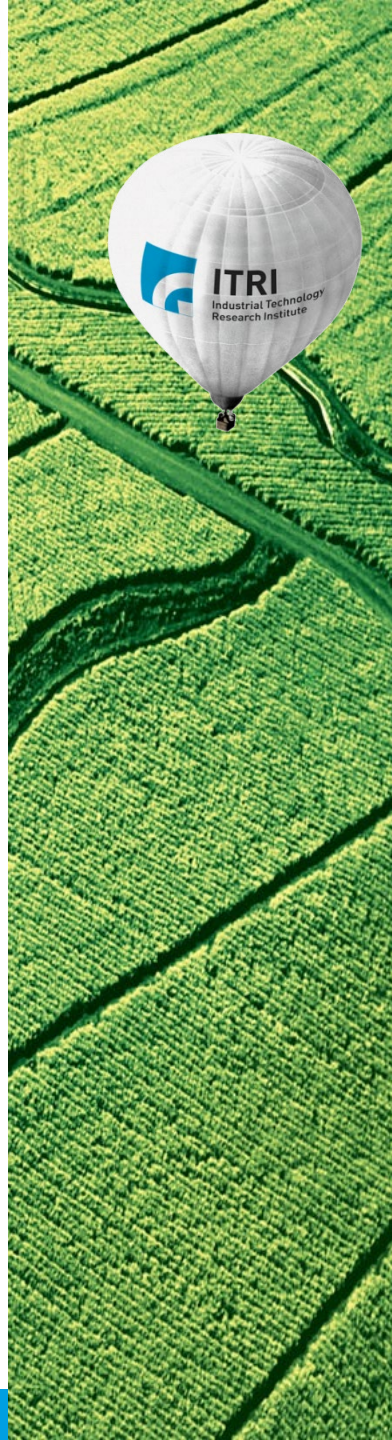

ElectroDialysis Reversal, EDR
水資源回收技術原理及整合應用

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Div. Of Water Technology Research

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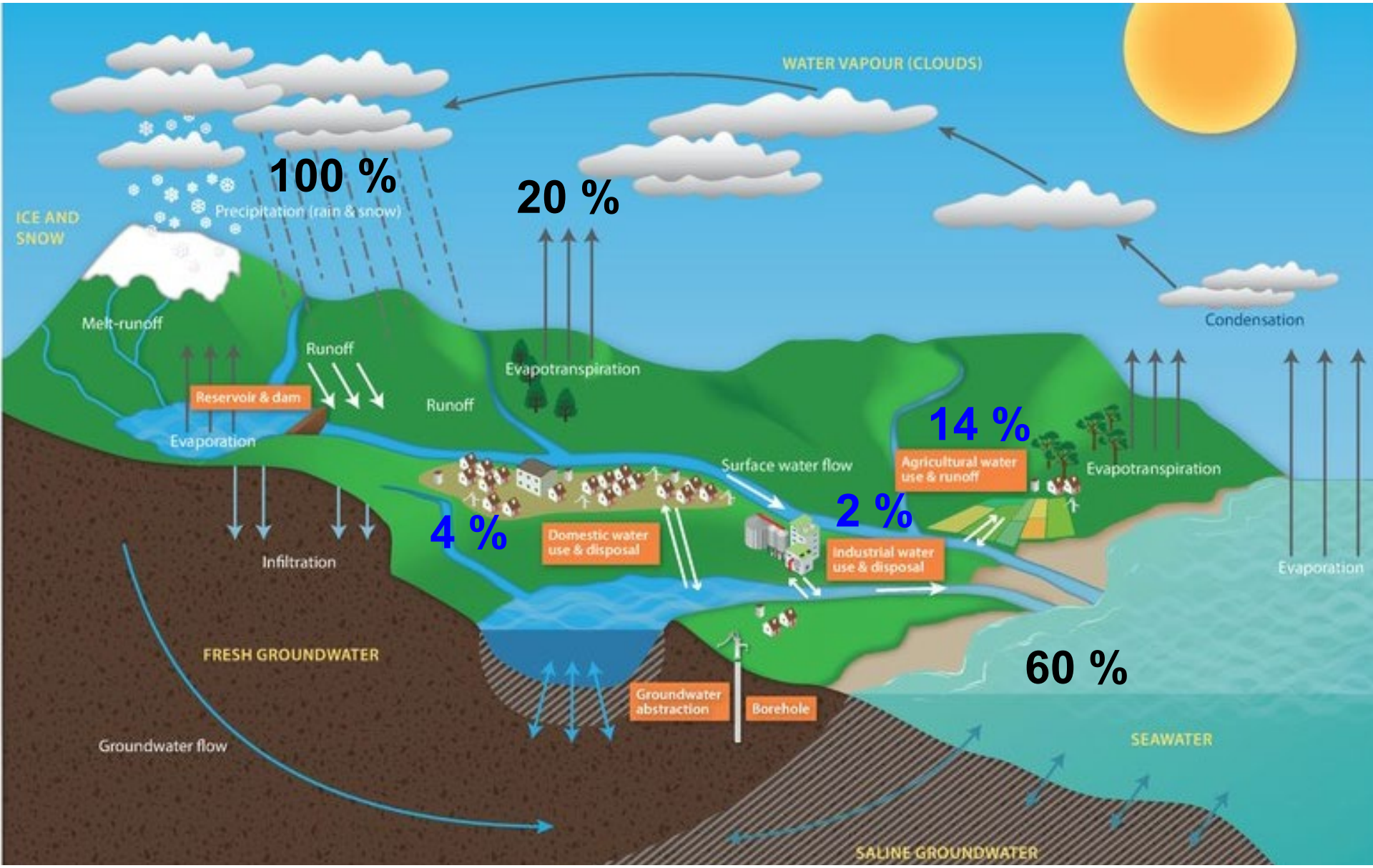
Phone: 0939-821-550

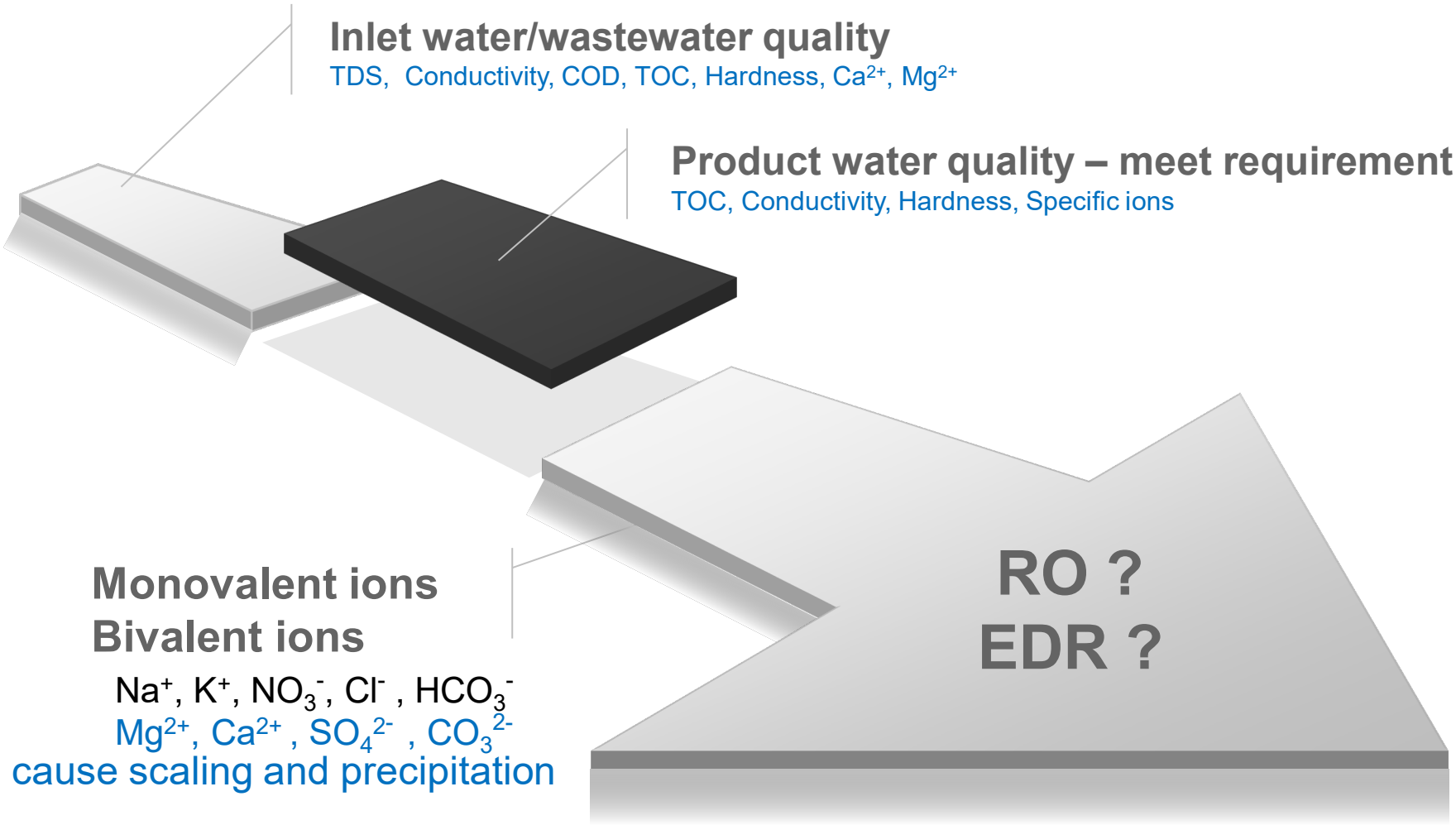
2025/06/17

Water cycle



https://en.wikipedia.org/wiki/File:Diagram_of_the_water_cycle_including_some_human_activity.pdf

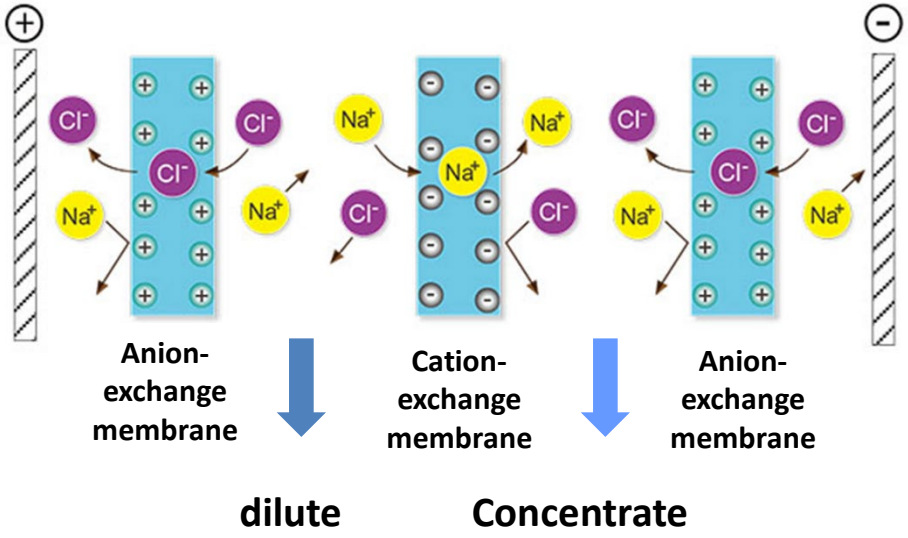
Ions Separation



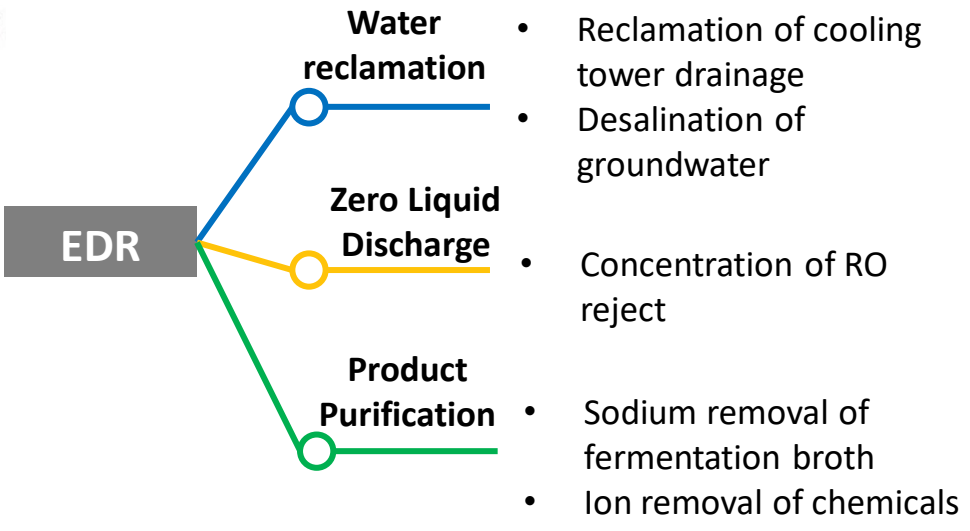
Electrodialysis Reversal (EDR)

Electrodialysis (ED) is a process that uses **direct current (DC)** to drive the movement of ions in water. By using membranes with different selectivities, ions in the water can be separated, resulting in streams of concentrated and diluted water. The **Electrodialysis Reversal (EDR)** technology developed by the ITRI enhances this process by periodically switching the polarity of the electrodes and altering internal flow paths. The process reduces scaling of ion-exchange membranes, thereby **improving the operational stability and extending the lifespan of the electrodialysis system.**

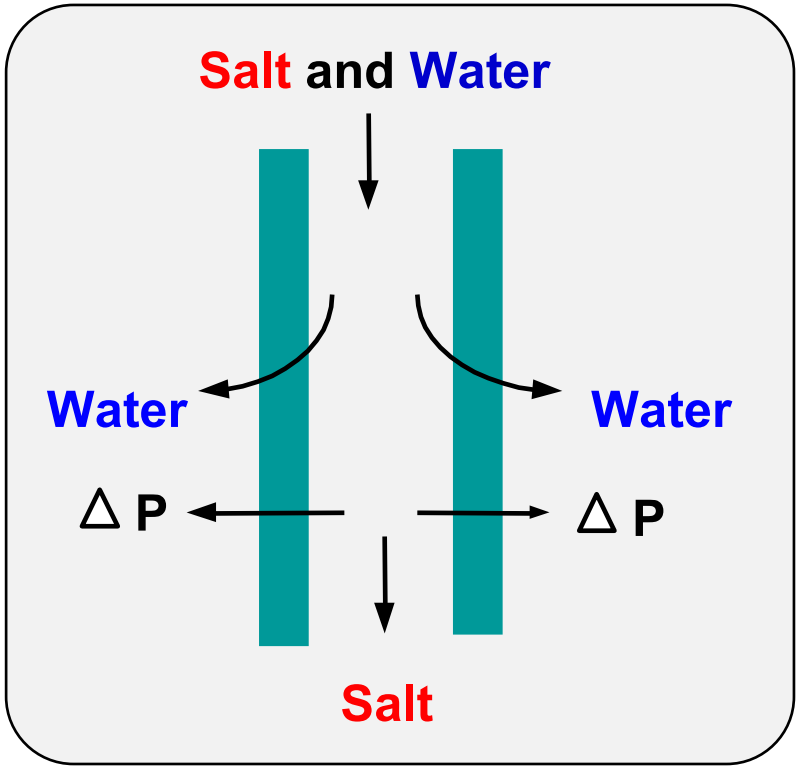
Theory



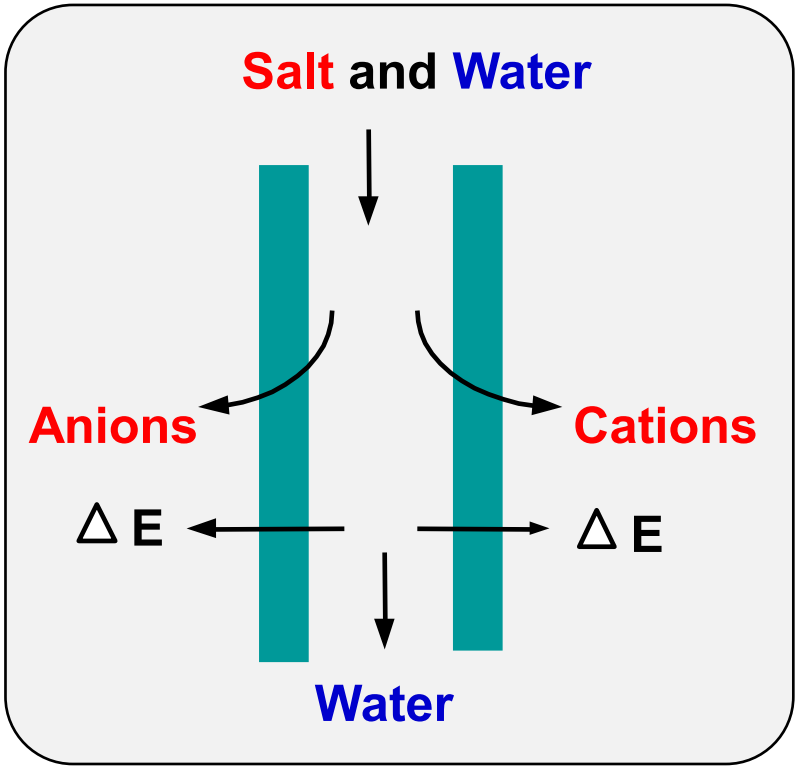
Applications



Technical difference



Reverse Osmosis
(半透膜)



Electrodialysis
(離子交換膜)

ITRI
Industrial Technology Research Institute

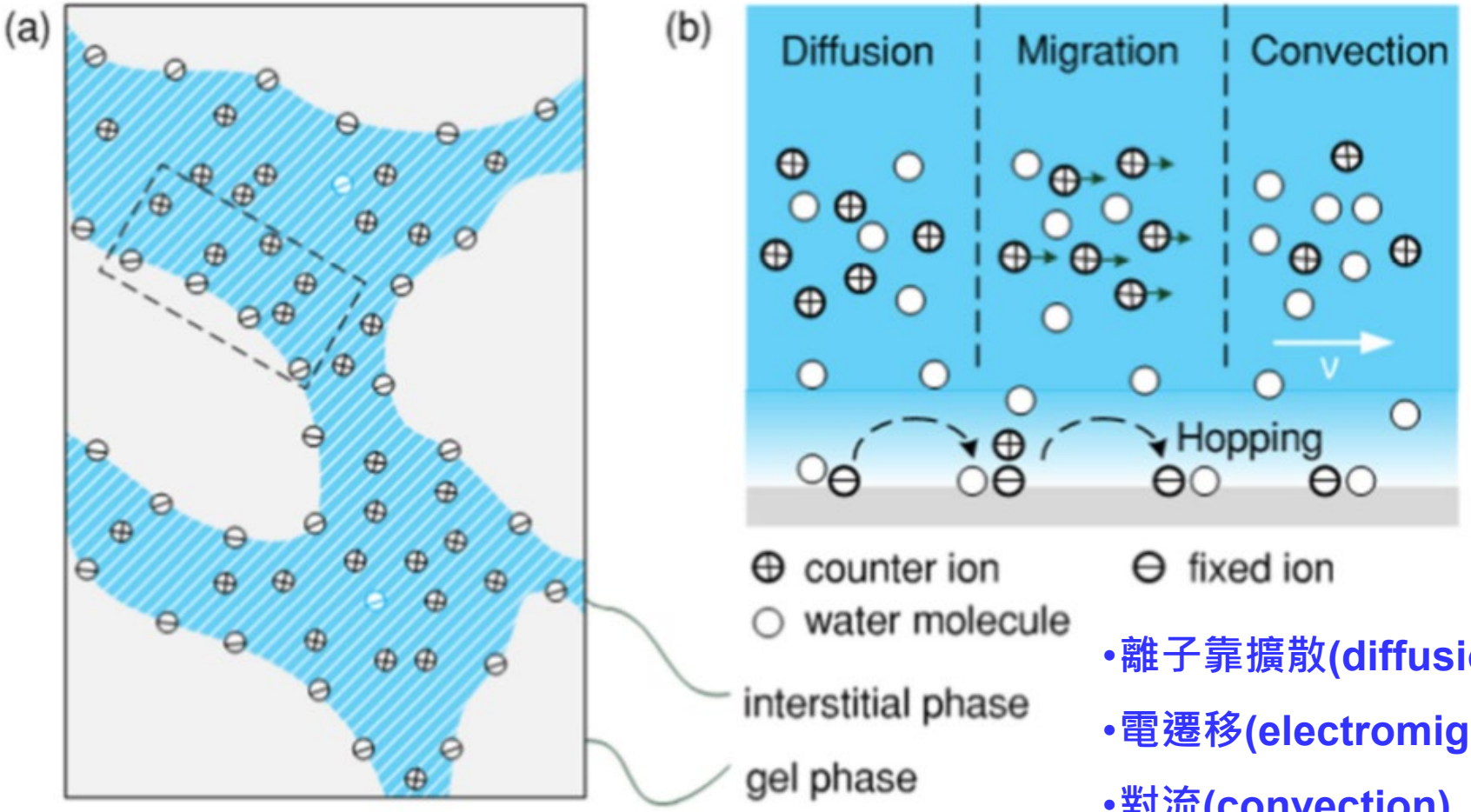
Advantages of EDR

	EDR	RO
Conductivity (μS/cm)	500~ 10,000	> 1,000
SDI	< 15	< 3
Silica	unlimited	undersaturated
Turbidity, NTU	< 1	< 0.1
TOC, mg/L	< 15	< 3
COD, mg/L	< 50	< 5
Fe, mg/L	< 0.3	< 0.05
Mg, Al, mg/L	< 0.1	< 0.05
Anti-fouling (Ca^{2+}, Mg^{2+},CO_3^{2-}, $CaSO_4$)	Good; polarity change	Poor (+ acid and scale inhibitor)
Biological adhesion and sediment	Good / adding sodium hypochlorite	Poor / fungicide (RO membrane resistant to Cl^-)
Water recovery	Good (50~80%)	Poor (40~60%)

- Suitable for various types of industrial wastewater
- Increase 20%~30% water recovery rate compared to RO

Principle and Structure

※Separation model

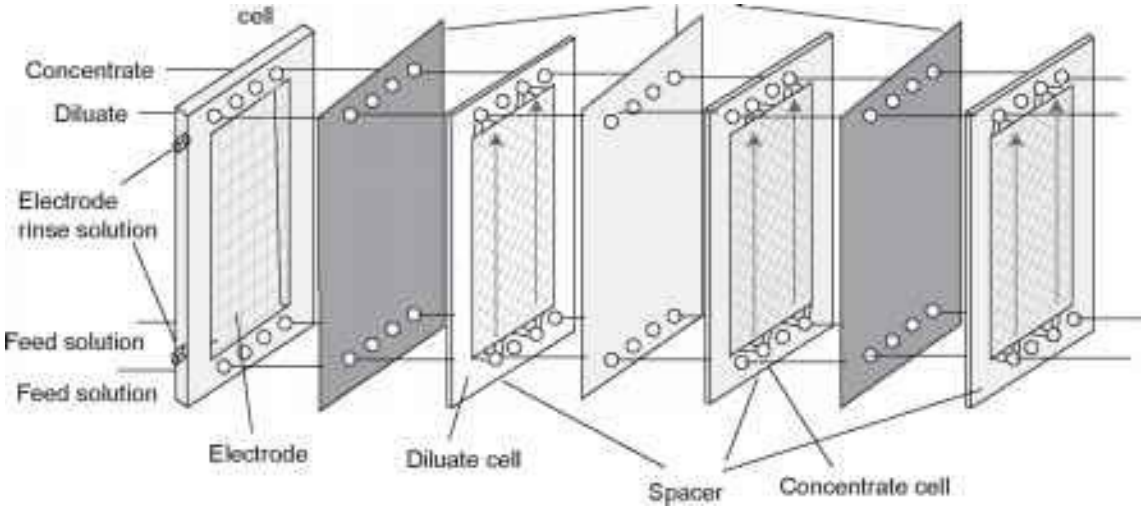


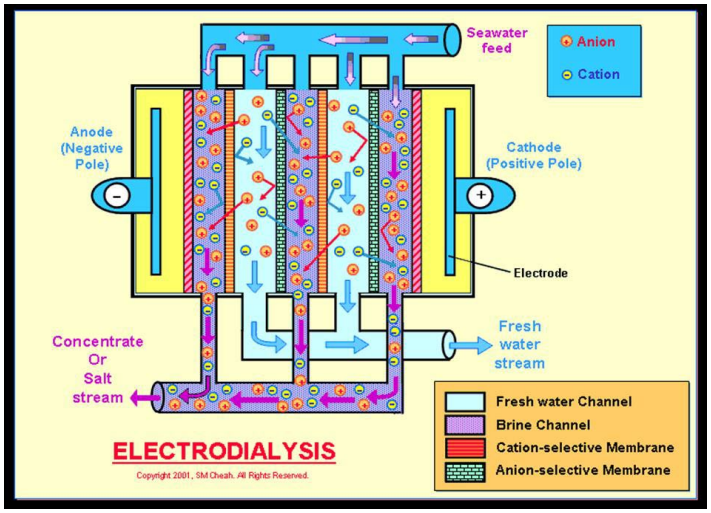
- 離子靠擴散(diffusion)
- 電遷移(electromigration)
- 對流(convection)
- 躍遷(hopping)

Source: Journal of Membrane Science 555 (2018) 429–454

Principle and Structure

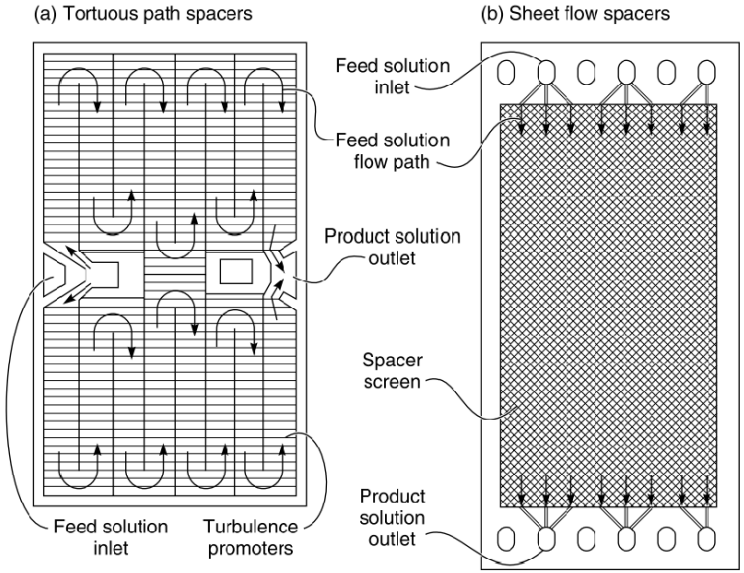
※ Electrodialysis system

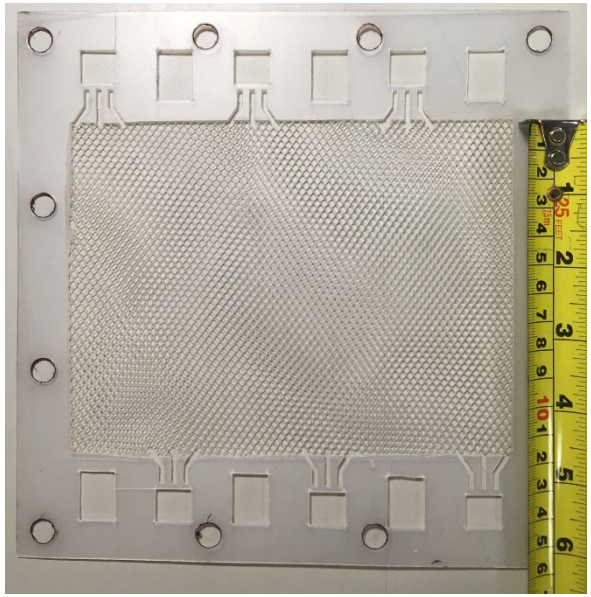


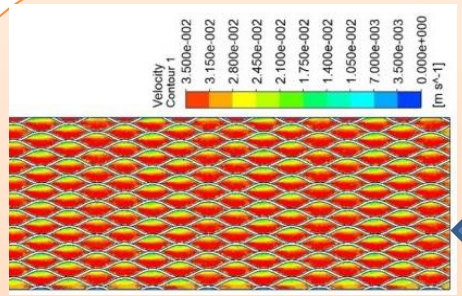


https://www.climate-policy-watcher.org/reverse-osmosis/electrodialysis-process-and-system-design.html

Spacer

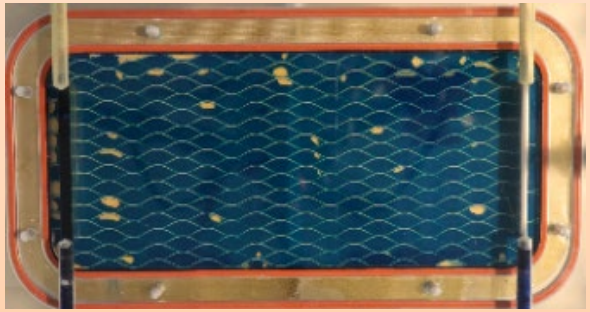




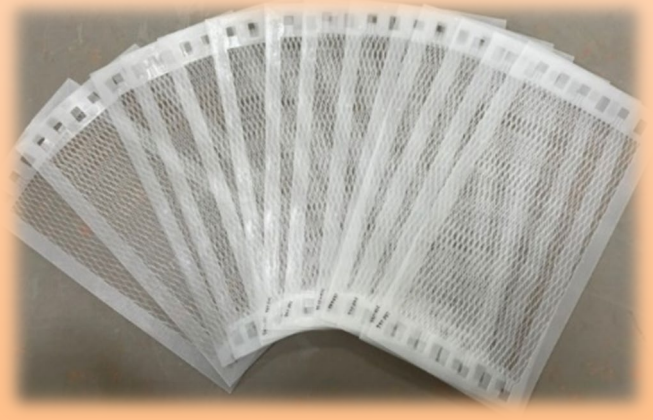


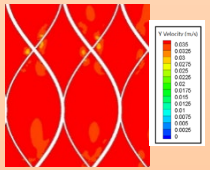
工業技術研究院
Industrial Technology Research Institute

模擬
非紅色區域減少
水流死角區域減少



膜面染色測試





專利紡錘網格
20 cm*40 cm
40 cm*80 cm

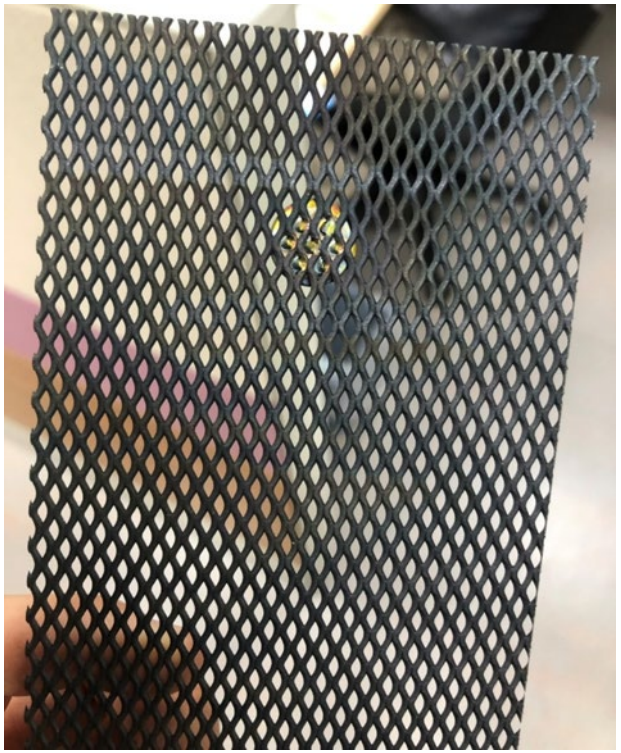
Baker R W (2004) Membrane Technology and Applications, 2nd ed., John Wiley & Sons, ISBN 0-470-85445-6
Journal of Membrane Science 572 (2019) 271–280

Electrode

棒狀/絲狀電極

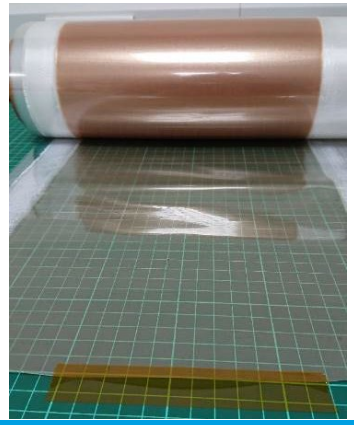
Ti/Rh、Pt/Ti
Stainless steel
Graphite
DSA-Ti/IrO_2

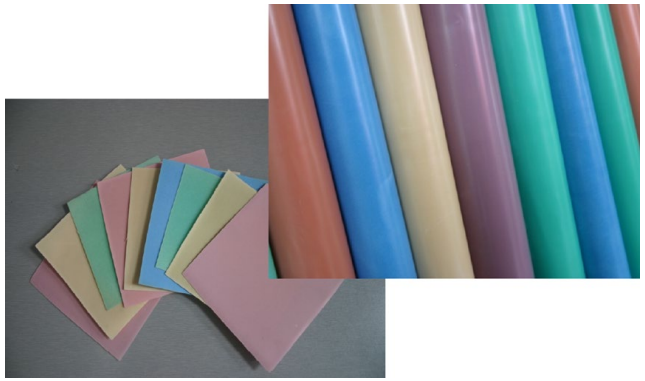
網狀電極



Ion Exchange Membrane

	均相膜	異相膜
孔隙率	小	大
厚度 (μm)	100-200	200~400
膜面電阻 ($\Omega.cm^2$)	<5	>10
膨脹率 (%)	<5	<10
耐酸鹼性 (pH)	0-14	2-12
製作方法	單體合成、交聯、塗佈	樹脂混料、熱壓成型
成本 (元/m^2)	>3,000	<1,200

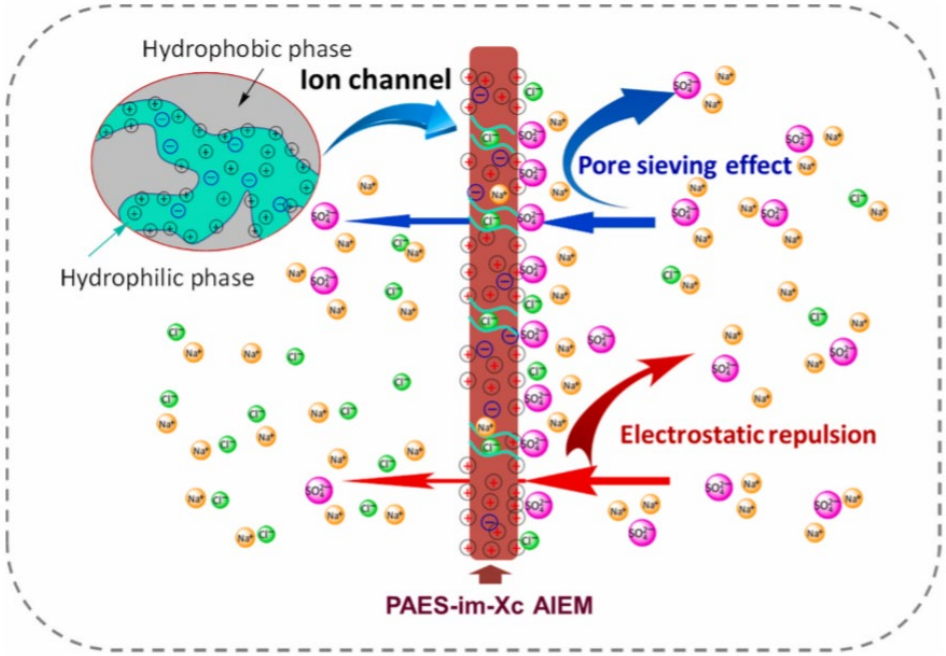




Functional IEM

※ Monovalent ions-selective membrane

Separation of monovalent and multivalent ions in the solution.



The possible mechanisms of perm-selectivity, including pore-size sieving effect, electrostatic repulsion and hydration energy difference etc.

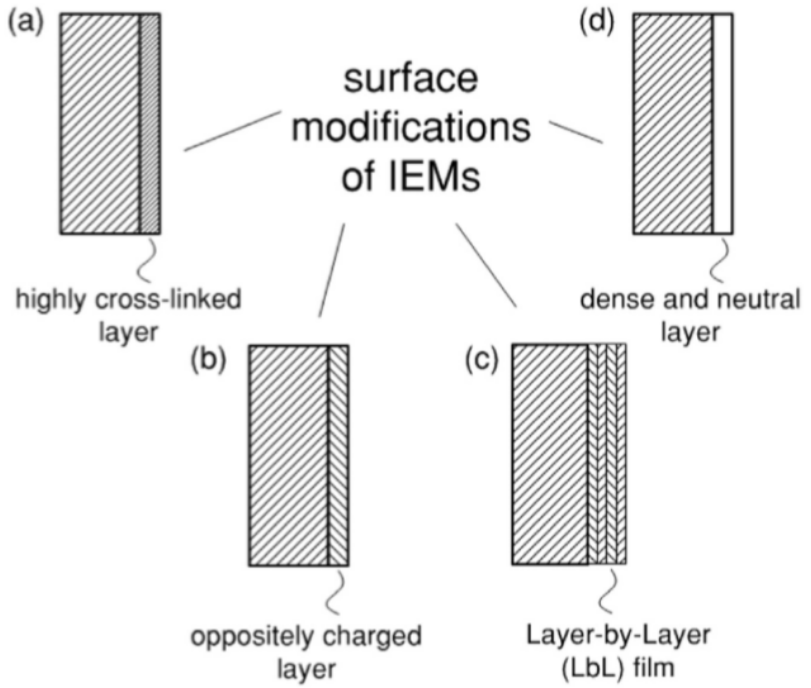
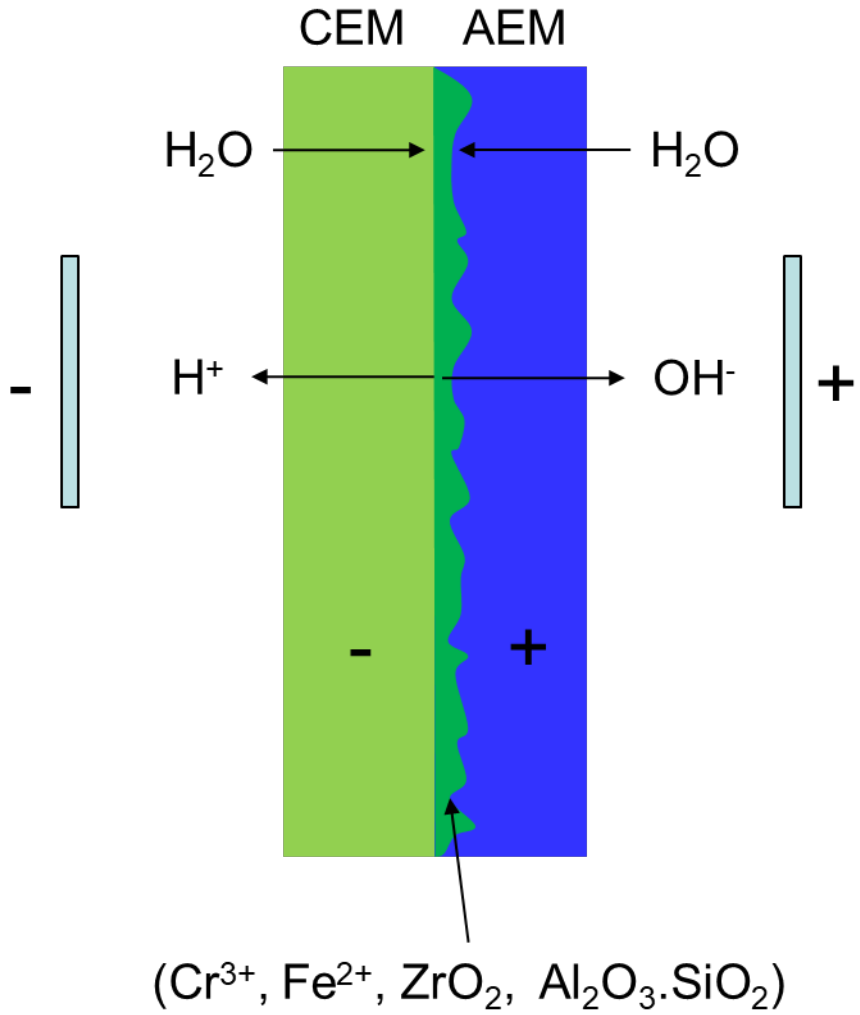


Fig. 12. Illustration of the surface modification types of ionic exchange membranes (IEMs). (a) Highly cross-linked surface layer with the same ion exchange groups as the membrane bulk, (b) surface layer with fixed ion exchange groups with charges opposite to those of the membrane bulk, (c) LbL film, and (d) surface layer formed from dense and (mostly) neutral polymers. Dimensions are not to scale.

Source: Journal of Membrane Science 555 (2018) 429–454; Journal of Membrane Science 577 (2019) 153–164

Functional IEM

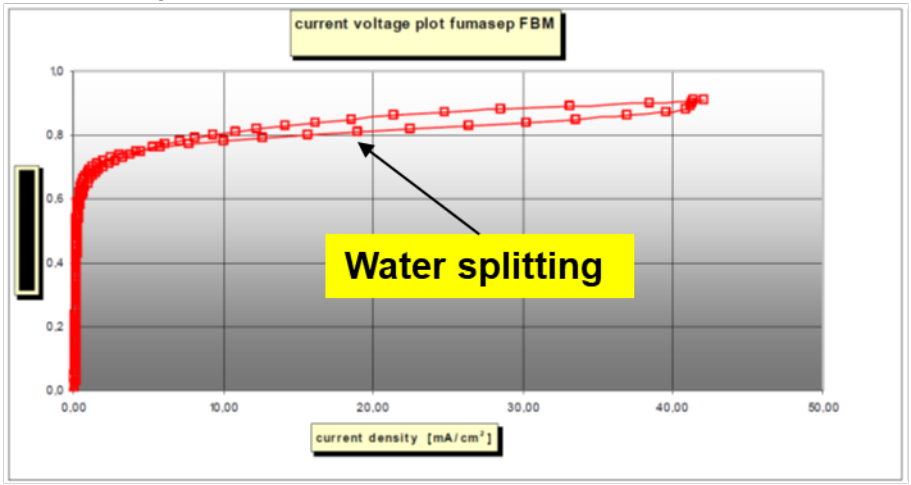
※ Bipolar membrane



- Thickness: 200-250 μm
- Burst strength: ≧0.25 MPa
- Water splitting voltage*: 0.8-1.2 V
- Water splitting efficiency*: 98%

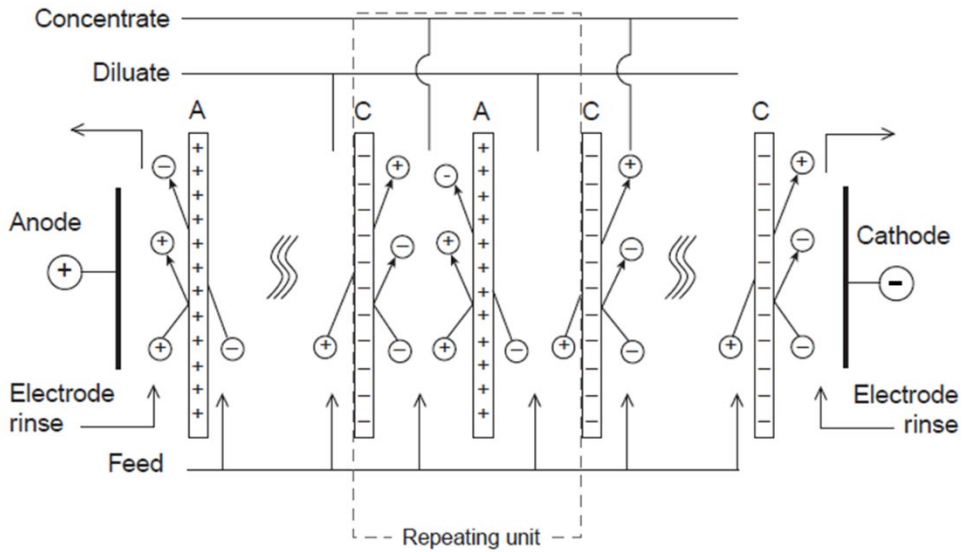
*Test condition: 1 N HCl, 1N NaOH, 100 mA/cm2, 30 ℃

Fumasep FBM

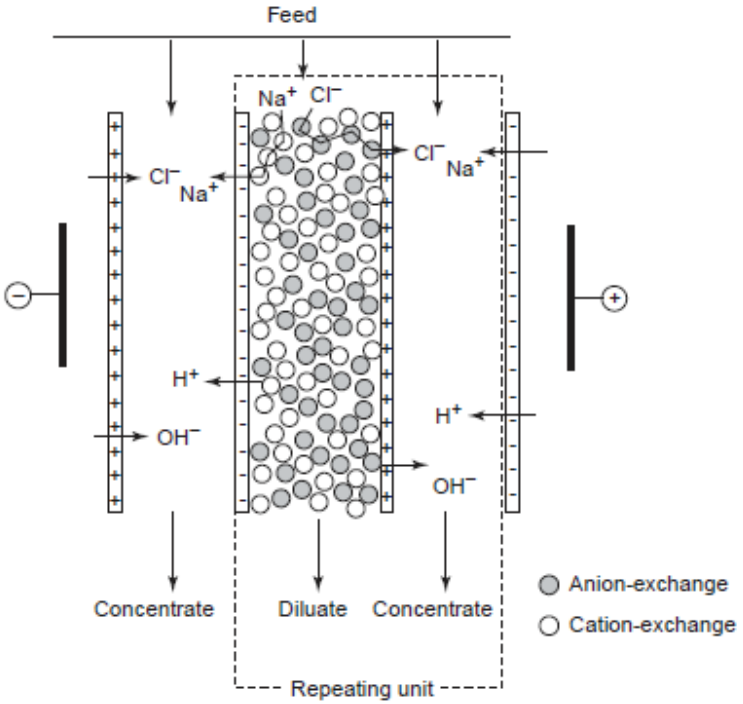


Application 1/2

ED/EDR-Reclamation

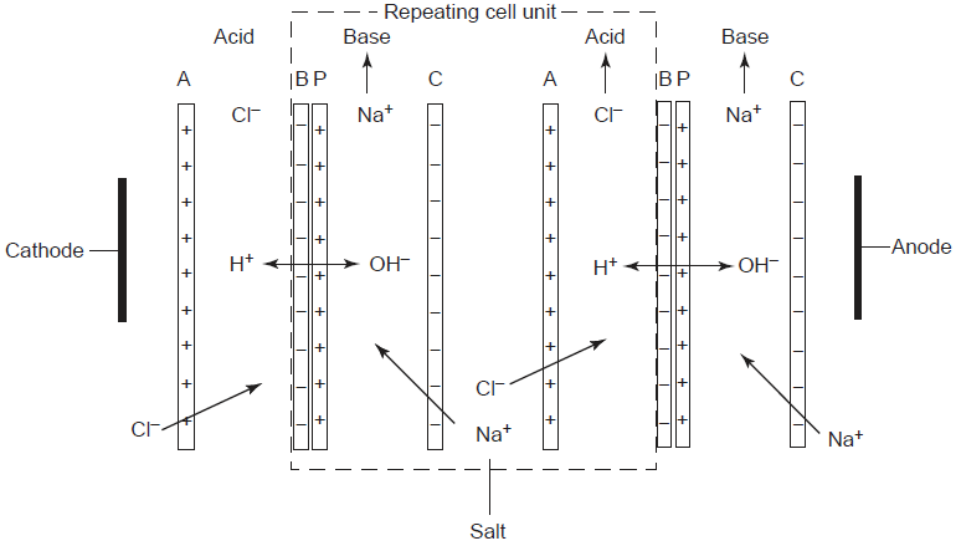


EDI-UPW

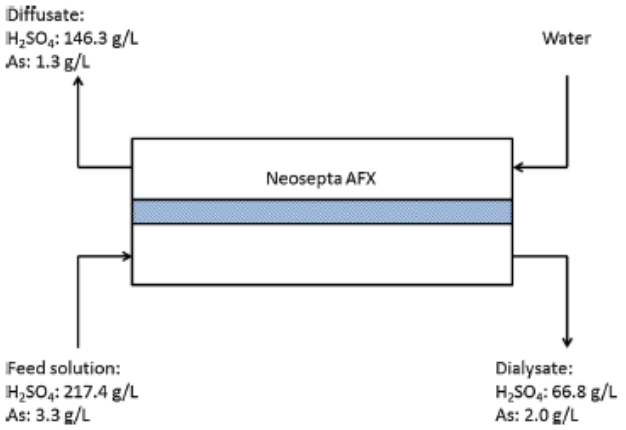


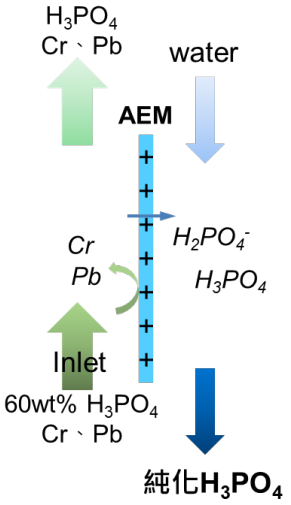
Application 2/2

BPED-Resourcezation



DD-purification





Recovery of Acid and Alkali (ITRI R2A)

R2A could effectively separate positive and negative ions from aqueous solution and further produce acid and base with novel arrangement of electrodialysis module.

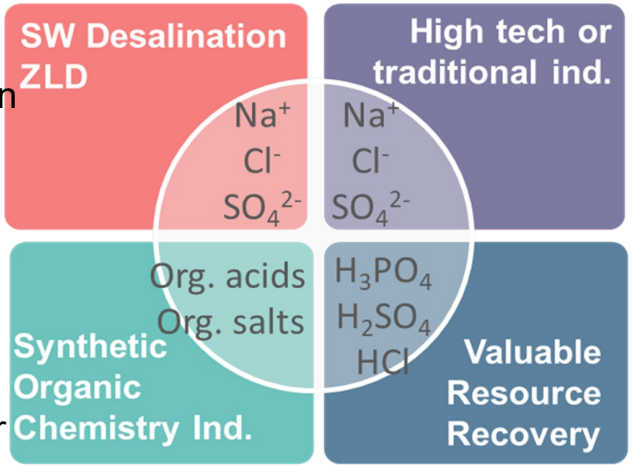
Highlight

- ✓ Reclaim valuable resource
- ✓ Complete ZLD process
- ✓ Low energy consumption
- ✓ Low operating cost

Applications of R2A technology

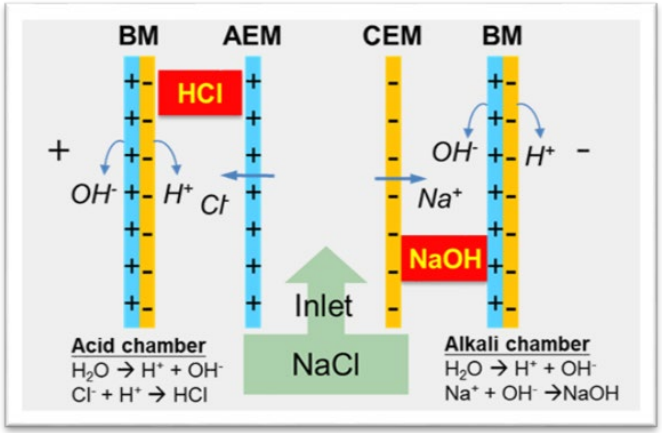
- SW desalination brine
- ZLD brine

- High salinity organic wastewater



- Resin regeneration waste
- High salinity wastewater

- Inorganic acid/base



EDR of ITRI

※ BPED – Recovery to Acid & Alkaline, R2A by ITRI

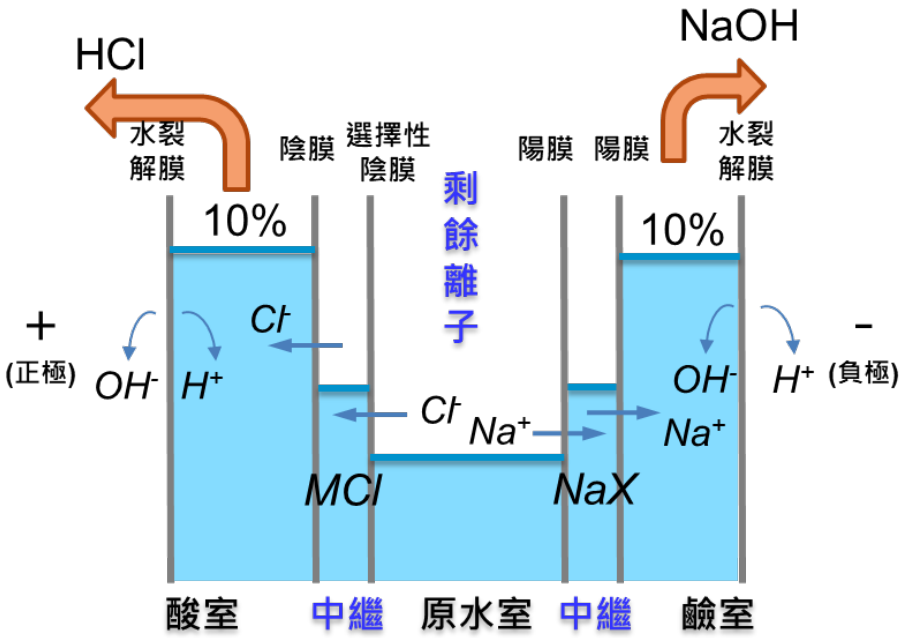
- Tank volume: 1.0 L
- Membrane area: 10 cm*20 cm
- Effective membrane area: 123 cm^2 (7 cm* 17.5 cm)
- Cell pair: 1~10 pairs
- Crossflow velocity: 3-6 cm/s
- Available operation current density (max): 80 mA/cm^2
- Available operation current voltage (max): 30 V

- Module type: 3 compartment (BACB arrangement)
- Tank volume: 10 L
- Membrane area: 20 cm*40 cm
- Effective membrane area: 488 cm^2 (16 cm* 30.5 cm)
- Cell pair: 30 pairs
- Crossflow velocity: 3-6 cm/s
- Available operation current density (max): 100 mA/cm^2
- Available operation current voltage (max): 600 V

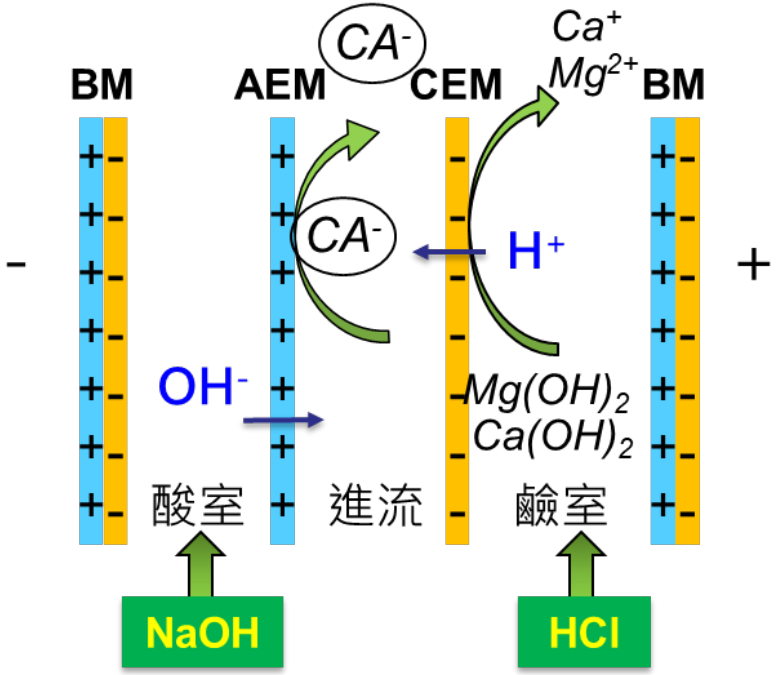
EDR of ITRI

※ BPED – Recovery to Acid & Alkaline, R2A by ITRI：Patent

- Efficiency enhancement

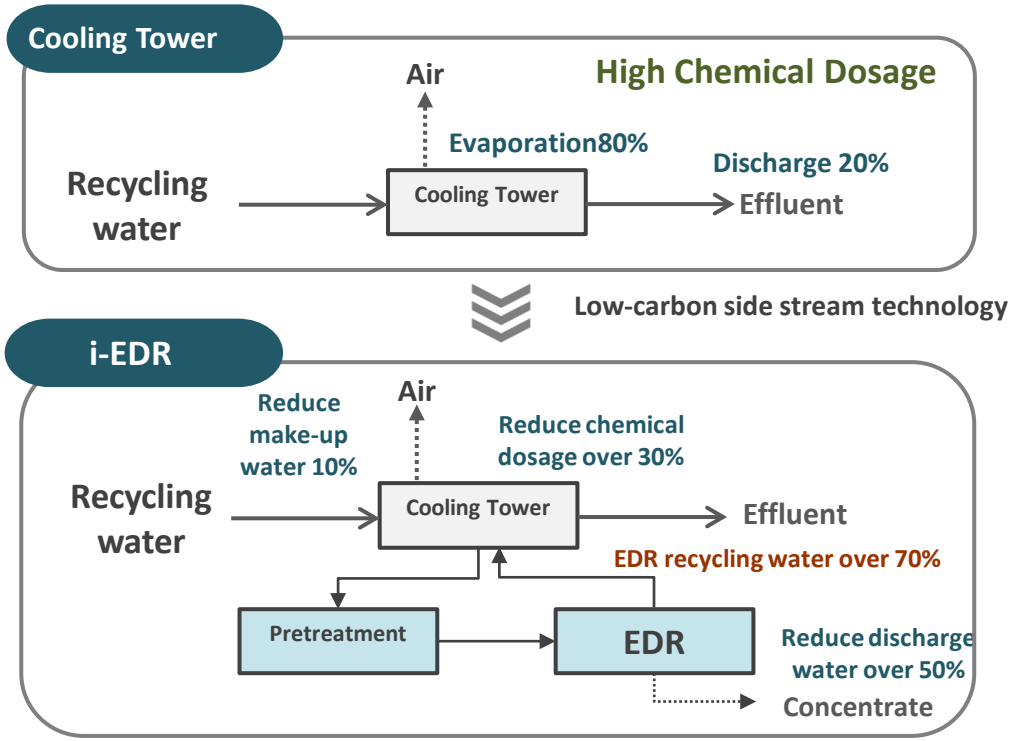


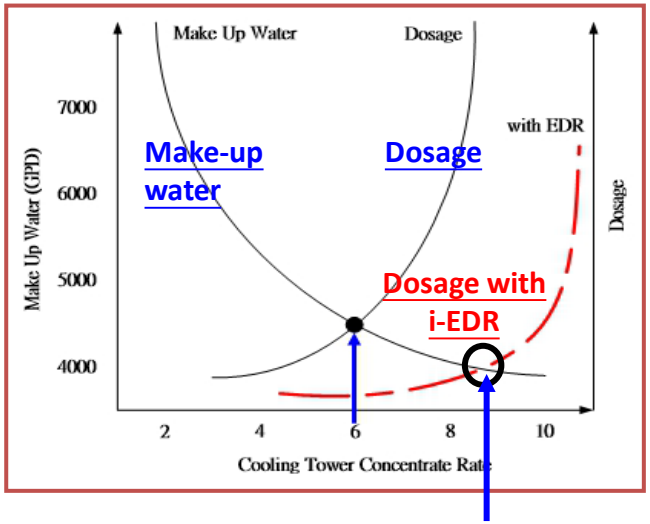
- Membrane activation



EDR of ITRI

- Address the high water demand of cooling towers, REDUCE AND KEEP the conductivity of cooling circulating water, and effectively decrease the make-up water volume, discharge volume, and chemical treatment costs.
- To prevent inorganic scaling issues in the cooling tower, the current approach is to continuously inject a large amount of scale inhibitor (~9 kg/day).





The EDR side stream treatment effectively increases the cooling tower's concentration factor to 9 times, saving 30% on chemical dosage.

EDR full scale case

※ Wastewater reclamation

- 電氣鍍鋅線(EGL) 的製程中需使用大量的純水清洗及潤濕鋼帶，以確保電鍍後鋼帶的表面品質
- 使用過的廢水須排入冷軋廢水處理場，每日廢水處理成本約13 萬元
- 廢水回收系統之處理量為每日768 公噸、回收率達70%，除可節省純水使用成本，減少廢水處理費用，亦創造廢水回收之績效，年效益可達1,160 萬元

EGL 產線廢水處理流程

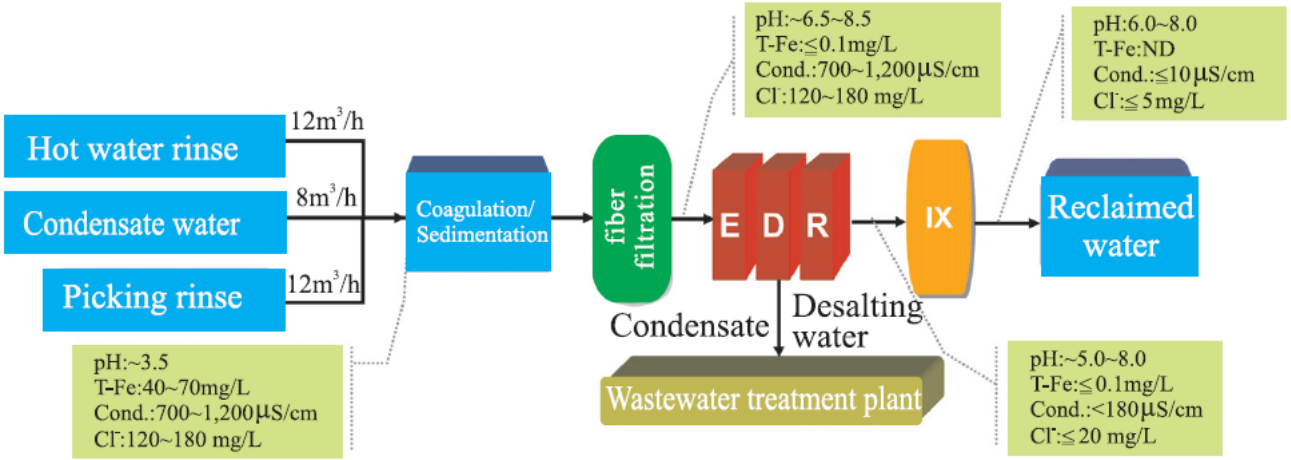
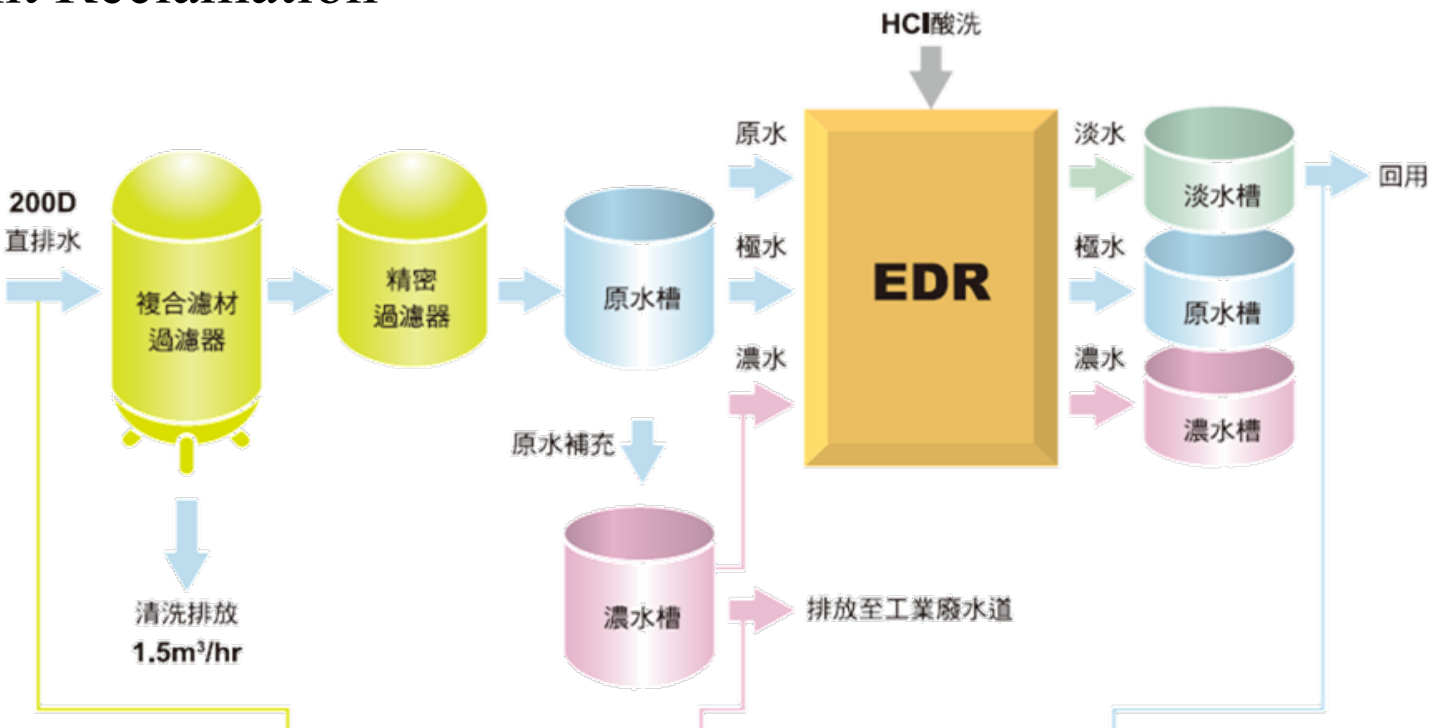


Fig.2. The process of wastewater reclamation and reuse in EGL.

EDR full scale case

※ Effluent Reclamation



原水水質			
流量	:	35	m3/hr
PH	:	8.5	
電導率	:	1800	μS/cm
總硬度	:	400	mg/L
Cl^-	:	280	mg/L
SO_4^{2-}	:	340	mg/L

濃水水質			
流量	:	8.5	m3/hr
PH	:	8.5	
電導率	:	6100	μS/cm
總硬度	:	1500	mg/L
Cl^-	:	1100	mg/L
SO_4^{2-}	:	1000	mg/L

處理後水質			
流量	:	25	m3/hr
PH	:	5.0~7.0	
電導率	:	≤350	μS/cm
總硬度	:	≤50	mg/L
Cl^-	:	≤30	mg/L
SO_4^{2-}	:	≤120	mg/L

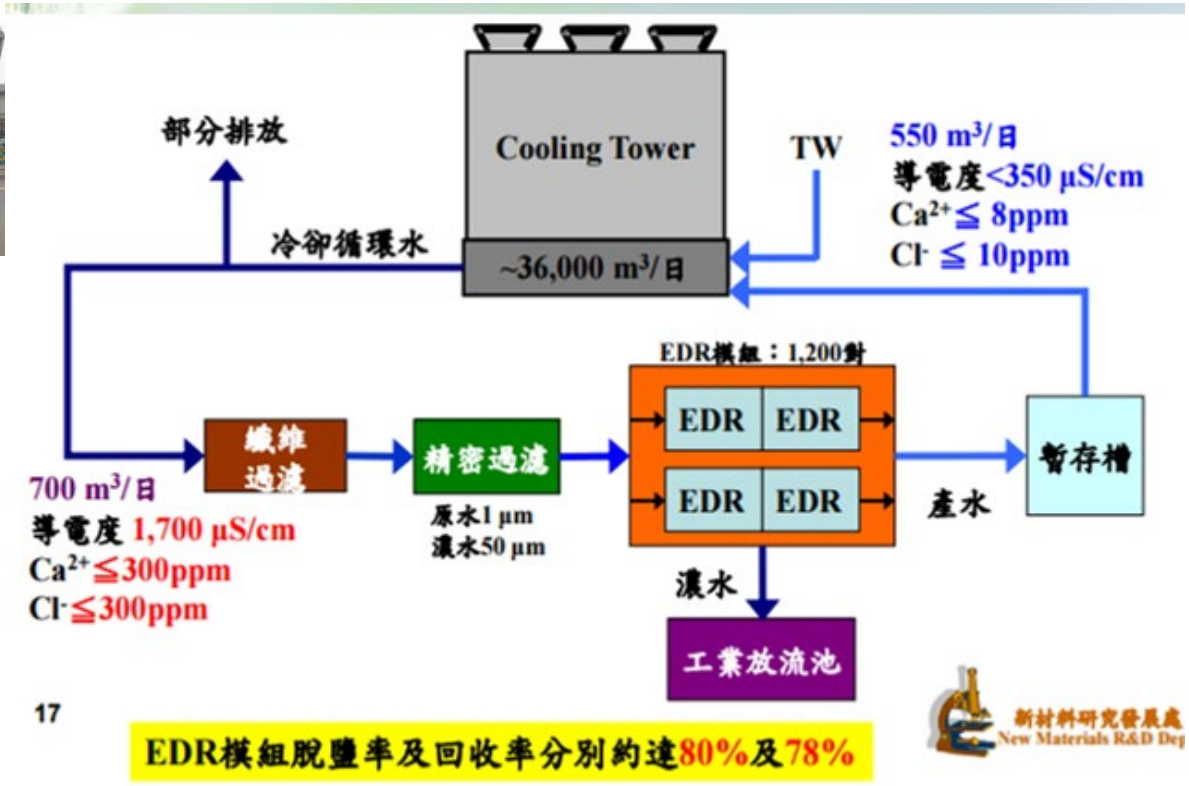
EDR full scale case

※ Cooling Tower Circulation

中鋼公司EDR實廠照片

效益

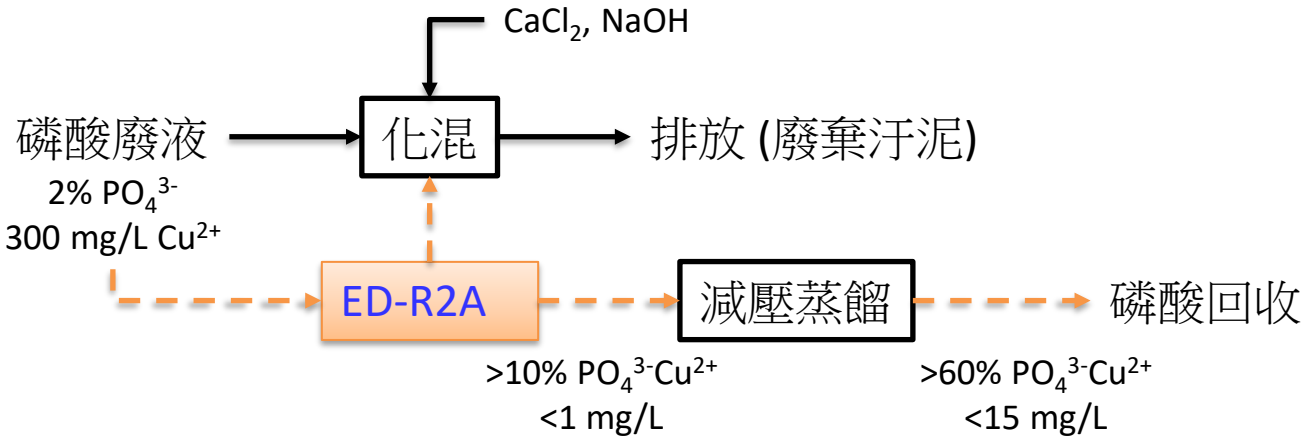
- 本案完成後不但可減少原水用量，同時可減少廢水場廢水處理量之雙重效益，
- 評估枯水期(約6個月)可節省2,150,000元；
- 評估豐水期(約6個月)可節省1,380,000元
- 預估全年可節省水費3,530,000元。

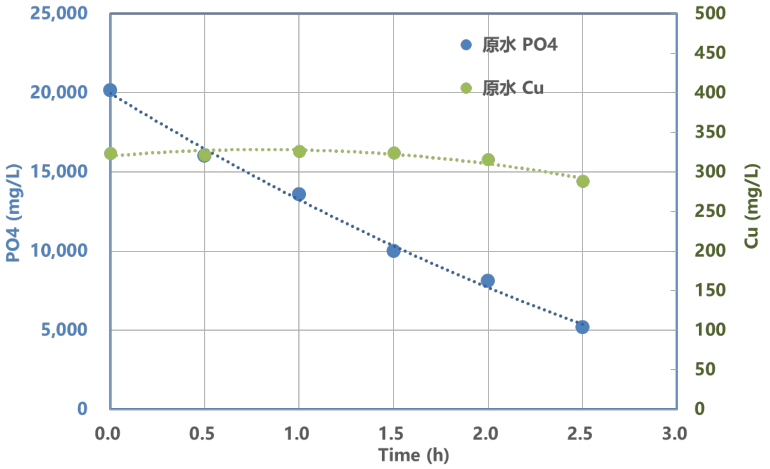


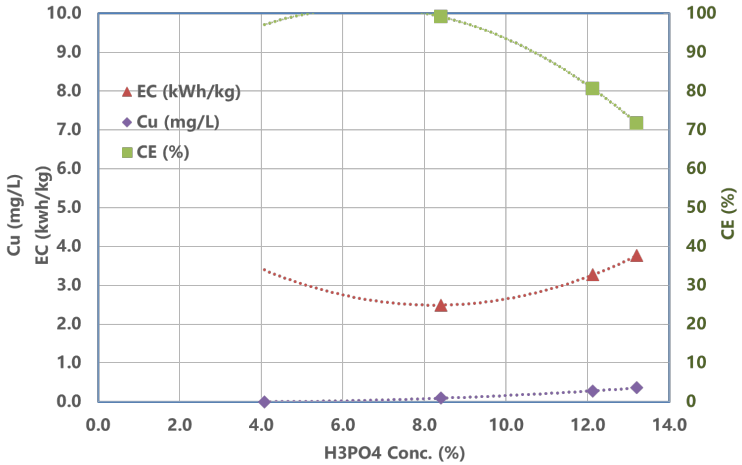
中鋼公司EDR處理流程示意圖

EDR full scale case

※磷酸廢液純化提濃



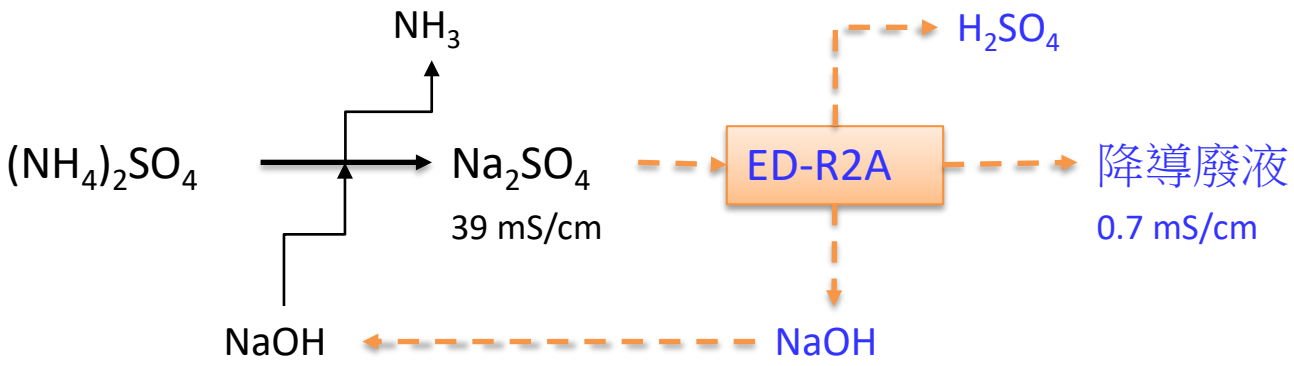


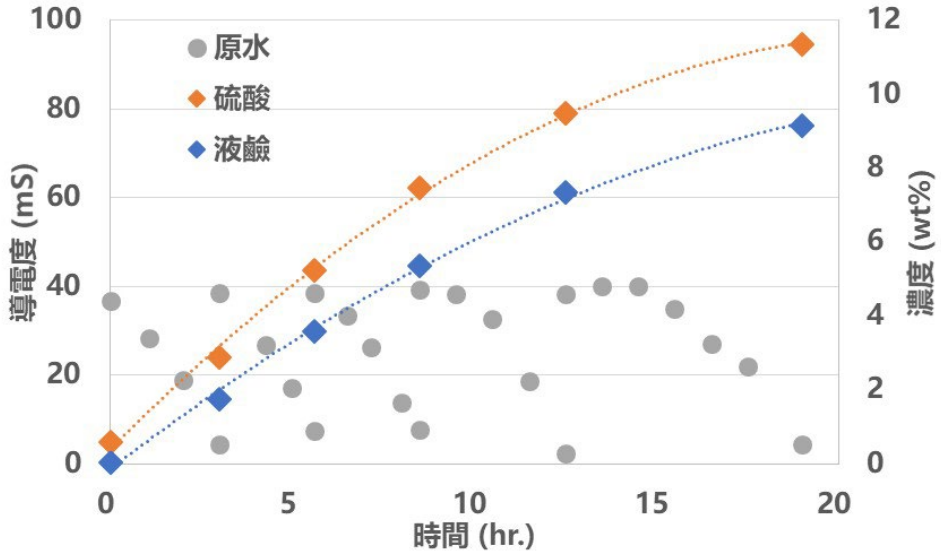


- 廢磷酸預提濃並純化為H_3PO_4 13 wt%，Cu^{2+} 0.36 mg/L
- 磷酸回收率75%，能耗3.8 kwh/kg-H_3PO_4

EDR full scale case

※硫酸鈉廢液資源化降導

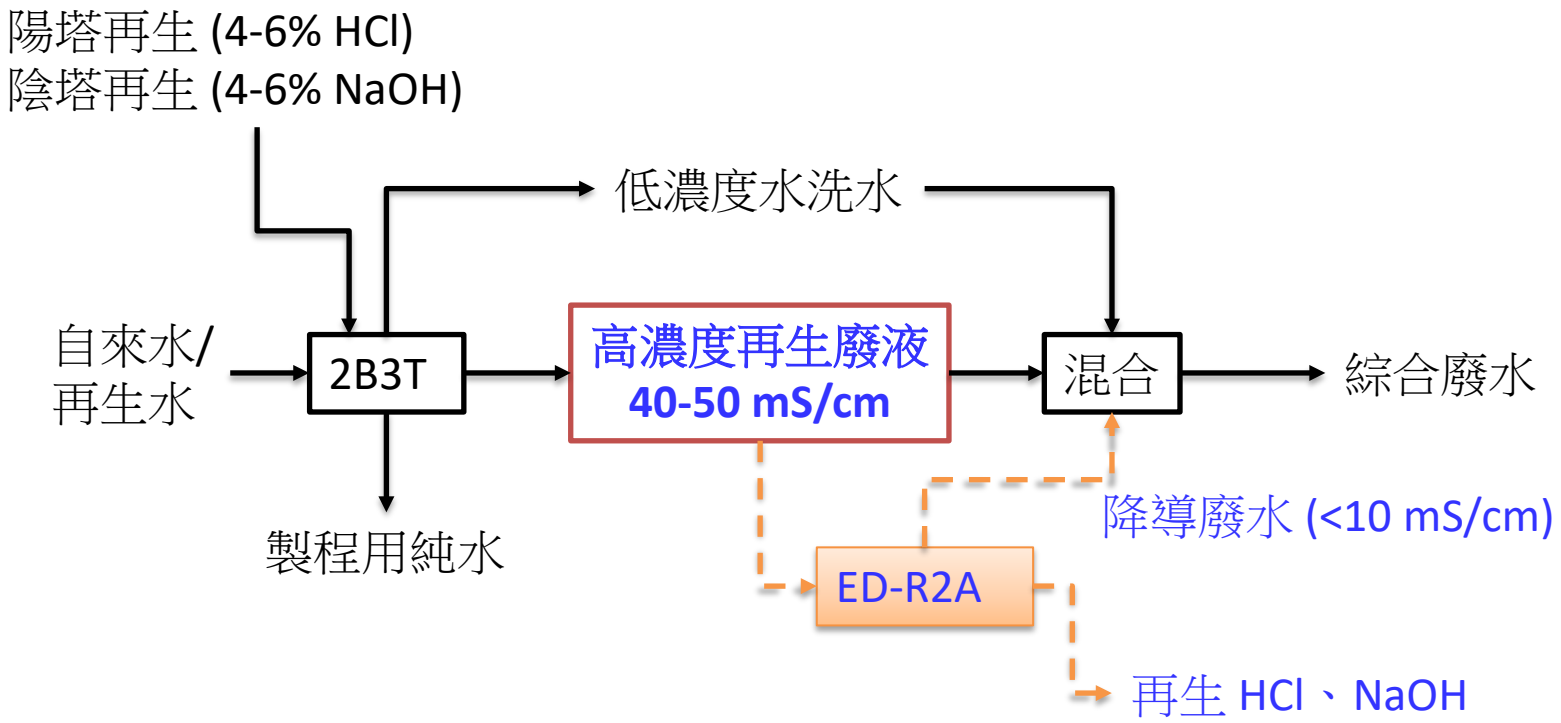




再生酸鹼液
9.0 wt% NaOH, 11 wt% H_2SO_4
能耗5.4 kWh/kg-NaOH
排水導電度降低80%，轉化為液鹼、硫酸回廠內再次利用

EDR full scale case

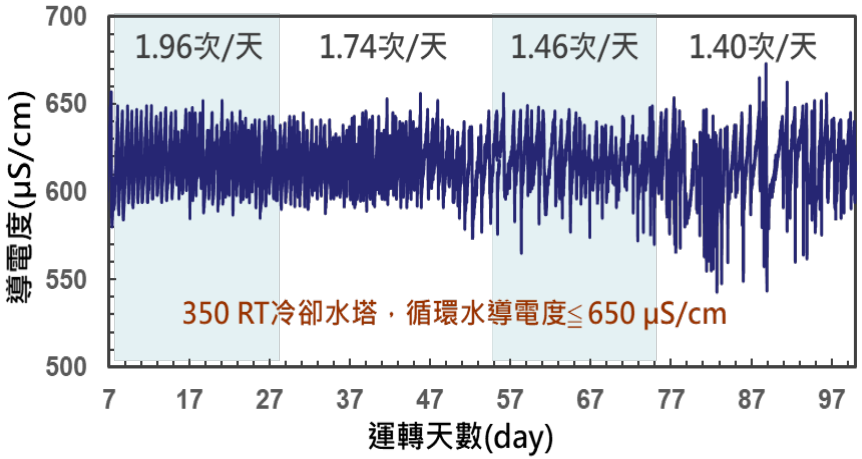
※R2A樹脂再生廢液

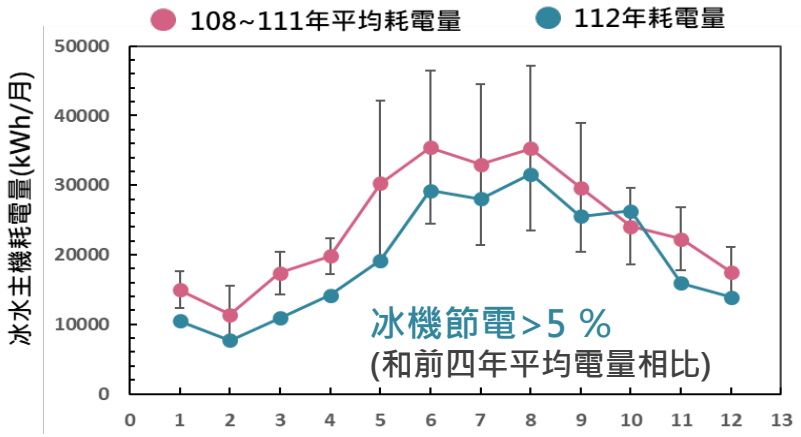


- 高濃度再生廢液降導轉化酸鹼，再生酸鹼廠內回用。
- 降低廢水排放導電度，減少廠內外購酸鹼量

EDR full scale case

※ 350 RT / 商辦用空調冷卻水塔





節水
17 %

節電
5 %

減排
55 %

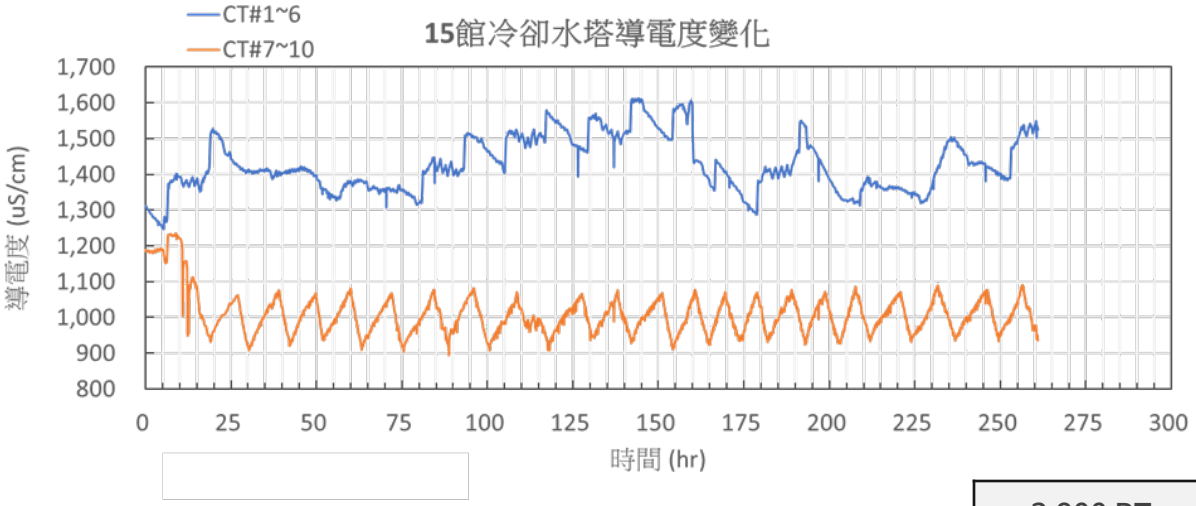
藥品減量
50 %

能耗
0.5 kWh/RT

減碳量
46 ton/yr

EDR full scale case

※ 2,800 RT / 製程試驗產線冷卻水塔



節水
20 %

節電
3.5 %

減排
75 %

藥品減量
60 %

能耗
0.62 kWh/RT

減碳量
297 ton/yr

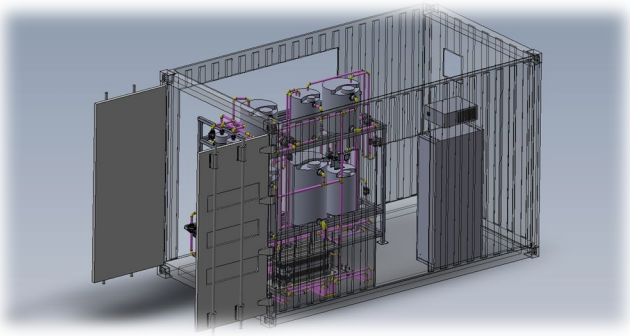
2,800 RT	SPEC.	裝設前	裝設後
導電度(μS/cm)	< 1500	1253±198	927
鹼度 (mg/L)	< 300	186±34.5	125
總硬度 (mg/L)	< 600	435±112	270
全鐵 (mg/L)	< 0.50	0.2±0.1	0.08
藥劑濃度(mg/L)	5~10	6.3±1.2	5.0
藍氏飽和指數 (LSI)	0.20 ~ 2.50	0.9±0.2	0.52

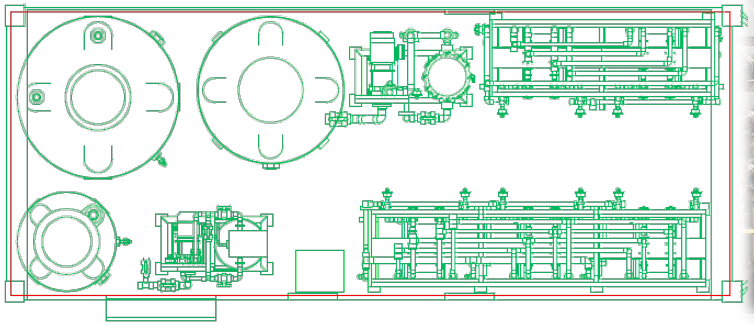
套裝式旁流設備

項目 / 機型	適用噸數	模組尺寸, mm			電源規格	
	RT	長 (L)	寬 (W)	高 (H)	電壓 (V)	電流 (A)
2040	< 500	300	300 - 450	600	< 40	< 30
4080	< 2,000	500	350 - 750	1,100	< 160	
40160	< 4,000	500	500 - 960	2,100	< 200	
80160	< 10,000	950	800 - 1,200	2,100	< 300	

操作溫差：5 – 8 ℃, 濃縮倍率：4 – 6 倍, 循環水量：9 – 12 LPM/RT

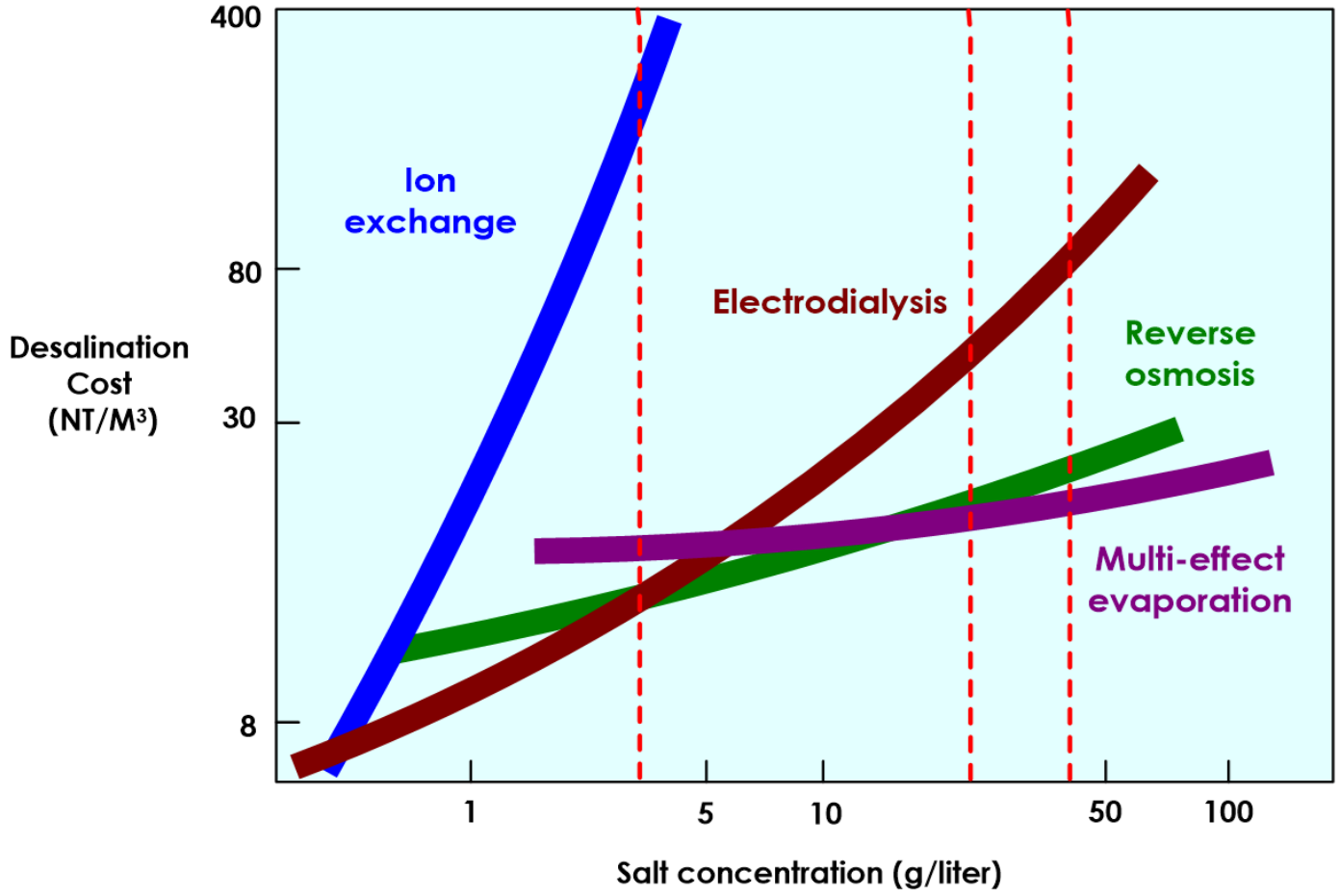
- 機型適用範圍廣泛，可依需求客製規劃
- 套裝式機架/成櫃設計，快速安裝工期短
- 可整合環境、熱交換系統及產線稼動率等連續監測數值，進行AI自動控制學習，主動式維持最高運轉效率



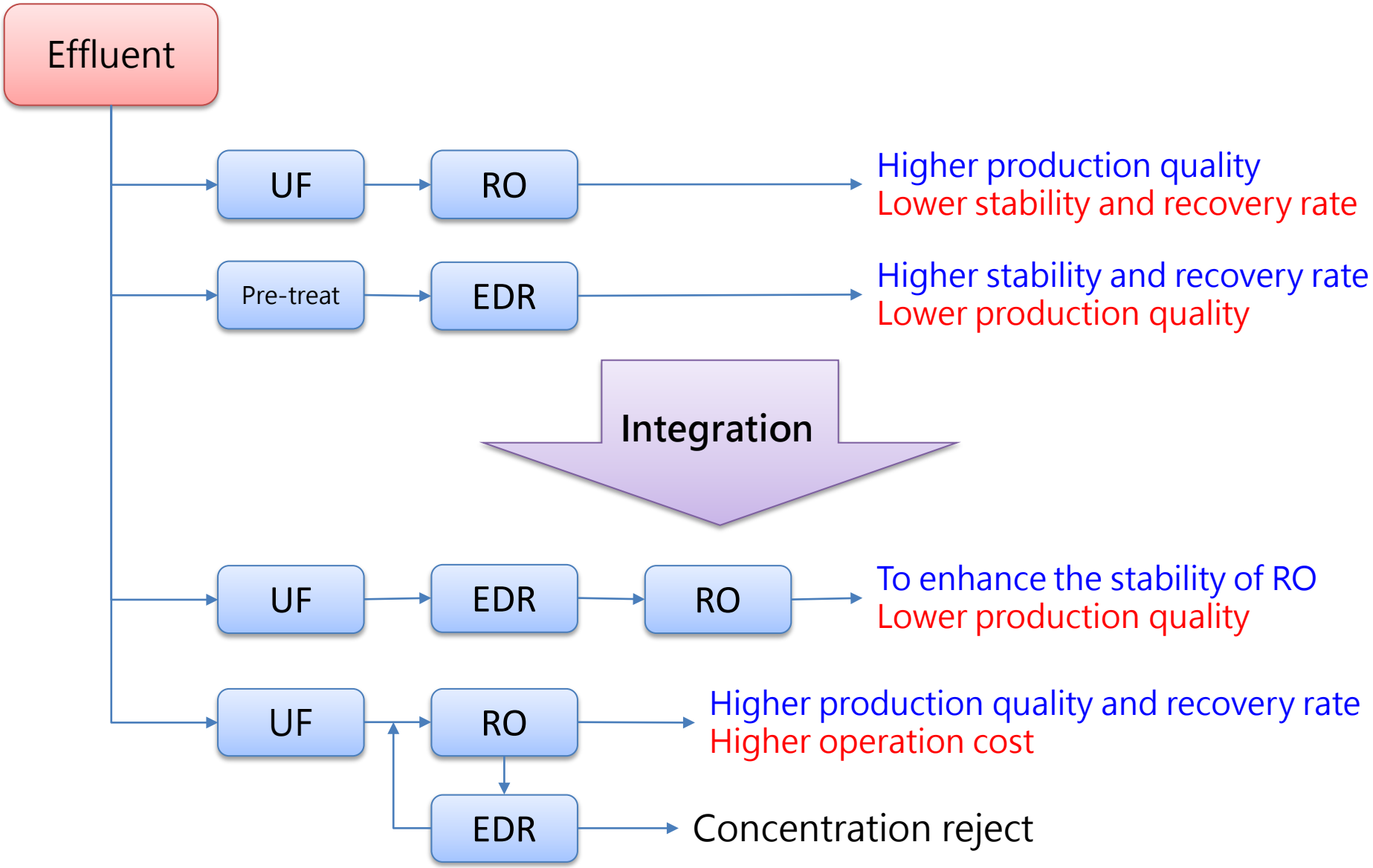


Applications Integration

Process wastewater → Secondary treatment → UF+**RO** (UF)+**ED** → Reclaimed water

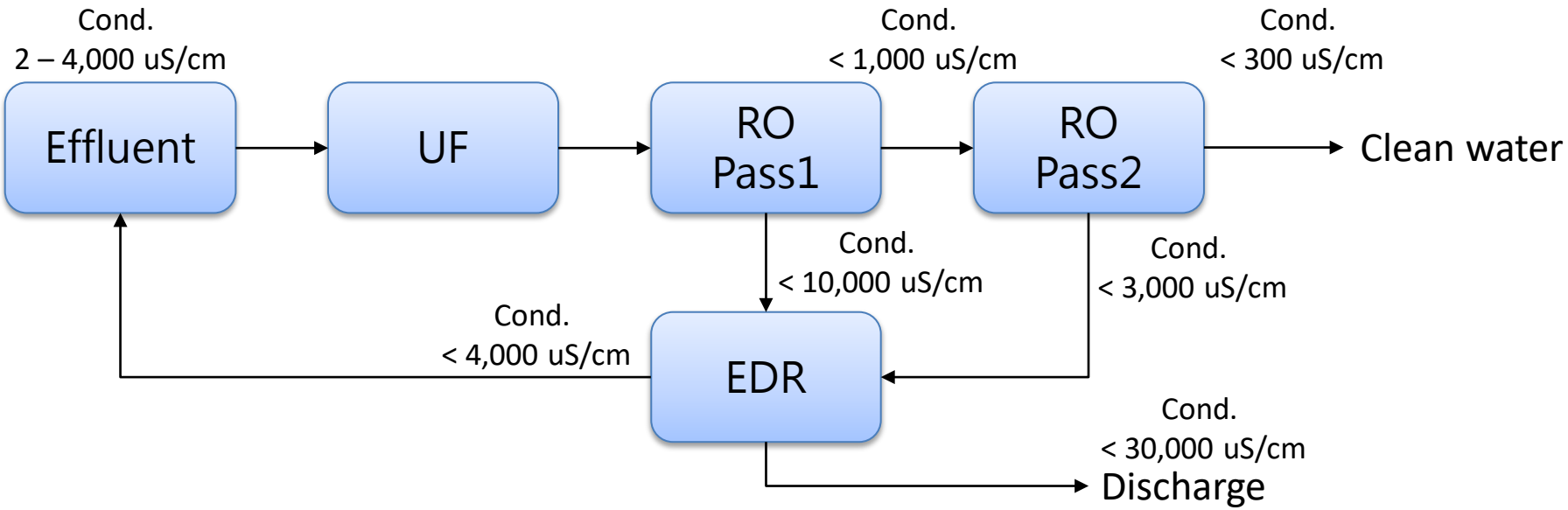


Applications Integration



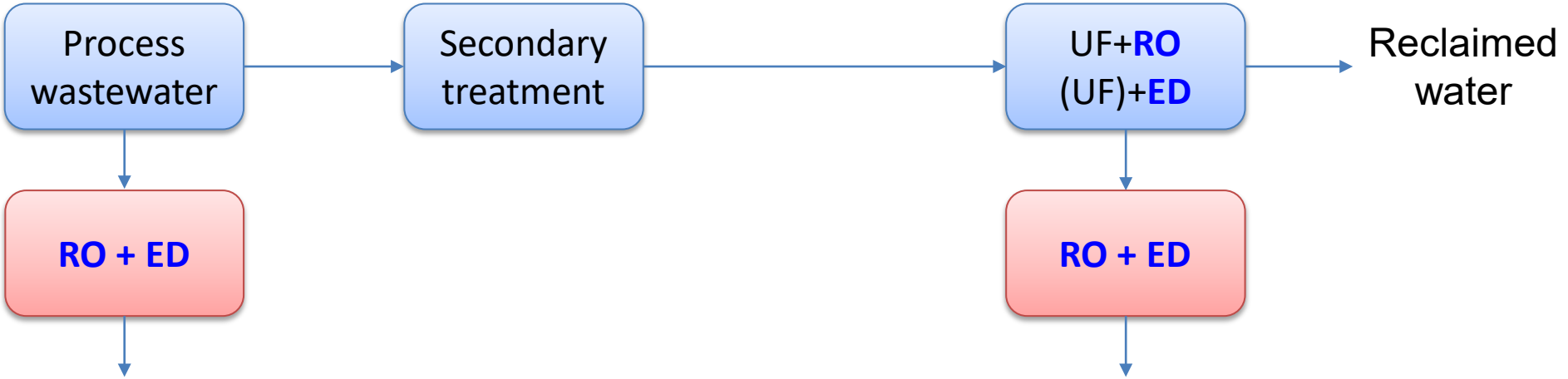
Applications Integration

※ Industrial wastewater reclamation



- 2Pass RO recovery rate 70 %
- EDR recovery rate > 80 %
- Whole system recovery rate > 90 %
- Using Pass 2 ROR to adjust the concentration of EDR

Applications Integration

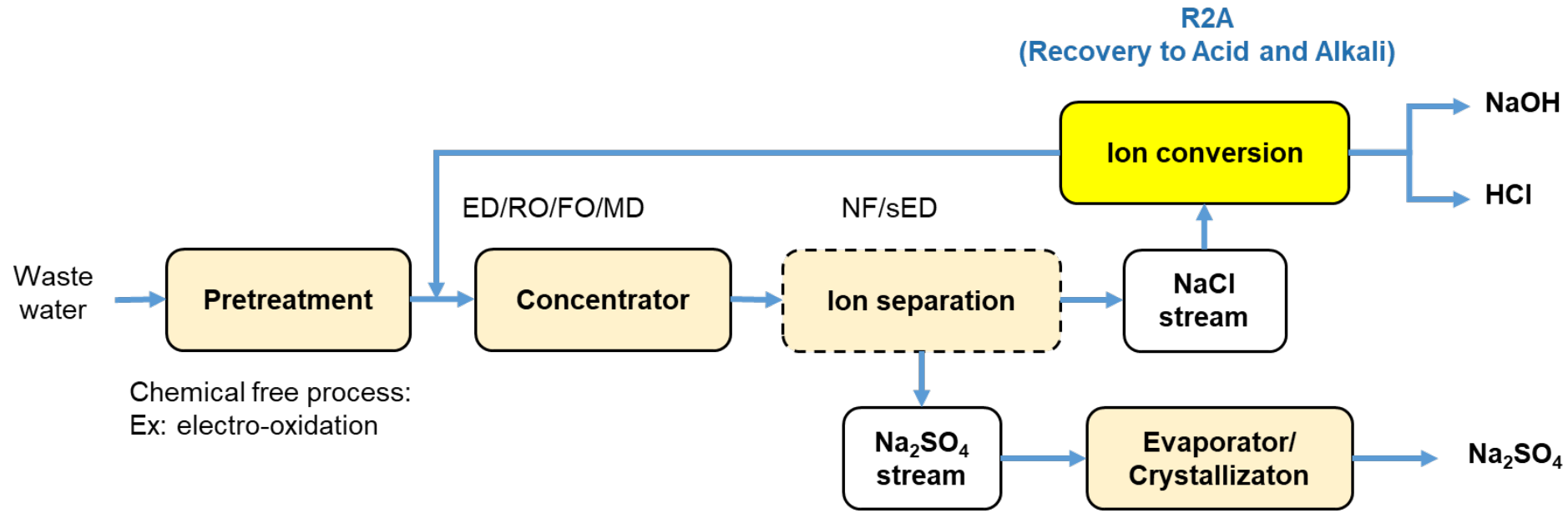


- Water reclamation
- Pharmacy recycle
- ZLD
- Ion resourcezation

- Concentration treatment
- Recovery rate enhancement
- ZLD
- Ion resourcezation

- Brine deionization (Na^+, Cl^-, SO_4^{2-})
- Waste effluent deionization (Na^+, Cl^-, SO_4^{2-})
- Organic wastewater deionization (Na^+, organic acid)
- Spent acid purification (H_3PO_4, H_2SO_4, HCl)

Applications Integration

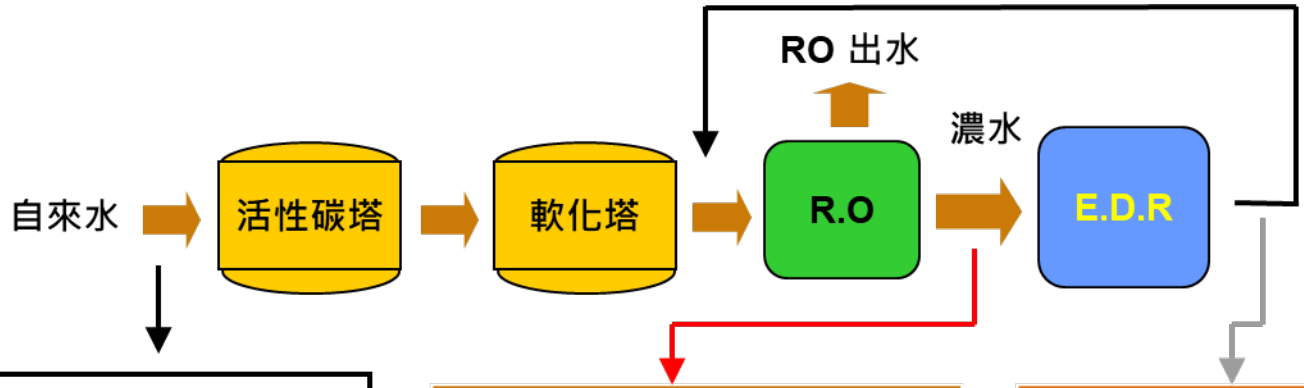


Recovery of Sodium Sulfate powder

Conversion of residual solution to NaOH/ HCl solution

Applications Integration full scale case

※ Primary pure water system



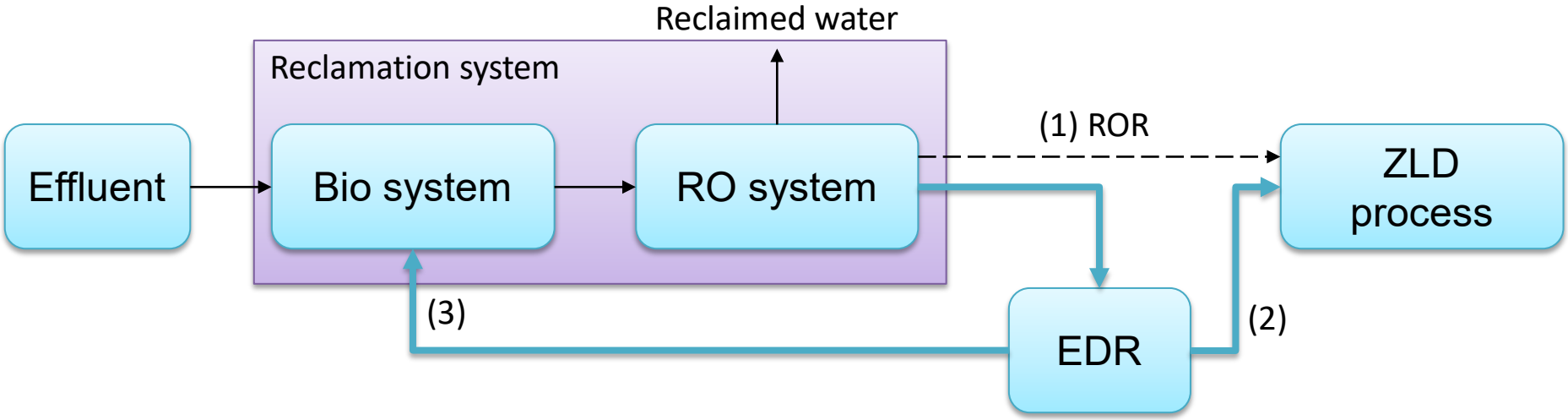
RO濃縮水水質			
pH	:	7.5	
電導度	:	760~800	μS/cm
總硬度	:	3~5	mg/l
氯離子	:	39~42	mg/l
SO_4^{2-}	:	180~190	mg/l

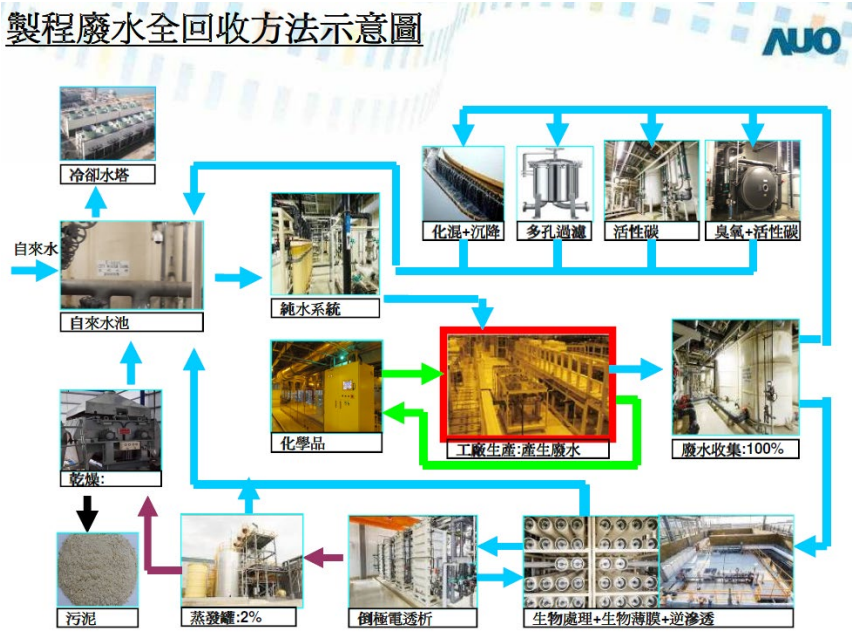
EDR處理後水質			
pH	:	6~8	
電導度	:	≤ 250	μS/cm
總硬度	:	ND	mg/l
氯離子	:	≤5	mg/l
SO_4^{2-}	:	≤30	mg/l

提高系統水回收率>15%

產水量 (m^3/day)	脫鹽率 (%)	EDR運轉成本(NT/m^3) (含電費、藥品費)
300	70↑	2.1

Applications Integration full scale case





1) Conventional ZLD process, the ROR entirely into the evaporation and crystallization units.
2) The ROR volume is reduced before entering the evaporation and crystallization unit, significantly lowering the operating cost of the ZLD system.
3) The permeate is returned to the reclamation system, increasing the overall water recovery rate. This eliminates the need to treat the RO reject directly to water reuse quality, effectively reducing the design capacity of the EDR system.

Applications Integration full scale case

Installation of a 3,000 CMD EDR water recycling system to mitigate the risk of production line shutdowns due to water shortages.

- The discharged water contains high levels of calcium and sulfate. The scaling effect makes it unsuitable for using RO. Therefore, the EDR desalination system was designed and implemented to achieve the goal of water recycling.
- The 3,000 CMD of recycled water can be used as make-up water for cooling towers, reducing the consumption of tap water. At the same time, it enhances the company's green image and supports the expansion of international business.

Constituent	Feed	Product	Brine
Conductivity (μS/cm)	4480	495	9950
Na^+ (mg/L)	210	48	470
K^+ (mg/L)	270	30	596
Ca^{2+} (mg/L)	400	10	990
Mg^{2+} (mg/L)	23	1	48
Cl^- (mg/L)	1510	137	3650
NO_3^- (mg/L)	20	2	38
SO_4^{2-} (mg/L)	450	45	1060

Module test evaluation

EDR Water Resource Center

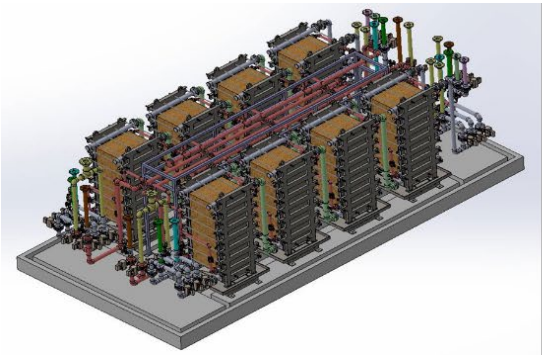
EDR Water Recycling Pipeline Project

EDR Water Recycling System

Applications Integration full scale case

Effluent → ASF (100 μm) → SMF (0.05 μm) → EDR → RO → Product water

Item	Effluent	Recycled Water
Volume (CMD)	6,000	3,000
pH	6.5-9.0	5.5-7.5
Conductivity **(μS/cm)**	<6,500	<550
COD (mg/L)	<70	<60
Si (mg/L)	<30	---
Na^+ (mg/L)	<350	<100
Ca^{2+} (mg/L)	<600	<80
Mg^{2+} (mg/L)	<35	<10
Cl^- (mg/L)	<2000	<250
SO_4^{2-} (mg/L)	<600	<200



Treatment water: 6,000 CMD

- 56 EDR stack
- 4 stacks/line
- 14 lines
- 220 pairs membrane/stack

Applications Integration full scale case

Item	Pricing basis	Annual cost (NT$/yr)	Cost* (NT$/$m^3$)
1.Electricity	=11,000 kWh/day×2.3 NT$/kWh×365 day	9,235,000	10.5
2.Chemicals	=830 kg/day×5 NT$/kg×365 day	1,515,000	1.7
3.Labor	=800,000 NT$/person/yr×1 person	800,000	0.9
4.Maintenance	=450,000,000(Capital cost) ×1%	4,500,000	5.1
	=18,600,000(Membrane replacement) ×20%	3,720,000	4.2
Total (1+2+3+4)		19,770,000	22.4

*Estimated at 2400 CMD of recycled water

EDR of ITRI

Industrial treated effluent → Electrodialysis Reversal(EDR) →
- **Industrial process water**
- **Cooling water**

※ Converting Industrial Wastewater into Resource

ITRI Electrodialysis Reversal (EDR) : 8 patents(Taiwan, China, Singapore), 2 pending

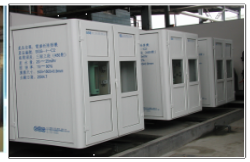
EDR desalination of Ground water for rinsing water (50 m^3/day)

EDR desalination of RO reject for rinsing water (electronics) (300 m^3/day)

Recovery of wastewater from screw manufactur-ing factory for rinsing water by EDR process (450 m^3/day)

Recovery of wastewater from PCB manufacturing factory for cooling tower by EDR process (1200 m^3/day)

Recovery of fluoride-containing wastewater from wafer factory for scrubber by EDR process (1200 m^3/day)



EDR desalination of high conductivity river water for process water (2400 m^3/day)

Desalination and reuse of RO concentrate stream (Food industry) (300 m^3/day)

Recovery of cooling water from electronics manufacturing factory by EDR process (Tiger company) (550 m^3/day)

Desalination and reuse of wastewater from precious screw manufacturing factory by EDR process (Nitto company, 350 m^3/day)

Desalination and reuse of direct cooling water from steel rolling by EDR process (China steel company,550 m^3/day)

Recovery of wastewater from chemical company for cooling water by EDR process (800 m^3/day)

Recovery of wastewater from zinc-plating process for rinse water by EDR process (China steel company, 700 m^3/day)

Recovery of wastewater from nylon fiber manufacturing company for cooling water by EDR process (800 m^3/day)

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Thanks