Process outline

Scheduled to start sales in FY 2025



Water treatment

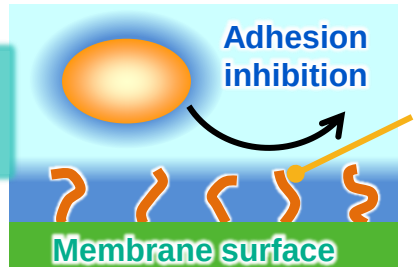
Pore size control technology
(Improved separation performance)



Technology fusion

Medical Products

Non-fouling technology (blockage control)



Solving issues by using Toray's membrane

◇ **Reduction of clogging and recovery loss**
⇨ **continuous filtration; quality stabilization; cost reduction**

◇ **Contribute to miniaturization of manufacturing processes**

Evaluation in collaboration with users is underway

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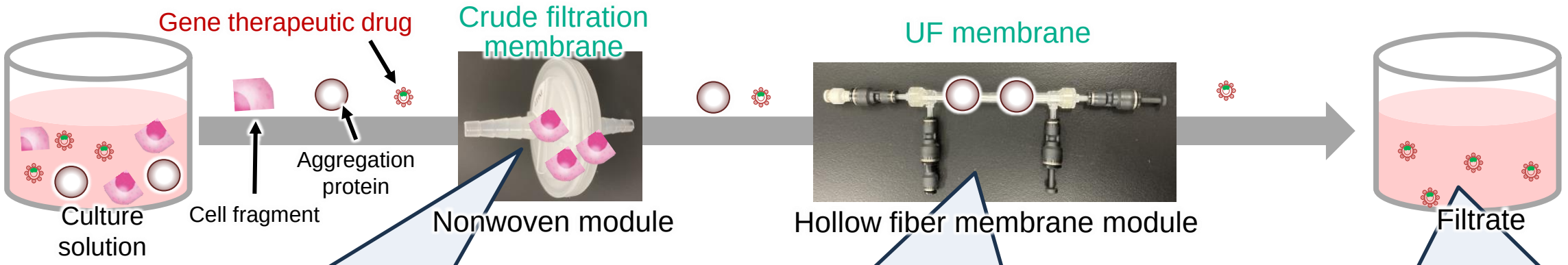
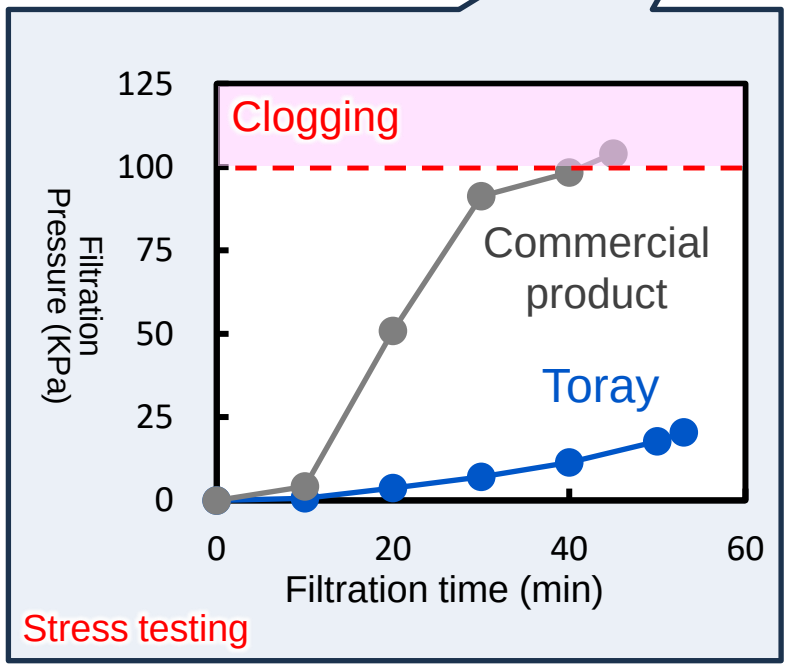
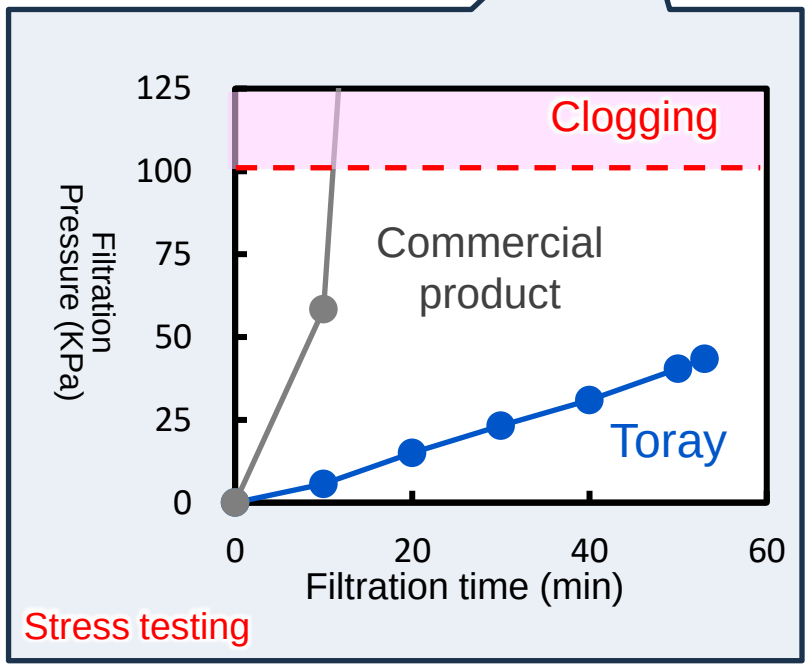
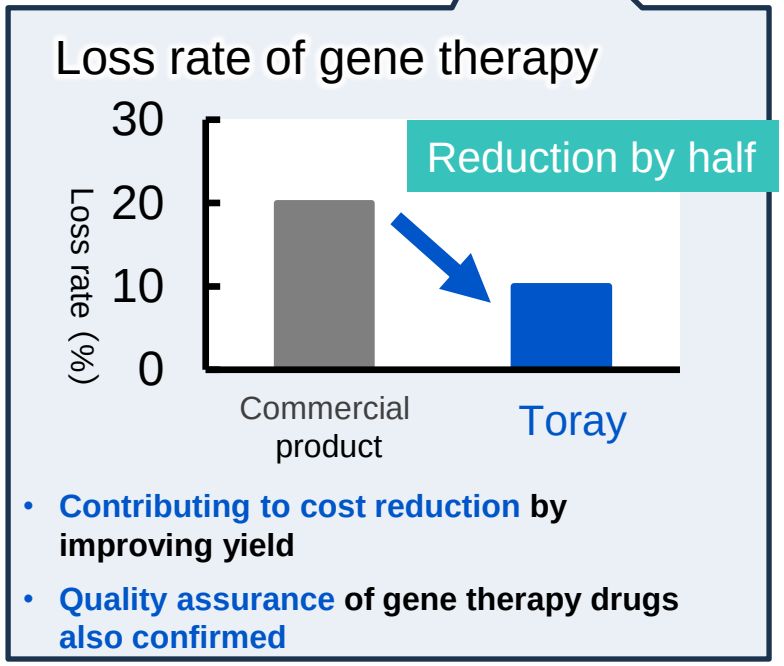
Initiatives in New Areas (1): Biopharmaceutical Separation Membranes /Property of Toray's membrane









The continuous filtration time can be prolonged by more than 2-fold

Loss ratio reduced by half

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Initiatives in New Areas (2): All-Carbon CO_2 Separation Membrane / Description

Technology characteristics

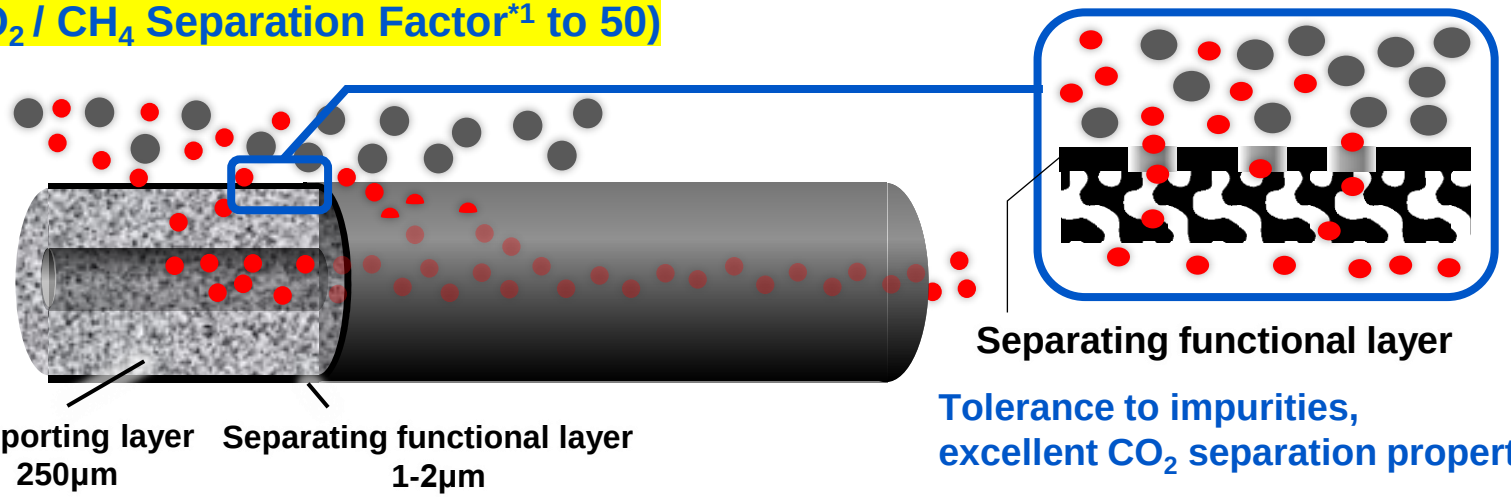

Water treatment

×


Carbon fiber

Screening by the size of the gas molecule (CO_2 / CH_4 Separation Factor*1 to 50)

*1.Ratio of permeability of gases



Tolerance to impurities, excellent CO_2 separation property

Natural gas (CO_2 / CH_4 Separation)

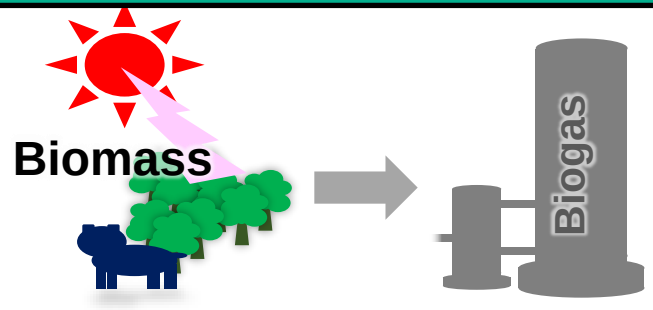
CO_2 Emissions*2

*2: coal=100

Coal	Oil	Natural gas
100	80	57

Core energy sources with low CO_2 emissions during combustion

Biogas (CO_2 / CH_4 Separation)



Environmentally-friendly clean energy

CO_2 recovery (CO_2 / N_2 Separation)

CO_2 emissions: 990 million tons (2021)

Thermal Power Plant etc.

Separation and collection of CO_2 is required

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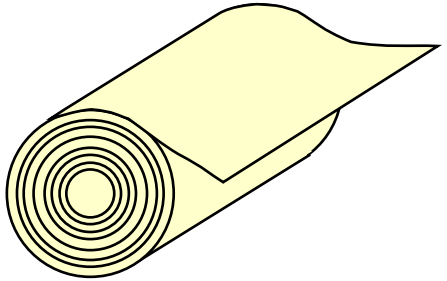
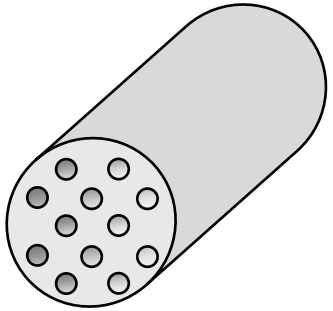
Initiatives in New Areas (2) : All-Carbon CO_2 Separation Membrane / Characteristics

Comparison of CO_2 / CH_4 separation membranes	Polymer membrane	Ceramic membrane	All-carbon CO_2 separation membrane
			
Heat and chemical resistance	△	○	○
Gas separation volume (per module)	○	△	○
CO_2 / CH_4 separation factor	△	○	○

New membrane with high heat and chemical resistance and excellent gas separation property

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Initiatives in New Areas (2): All-Carbon CO_2 Separation Membrane / Demonstration

Actual gas test

*Steam and aromatic compounds

Toray's Tokai Plant Biogas

Fermentation

Natural-gas-like impurity*

Process waste liquid

Biogas (CH_4 / CO_2)

Energy Use

Branch duct

Potting resin

Container

CO_2separator

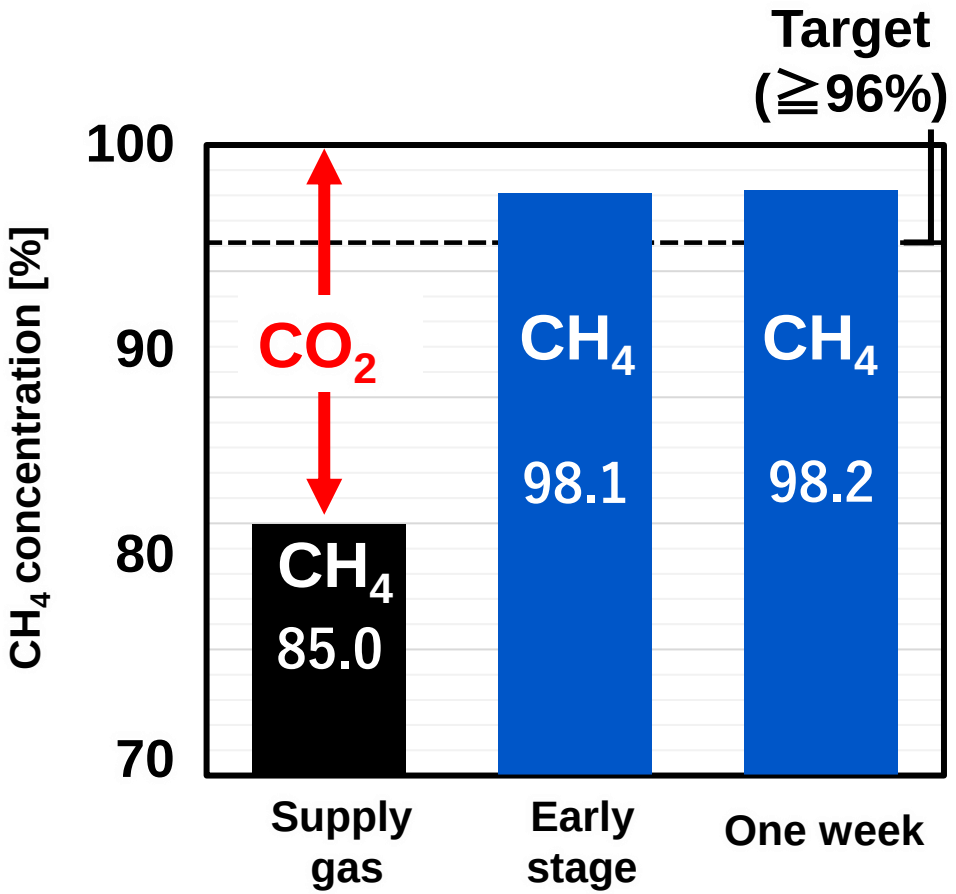
Similar structure to existing membranes

Membrane element

CO_2

CH_4

Membrane separation



Confirmed stable CH_4 refining for one week using real gas

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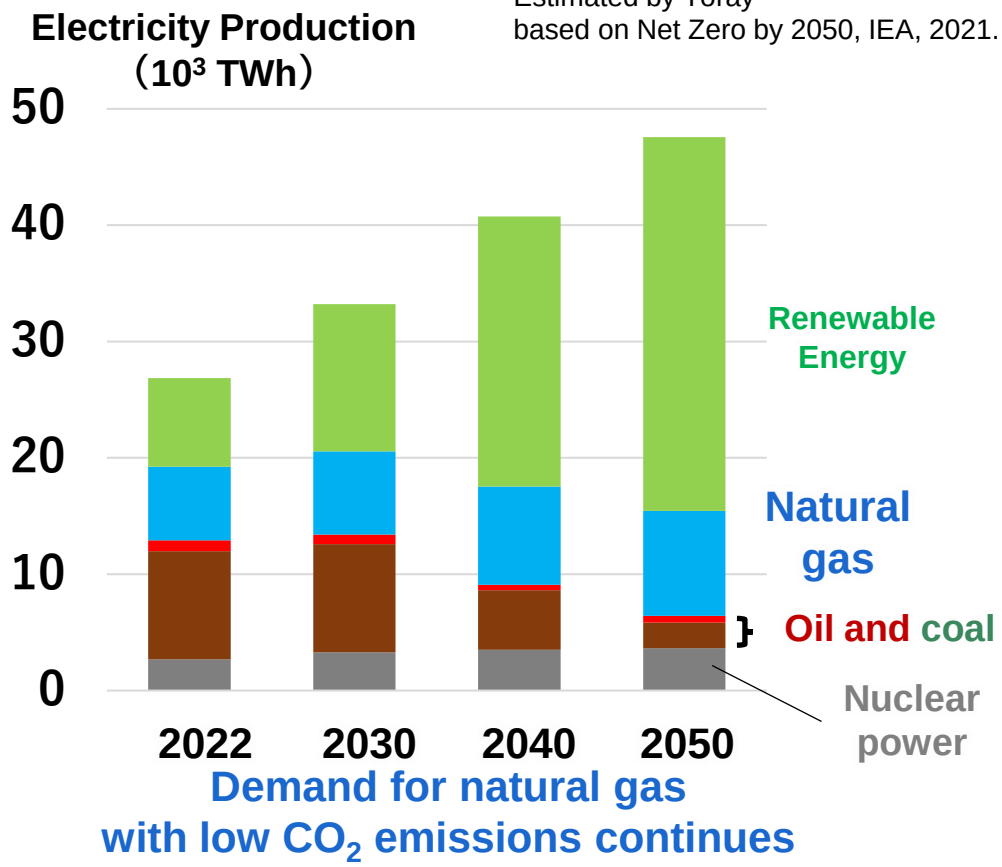
Initiatives in New Areas (2): All-Carbon CO_2 Separation Membrane / Brief Summery of Natural Gas Field

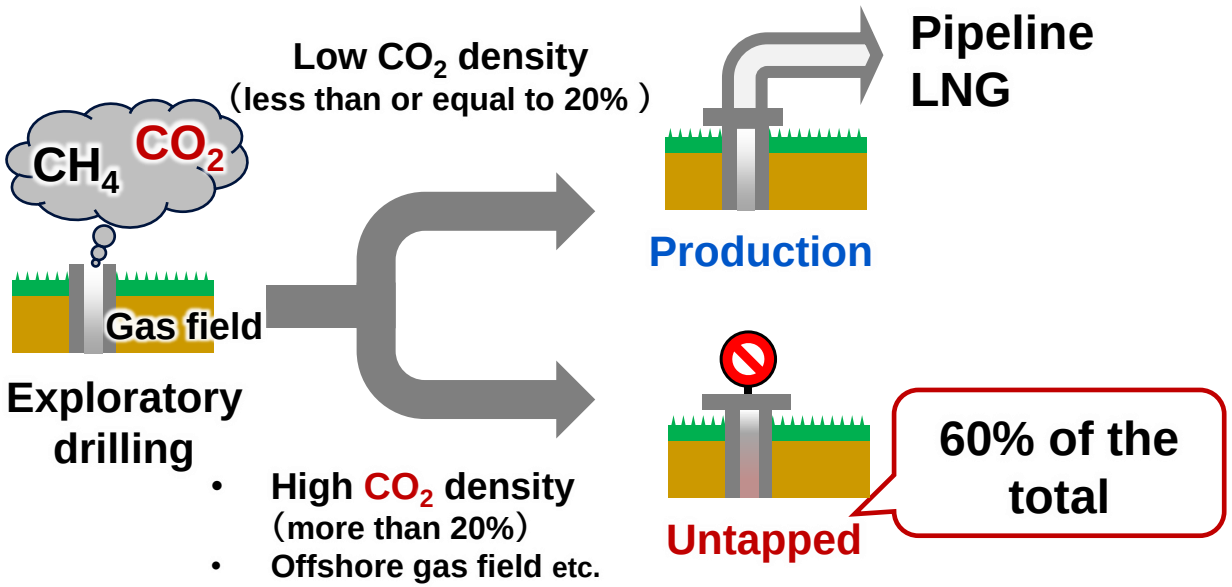
Energy demand outlook

Estimated by Toray
based on Net Zero by 2050, IEA, 2021.



Demand for natural gas with low CO_2 emissions continues

Status of Natural gas field development



- High CO_2 density
  （more than 20%）
- Offshore gas field etc.

- **High CO_2 density gas fields are expensive to refine (CO_2 elimination) and remain unused**
  （Exploration cost: 3-10 billion yen per well）

Continued demand for natural gas
Developing untapped gas fields after exploration remains a challenge

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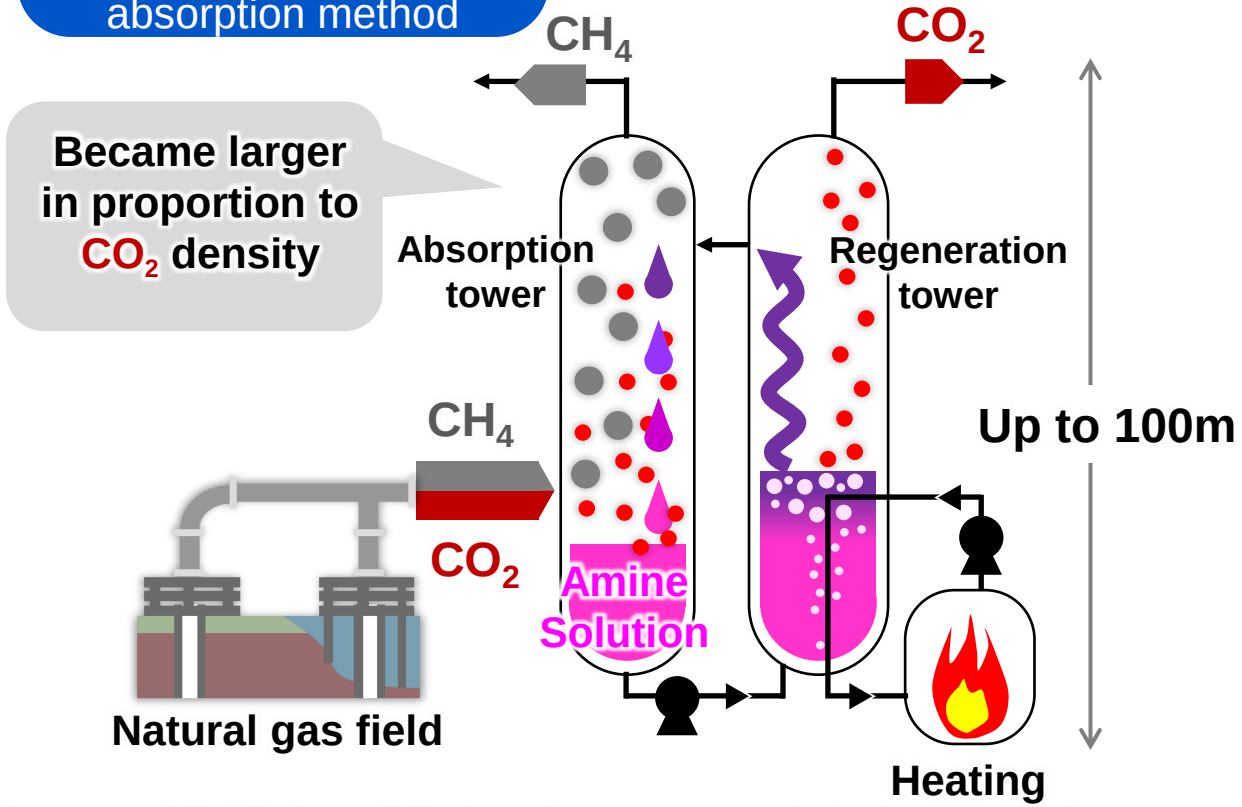
Initiatives in New Areas (2): All-Carbon CO_2 Separation Membrane / Expectations

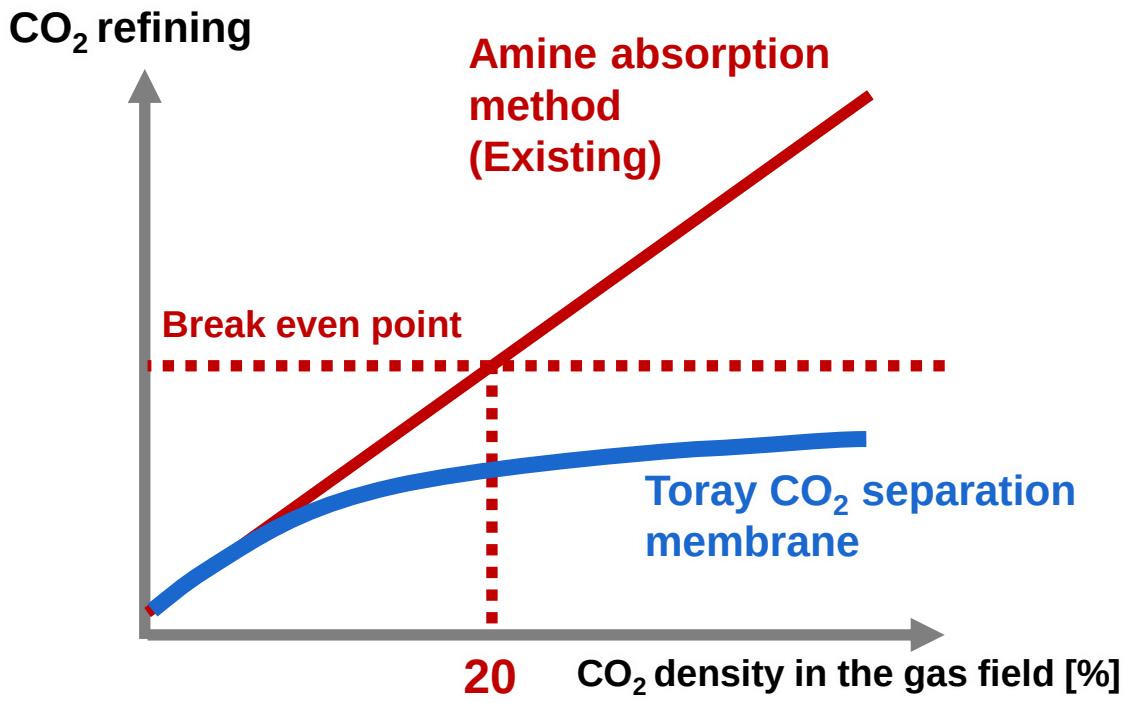
Existing amine absorption method



Issues (1) Higher CO_2 levels are associated with higher refining costs

(2) Plant size is large, while installation site is limited

Comparison of costs for natural gas refining (image)



Expand the CO_2 separation membrane to high CO_2 density gas fields where existing methods is unprofitable

With Toray's CO_2 separation membrane, untapped gas fields are expected to be developed and effectively utilized

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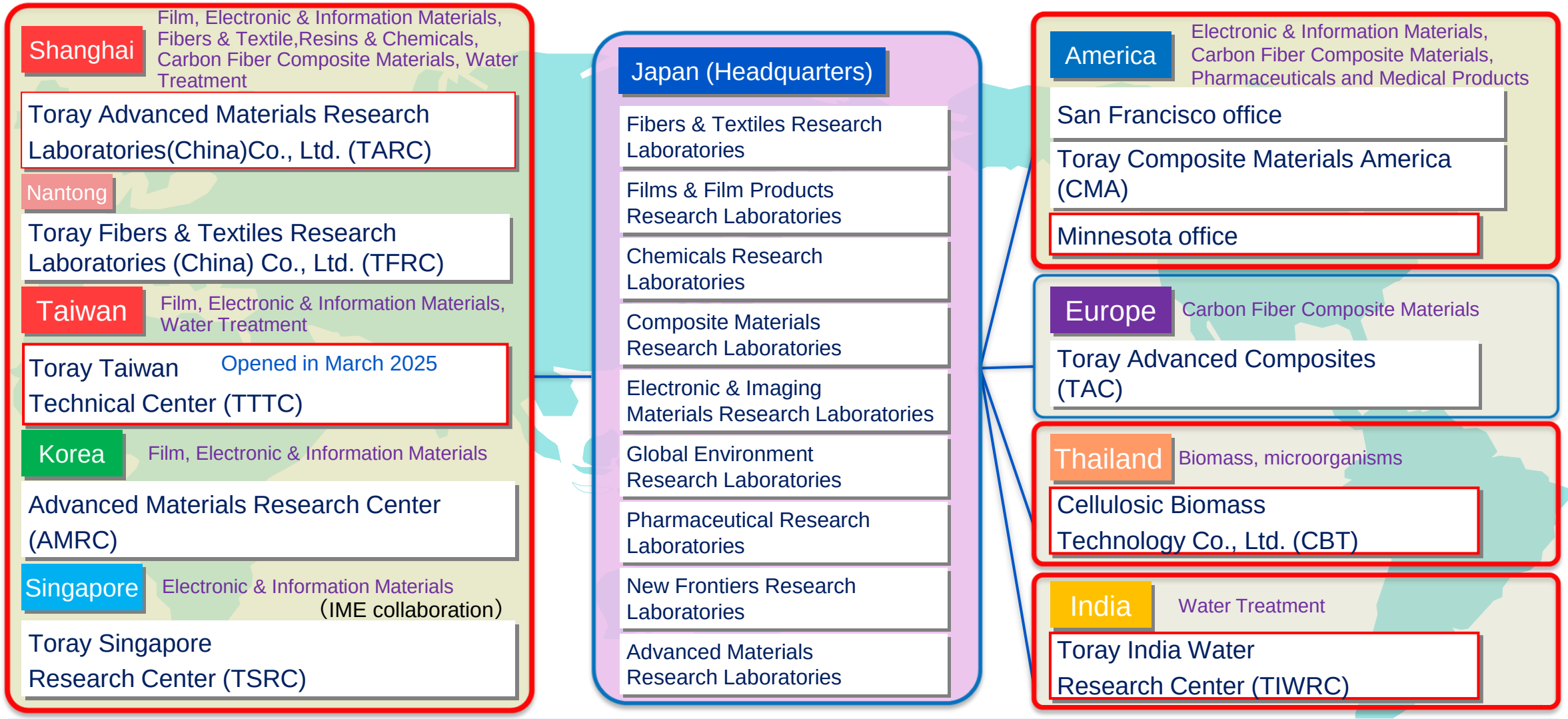
III

Future Perspectives

Global Research Center



Utilizing global bases to accelerate development of separation membrane-related business

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R&D Targets

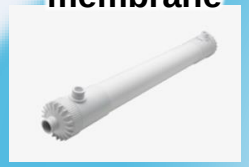
We will expand our existing businesses (water treatment and medical products) by evolving and fusing the separation membrane-related technologies we possess. At the same time, we will create new products and businesses by developing new businesses.

Water Treatment

Artificial kidneys

Adsorption column

UF membrane



Wastewater reuse

Food applications

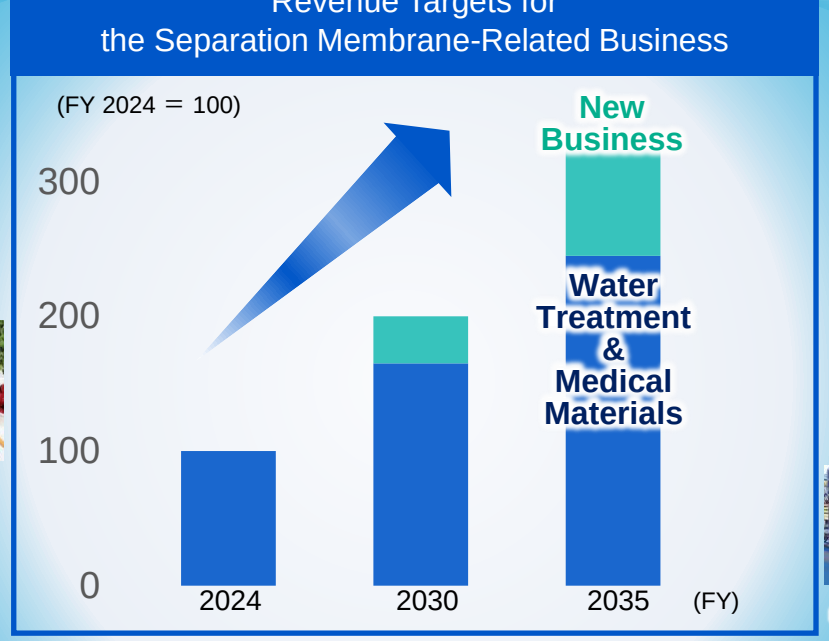
Biopharmaceutical separation membrane

Membrane-based bio-materials

Biomass

Monomer

Polymer



MBR

Recovery of valuable substances (NF membrane)

Reuse

All-Carbon CO_2 separation membrane

RO membrane

Fuel cell humidifying membrane

Ultrapure water for semiconductors

H_2 separation membrane

Sewage desalination

Seawater desalination

Gas separator for semiconductors

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Innovation by Chemistry

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