TAIWAN INT'L WATER WEEK

Sep. 10 ▸ 11
TICC台北國際會議中心

Water Towards Safety、Sustainable Environment and Prosperity

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Water Towards Safety Sustainable Environment and Prosperity 水與安全、環境、發展

Application of Fluidized-Bed Homogeneous Crystallization Technology for Recovering Metal and Non-metal Resources from Wastewater

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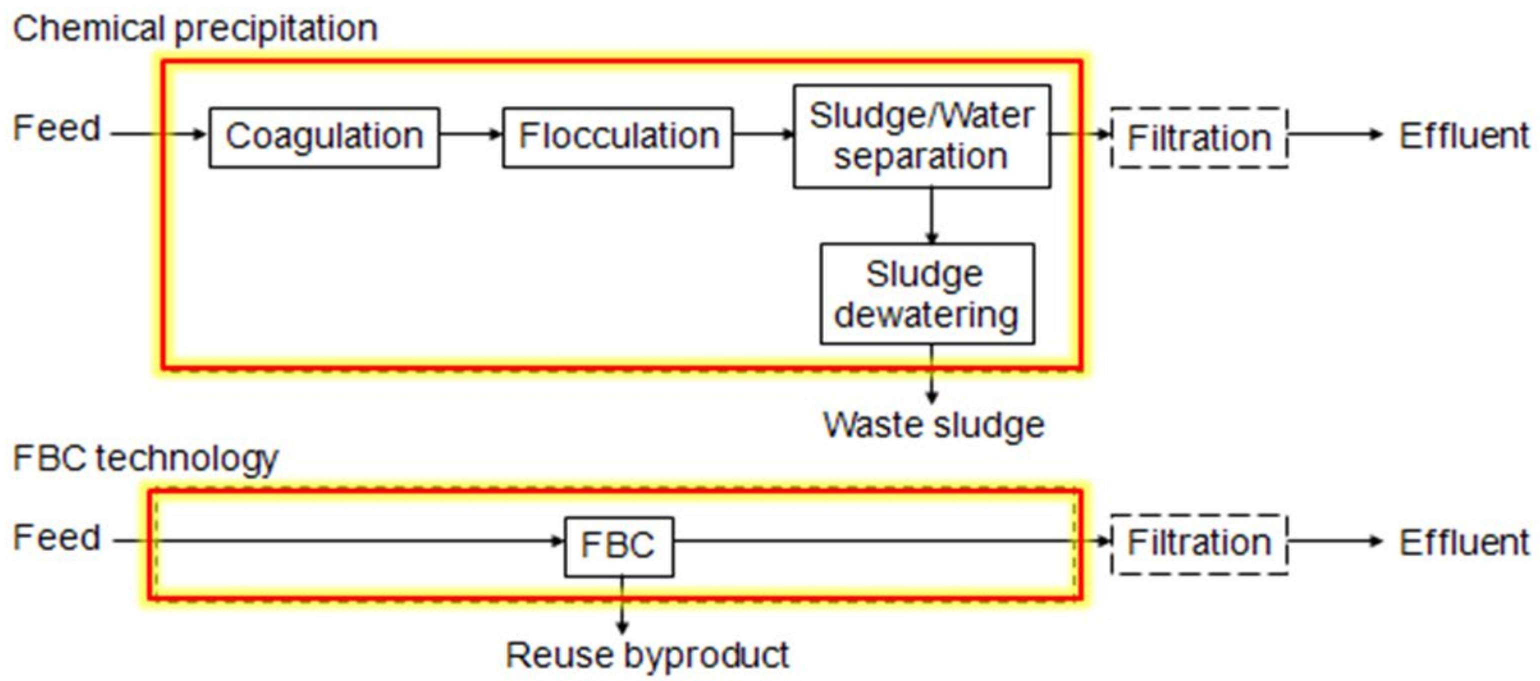
Department of Environmental Engineering
National Chung Hsing University
Taichung, TAIWAN

Content

- Principle of Homogeneous Crystallization Technology
- Technical Advantages
- Application
    - Metal and non-metal recovery
    - Carbon dioxide capture from flue gas
    - Resource recovery from brine
- Take-home messages

Sludge after dewatering



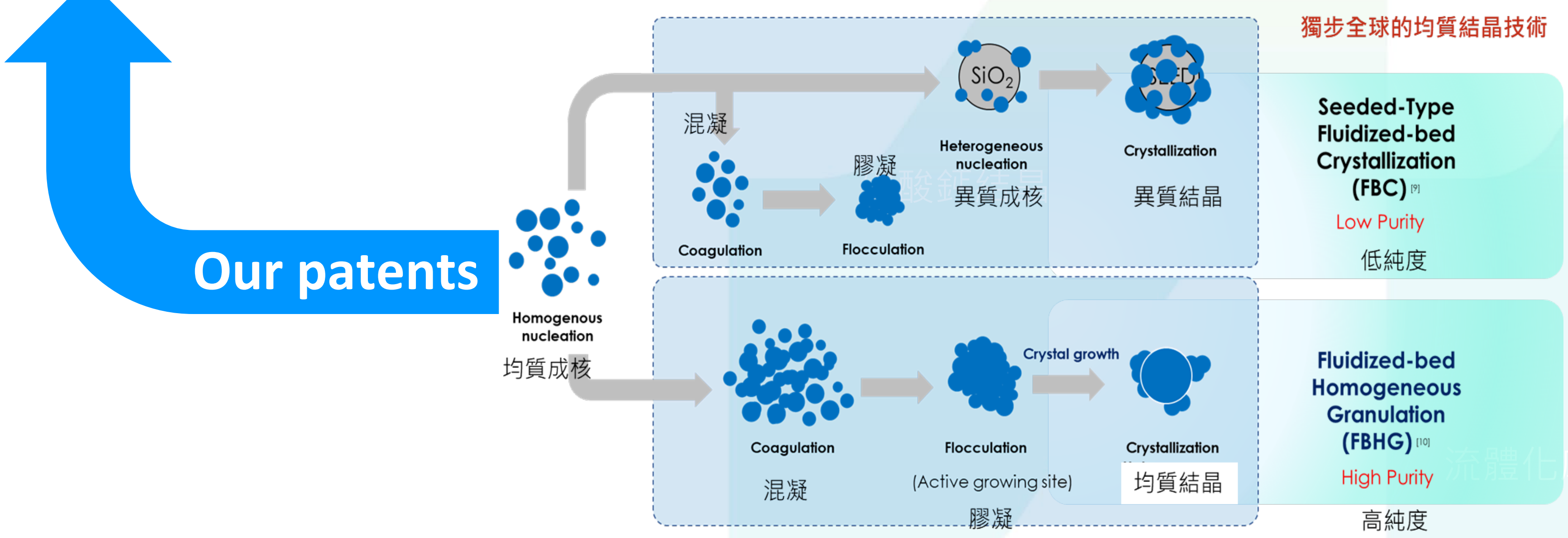
Comparison of chemical precipitation and crystallization processes

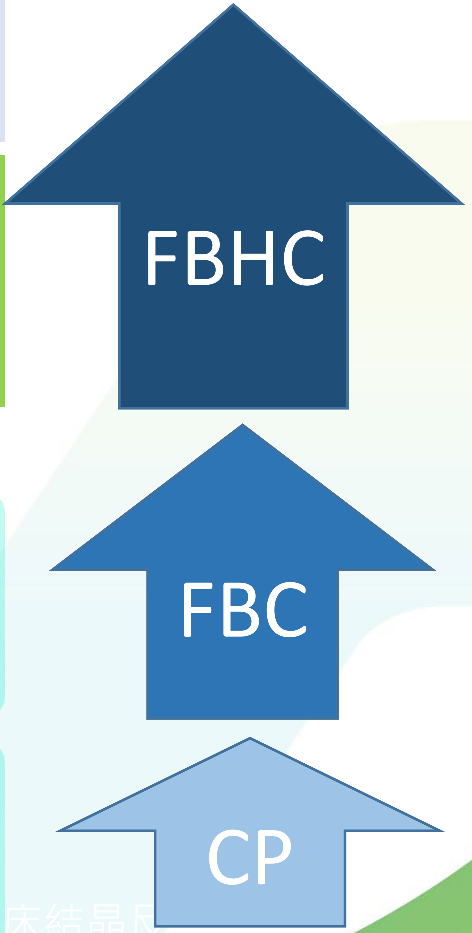
■Principle

Using a fluidized bed reactor to recover metal or non-metal ions in the form of homogeneous crystal granules as resources for reuse

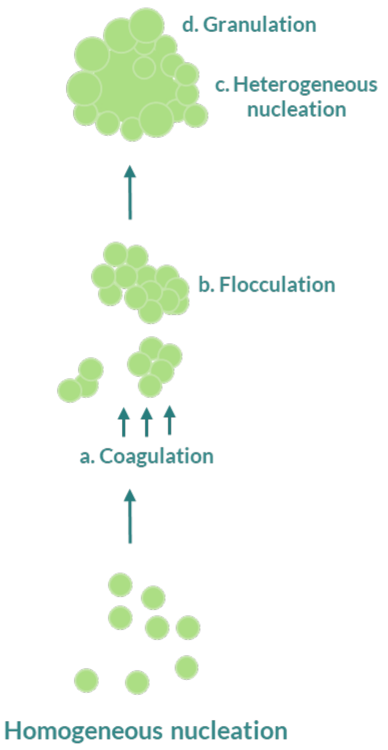
Unique in the world : The **homogeneous** crystallization technology

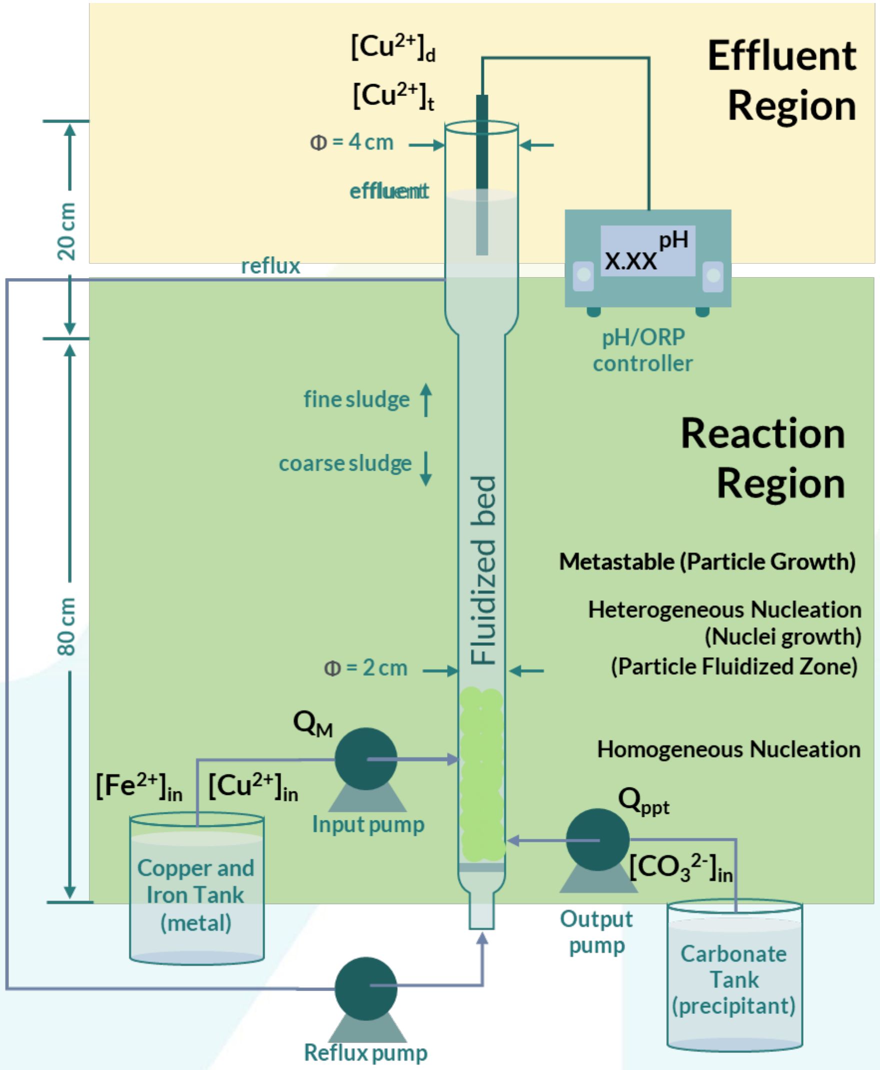
Comparison of chemical precipitation (CP), fluidized bed heterogeneous crystallization (FBC) and fluidized bed homogeneous crystallization crystallization (FBHC)

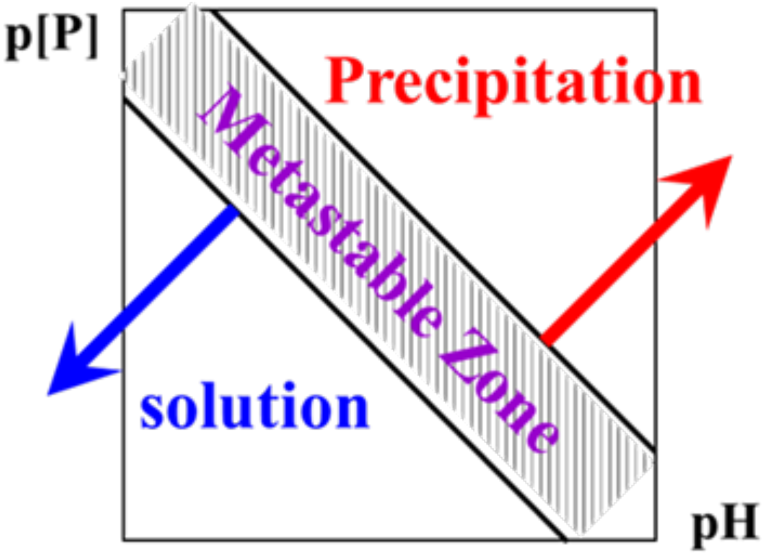


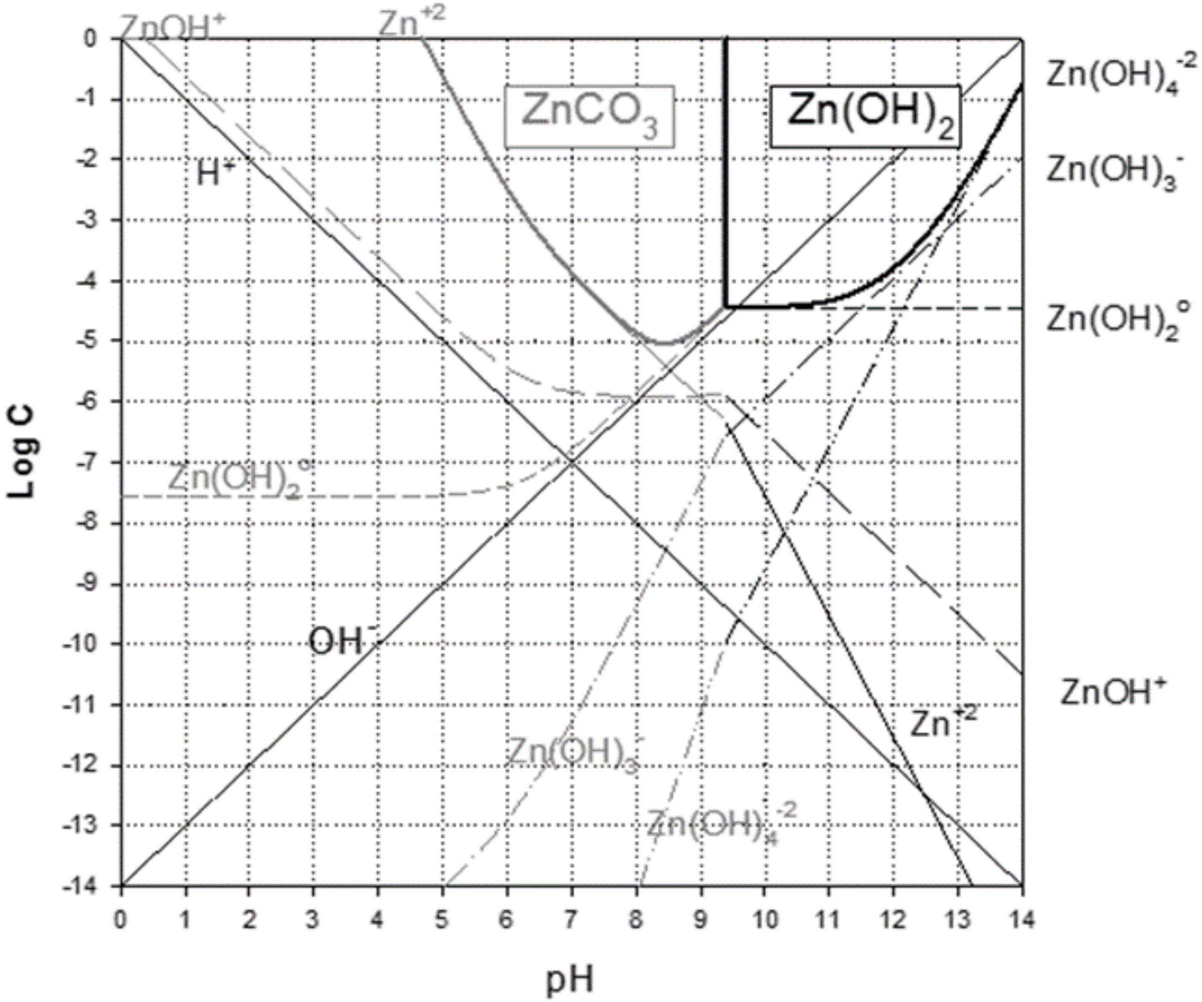


FBHC process

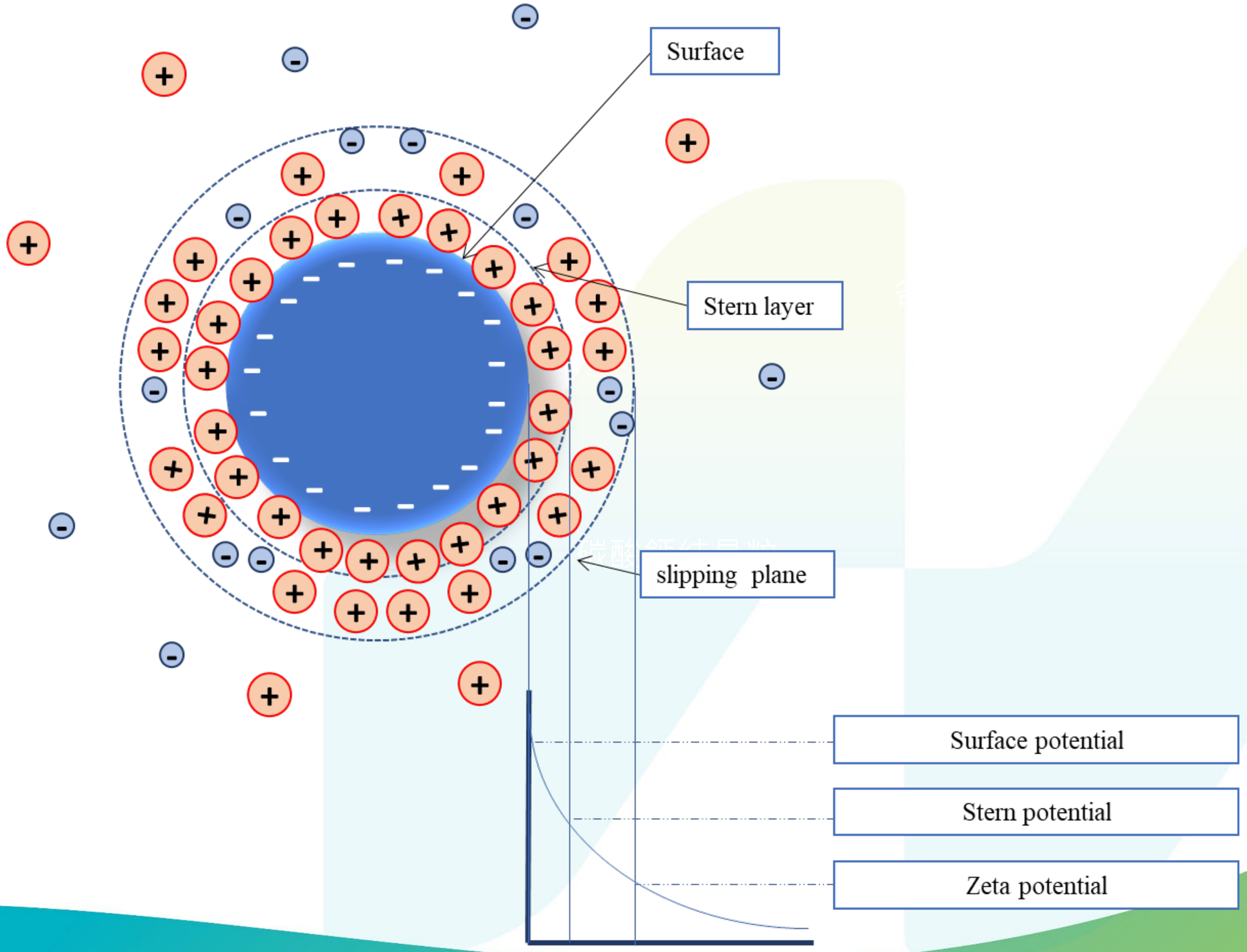





p[P]
Precipitation
Metastable Zone
solution
pH

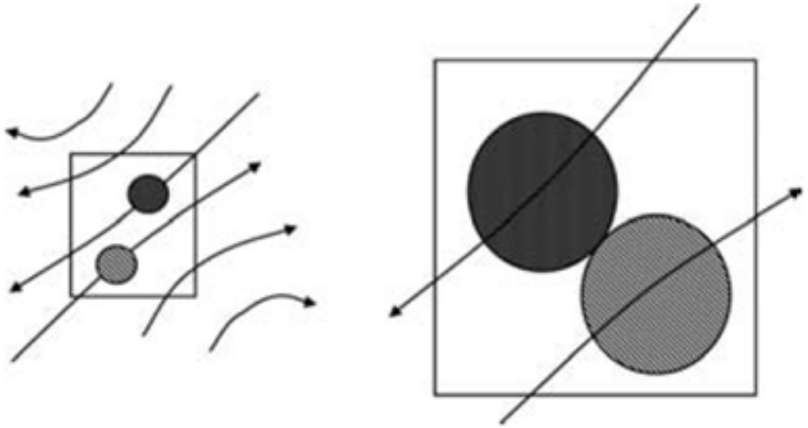

ZnOH+
Zn+2
ZnCO3
Zn(OH)2
H+
OH-
Zn(OH)2°
Zn(OH)3-
Zn(OH)4-2
Zn(OH)4-2
Zn(OH)3-
Zn(OH)2°
ZnOH+
Zn+2
Log C
pH
0
-1
-2
-3
-4
-5
-6
-7
-8
-9
-10
-11
-12
-13
-14
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14

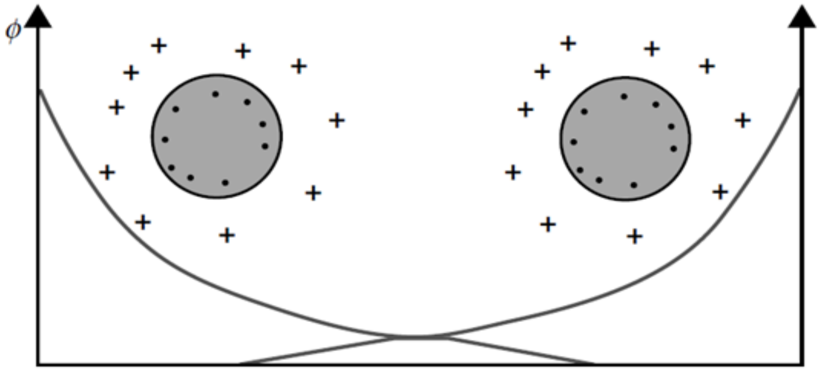
COLLOIDAL STRUCTURE AND STABILITY

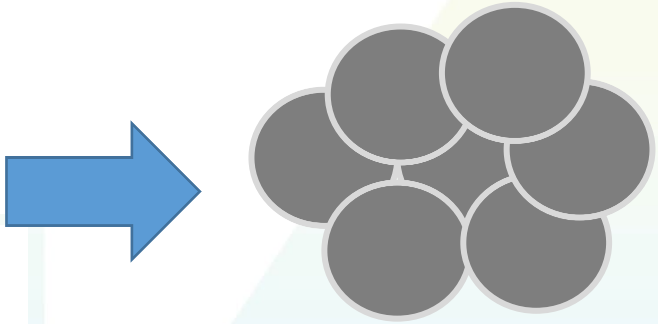


Process of Agglomeration

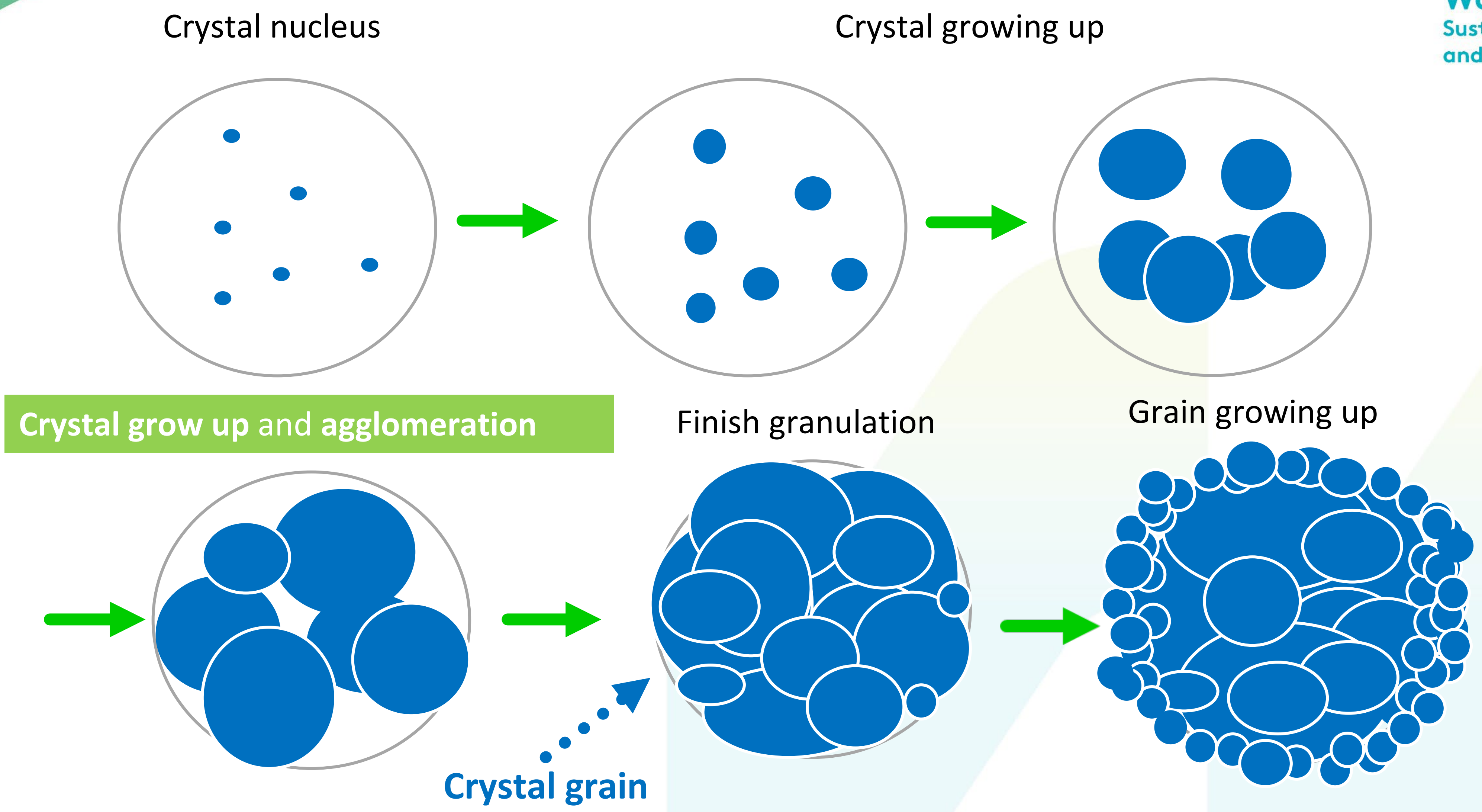
- ✓ For agglomeration to occur, two particles have to collide and the attractive forces between the two particles have to exceed the force resulting from the inertia of the particles to disintegrate again.
- ✓ The particles hit, tumble and either disintegrate or agglomerate. This first binding has to be fast.







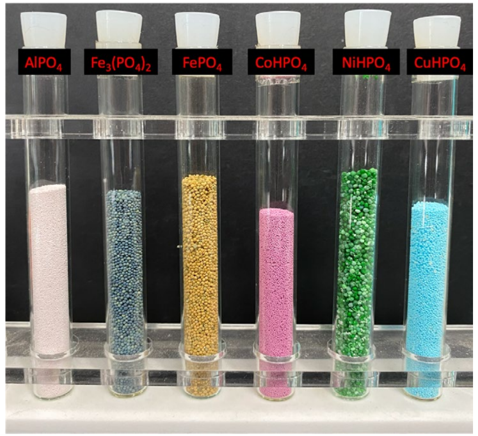
Agglomeration

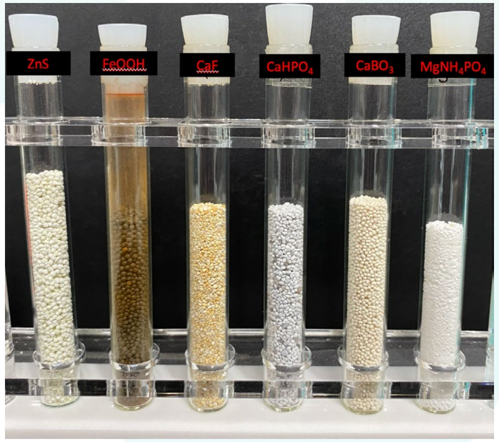


Granulation pathway

■Application

- ☐ Metal-Containing Wastewater Treatment and Resource Recovery
    - ✓ calcium, magnesium, iron, aluminum, copper, nickel, zinc, lead, cobalt, strontium etc.
- ☐ Nonmetal-Containing Wastewater Treatment and Resource Recovery
    - ✓ phosphate, oxalate, sulfate, molybdate, tungstate, ammonium, sulfur etc.
- ☐ Carbon dioxide capture and resource recovery from flue gas





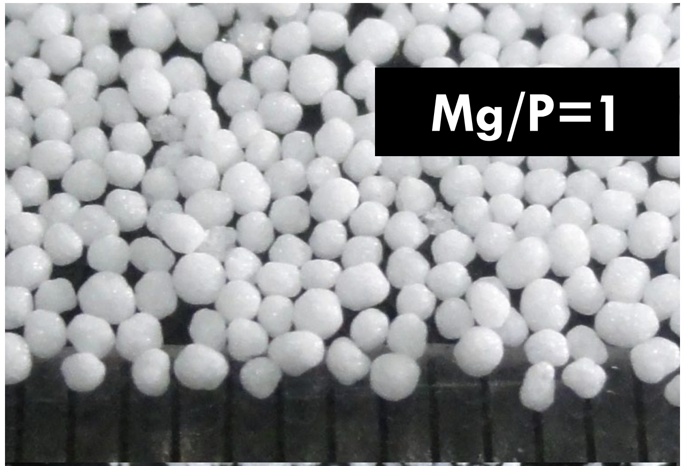
各種不

METAL REVOVERY

碳酸鈣結晶粒

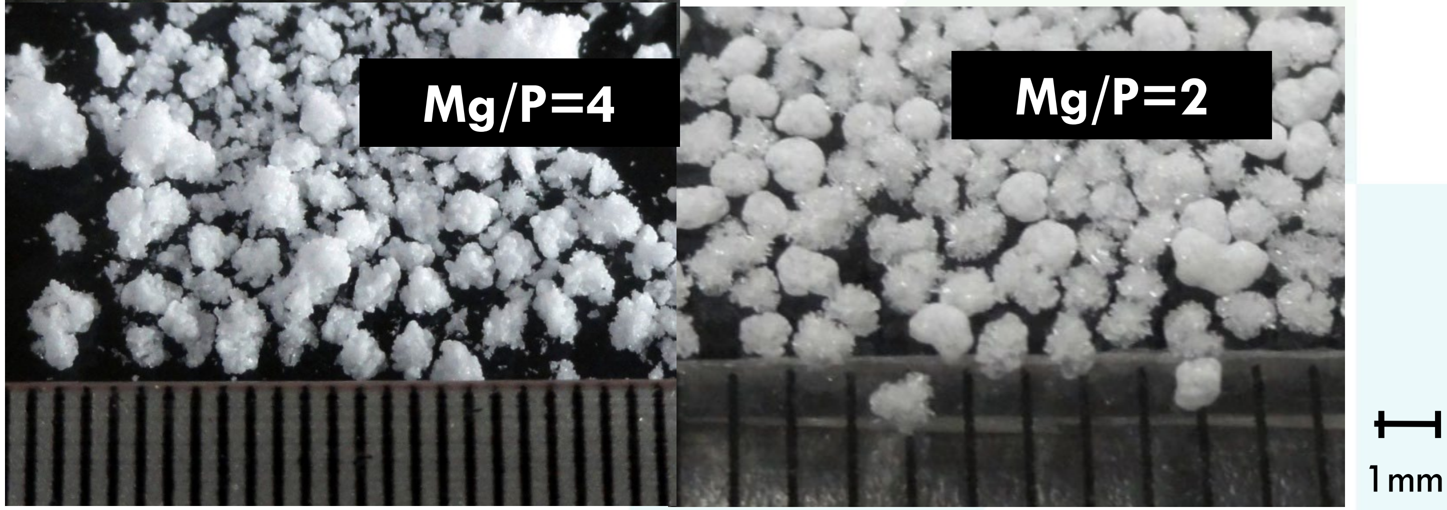
碳酸

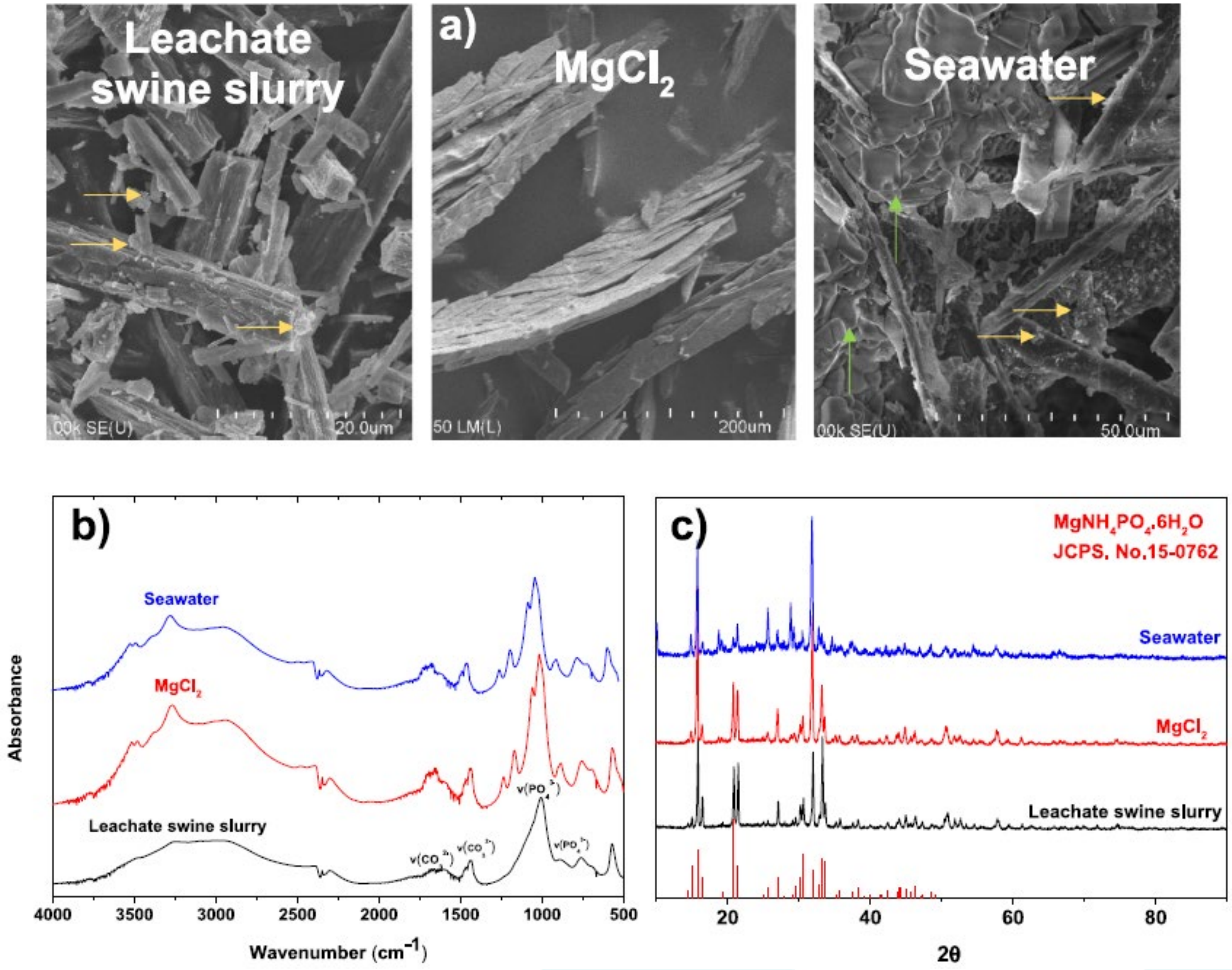
NON-METAL REVOVERY

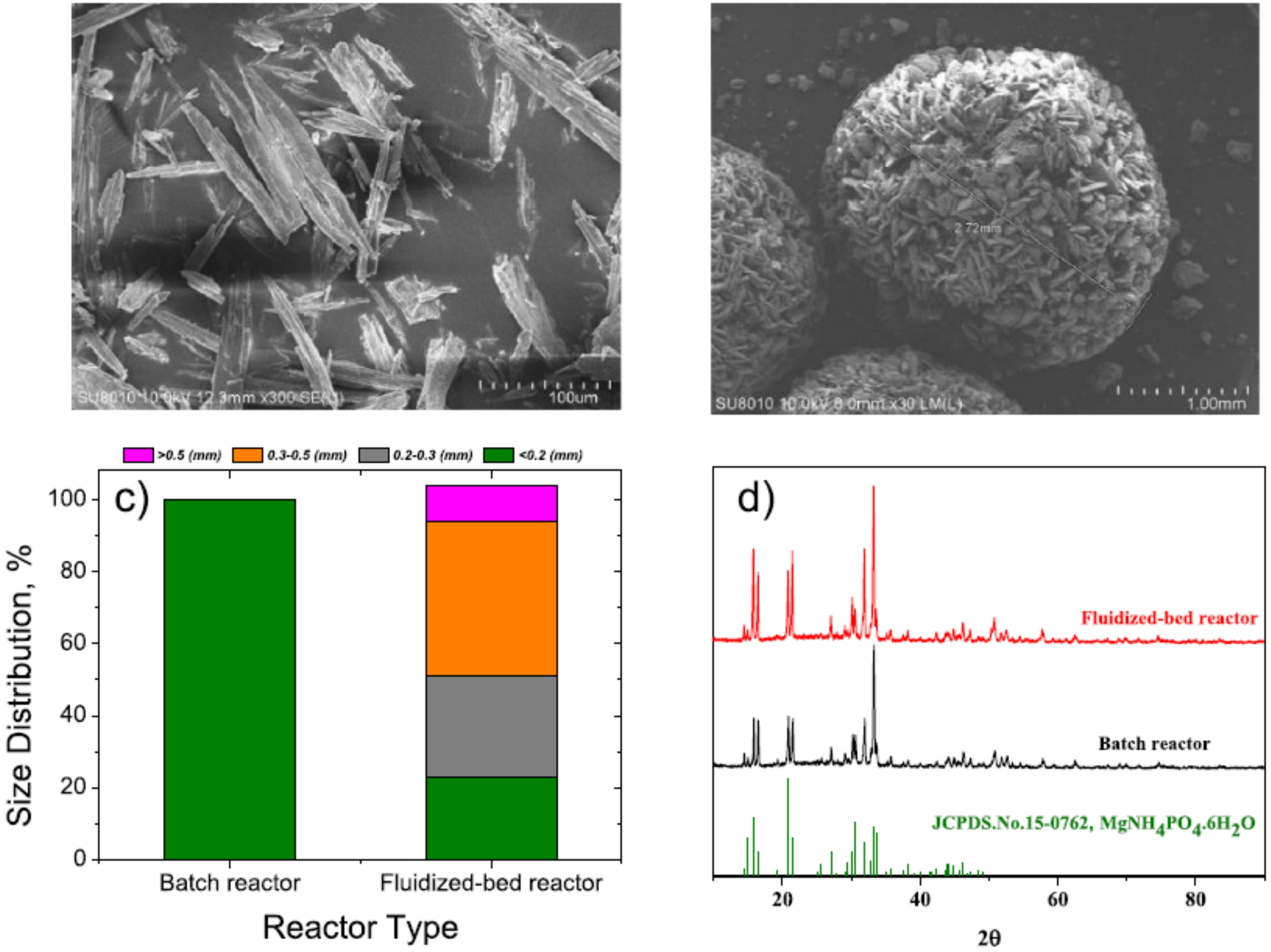


Struvite
magnesium ammonium phosphate(MAP)
$MgNH_4PO_4 \cdot 6H_2O$

MAP at different Mg/P molar ratio. [pH 9.0; 300mg-L^{-1}; N:P=6:1]

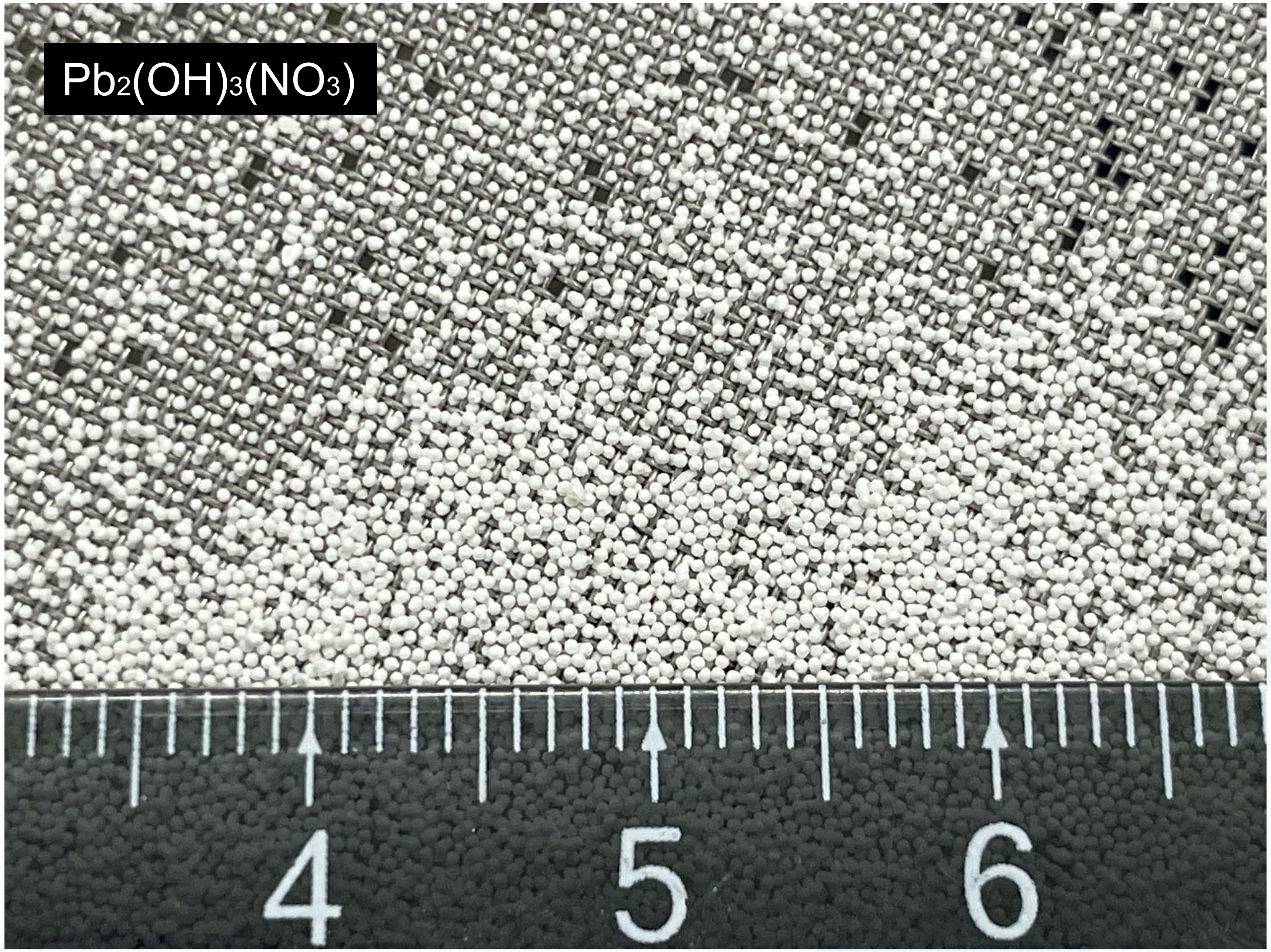


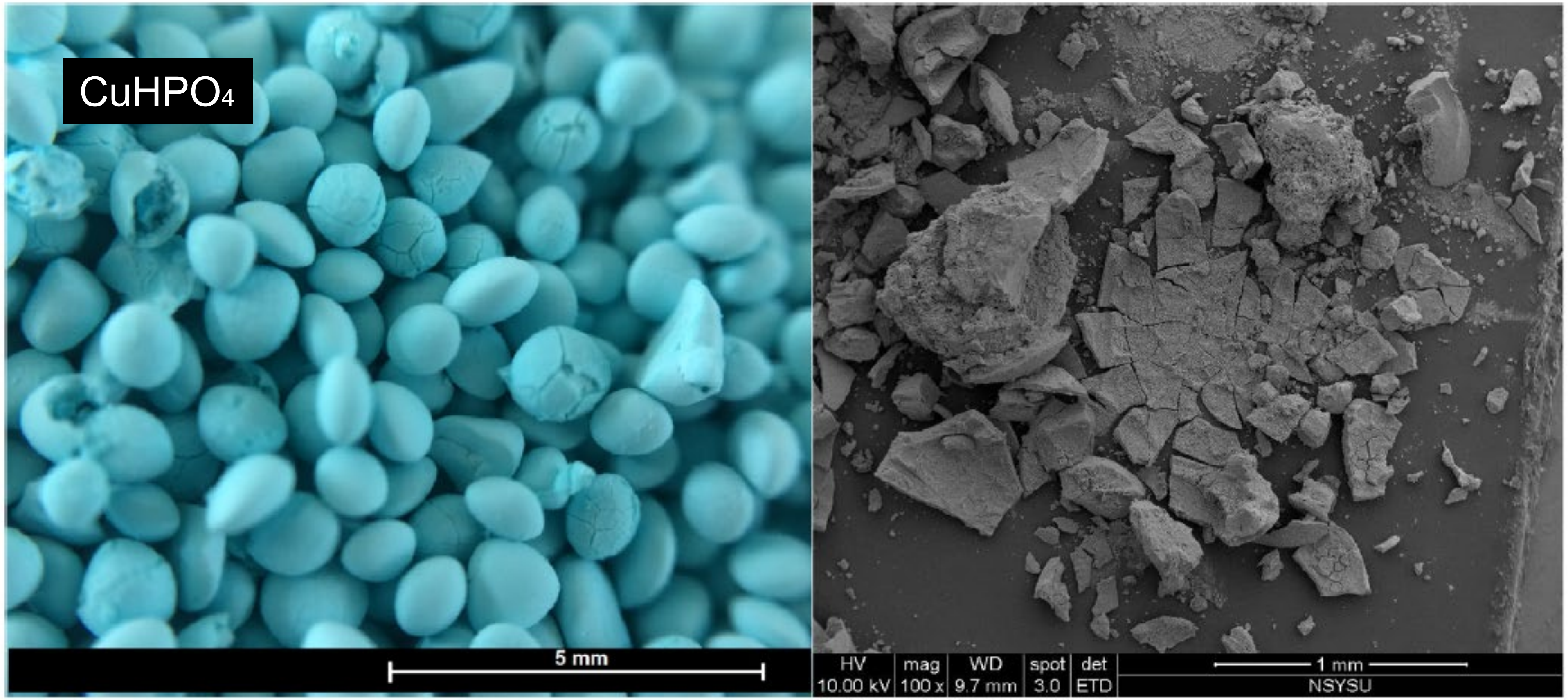

a)
Leachate swine slurry
MgCl2
Seawater
20.0um
200um
50.0um
b)
Seawater
MgCl2
Leachate swine slurry
Absorbance
Wavenumber (cm-1)
4000 3500 3000 2500 2000 1500 1000 500
c)
MgNH4PO4.6H2O
JCPS. No.15-0762
Seawater
MgCl2
Leachate swine slurry
20 40 60 80
2θ



Thi-Hanh Ha, Nicolaus N.N. Mahasti, Cai-Sheng Lin, Ming-Chun Lu*, Yao-Hui Huang*, 2023, Enhanced struvite ($MgNH_4PO_4 \cdot 6H_2O$) granulation and separation from synthetic wastewater using fluidized-bed crystallization (FBC) technology, Journal of Water Process Engineering, 53, 103855.

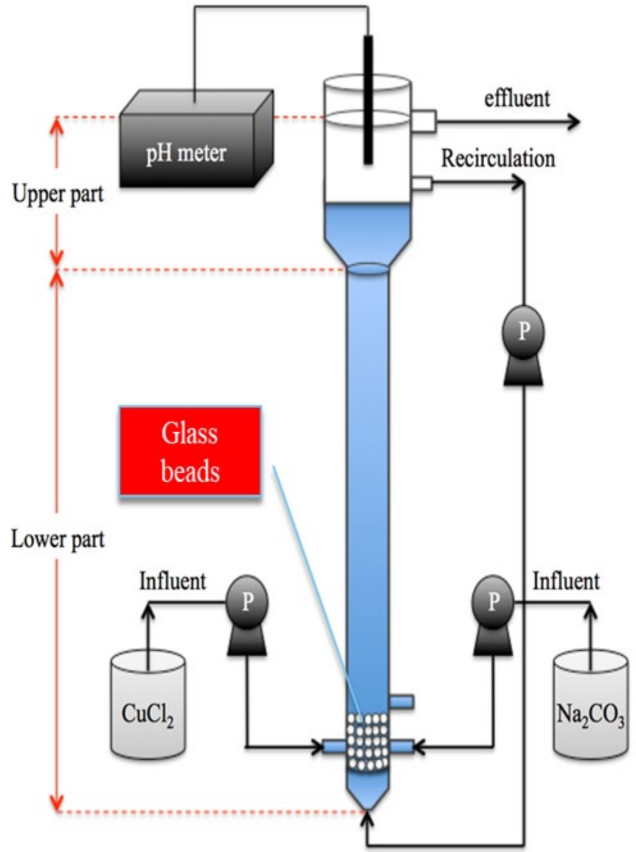
BOTH METAL AND NON-METAL REVOVERY


$Pb_2(OH)_3(NO_3)$
4
5
6



Lester Lee E. Bayon, Florencio C. Ballesteros Jr. Sergi Garcia-Segura, Ming-Chun Lu*, 2019, Water reuse nexus with resource recovery: On the fluidized-bed homogeneous crystallization of copper and phosphate from semiconductor wastewater, Journal of Cleaner Production, 236, 117705.

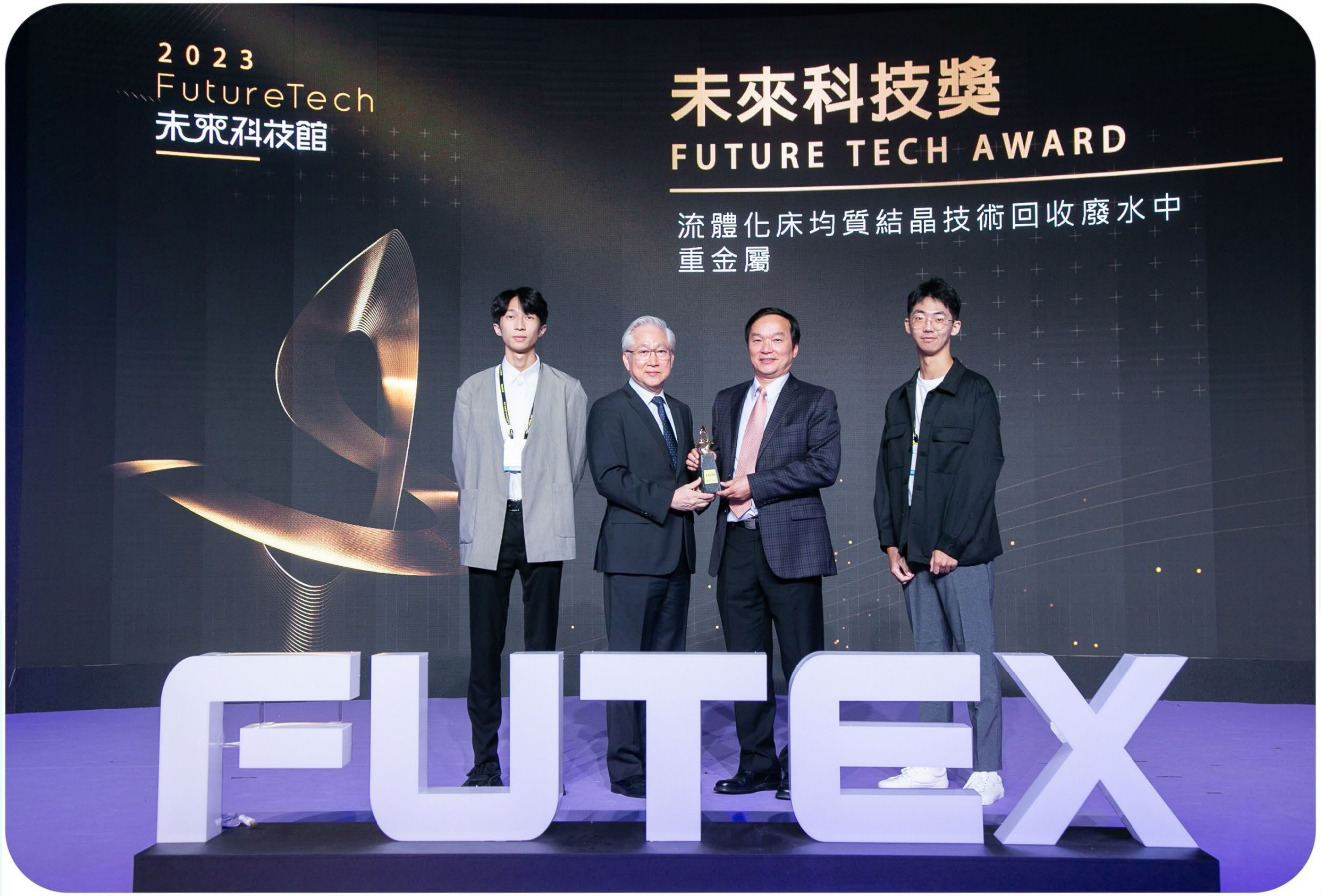
■Fluidized-bed reactor



For 10 CMD

For 7000 CMD


2023
FutureTech Award
未來科技獎
興大 4 團隊
盧明俊、黃輝耀
流體化床均質結晶技術
回收廢水中重金屬
榮獲未來科技獎
未來科技館
未來科技獎
FutureTech Award


2023
FutureTech
未來科技館
未來科技獎
FUTURE TECH AWARD
流體化床均質結晶技術回收廢水中
重金屬
FUTEX

■Technical advantages

- ☐ Less energy consumption due to operation at normal temperature and pressure
- ☐ Removing both metal and non-metal salts in water.
- ☐ Saving at least 50% of the treatment cost because the moisture content of the crystals obtained is only 5%,

- ☐ High potential for subsequent resource recovery due to high purity of crystals obtained by homogeneous crystallization technology
- ☐ High treatment efficiency and high operational flexibility

- ☐ Integrating vertically the units in a single one to reduce land costs

Comparison benchmark:

Crystal grain moisture content 5%

Dewatered sludge moisture content: 70 %

Dewatered sludge moisture content reduced from 70% to 5%

Reduce carbon emissions:

>234 kg CO_2/ 1000 kg sludge

CARBON DIOXIDE CAPTURE AND CRYSTALLIZATION FROM FLUE GAS

President Tsai Ing-wen presented the championship award

gold medal

2022 Taiwan Innovation Technology
Expo Invention Competition

TTV News


YouTube AU
搜尋
台視新聞HD
發現科學
主播 黃品寧
1300
生成"碳酸鈣"可回收再利用 減碳量驚人
13:39:00
台視
訂閱
生成「碳酸鈣」可回收再利用 減碳量驚人【發現科學】


YouTube TW
搜尋
發現科學
台視新聞HD
碳捕集新技術
能有價回收再利用
純度都可以高到99.5%以上
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13:39:58
最新快訊
央行總裁楊金龍今出席立院財委會，接受立
台視
訂閱
生成「碳酸鈣」可回收再利用 減碳量驚人【發現科學】
台視新聞 TTV NEWS
112萬位訂閱者
訂閱
109
分享
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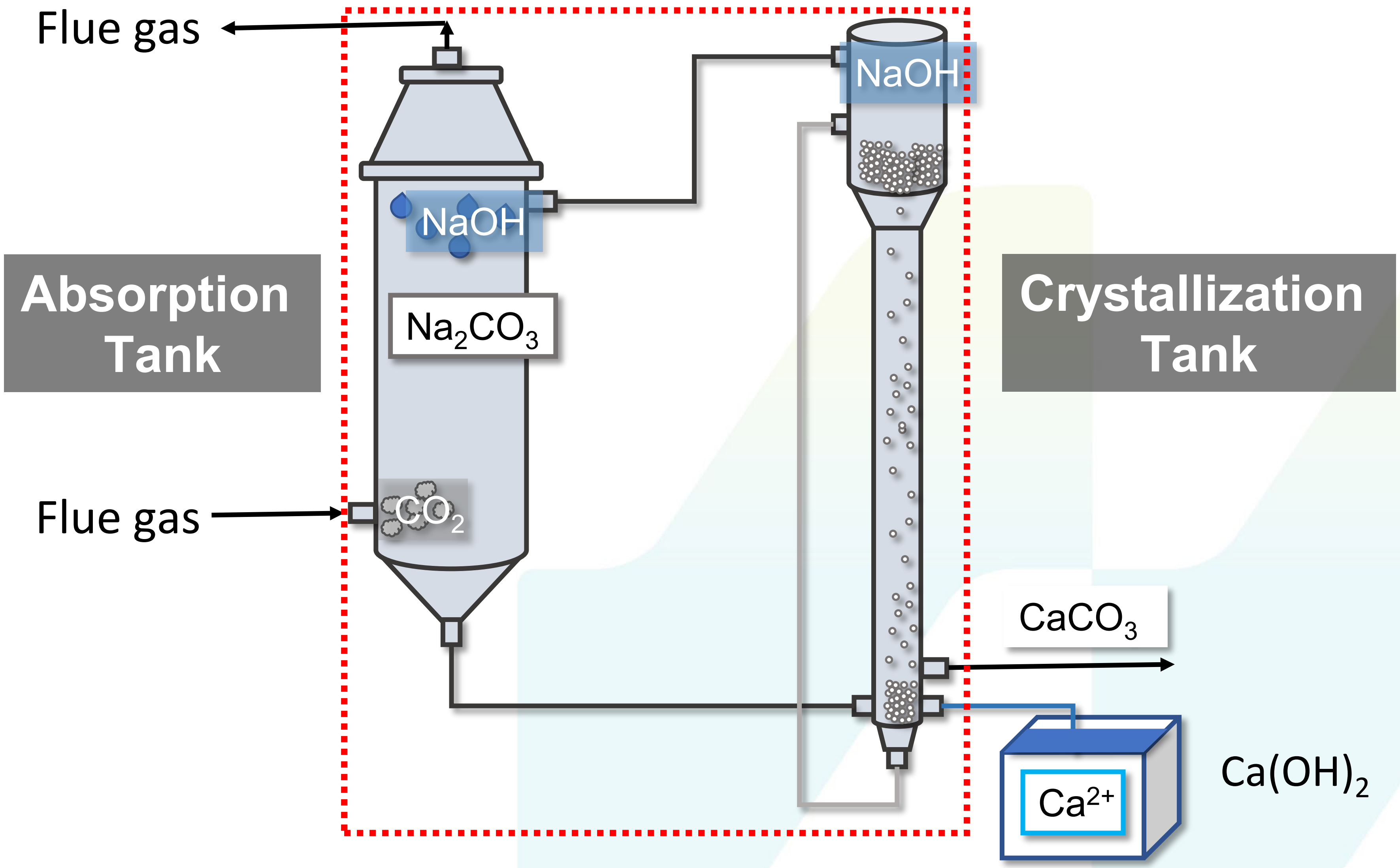
觀看次數：6287次 4 天前 #碳酸鈣 #二氧化碳 #減碳


Flue gas
NaOH
Absorption Tank
NaOH
Na_2CO_3
Flue gas
CO_2
Crystallization Tank
$CaCO_3$
$Ca(OH)_2$
Ca^{2+}


中華民國專利證書

發明第 I660770 號

發 明 名 稱：二氧化碳捕集與利用之裝置及處理方法

專 利 權 人：正紡興業有限公司

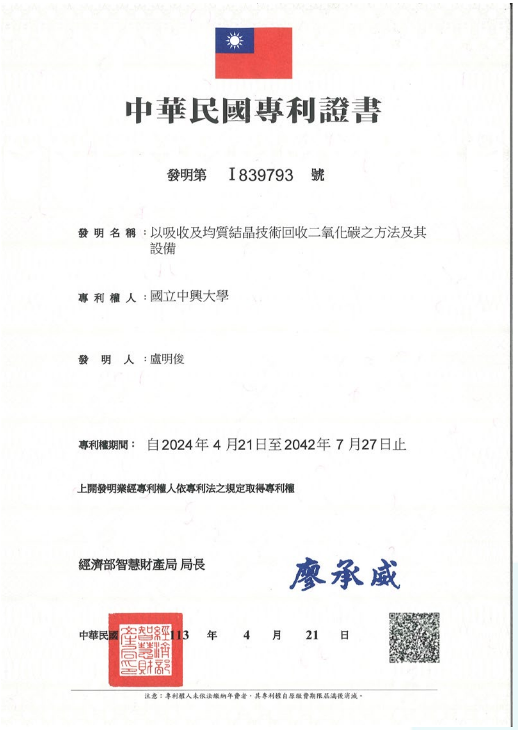
發 明 人：盧明俊、黃耀輝、吳 玄東

專利權期間：自2019年6月1日至2037年5月25日止

上開發明業經專利權人依專利法之規定取得專利權

經濟部智慧財產局 局長 洪淑敏

中華民國 110 年 1 月 19 日（換發）


中華民國專利證書

發明第 I839793 號

發 明 名 稱：以吸收及均質結晶技術回收二氧化碳之方法及其設備

專 利 權 人：國立中興大學

發 明 人：盧明俊

專利權期間：自2024年4月21日至2042年7月27日止

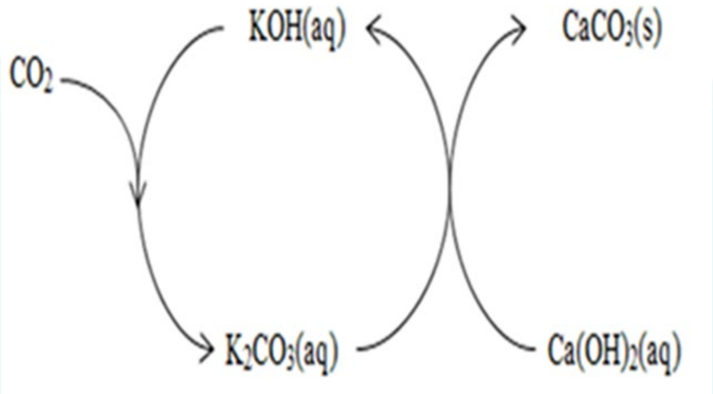
上開發明業經專利權人依專利法之規定取得專利權

經濟部智慧財產局 局長 廖承威

中華民國 113 年 4 月 21 日

□ The third one is under review

NaOH, KOH or other alkaline agents……



- According to the carbonate solubility curve

  pH 8-12 : HCO_3^- and CO_3^{2-} , pH ＞12 : CO_3^{2-}

$$CO_2 + H_2O \leftrightarrow H_2CO_3$$

$$H_2CO_3 \leftrightarrow HCO_3^- + H^+; K_{a1} = \frac{[H^+][HCO_3^-]}{[H_2CO_{3(aq)}]} = 4.8 \times 10^{-11}$$

$$HCO_3^- \leftrightarrow CO_3^{2-} + H^+;\ K_{a2} = \frac{[H^+][CO_3^{2-}]}{[HCO_3^-]} = 4.3 \times 10^{-7}$$

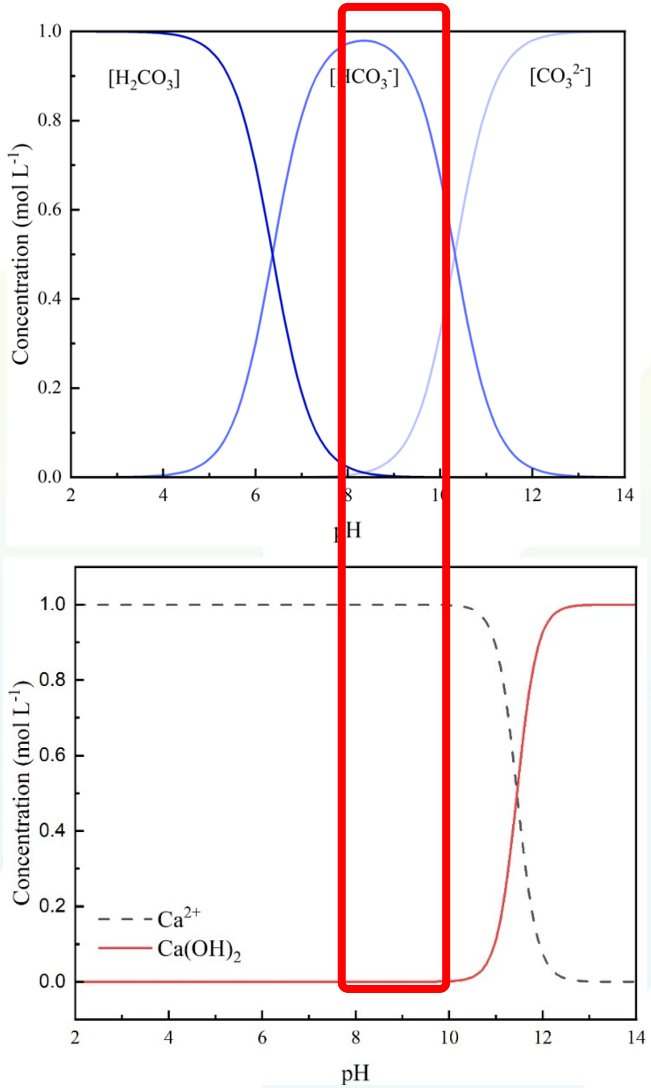
- According to the calcium solubility curve

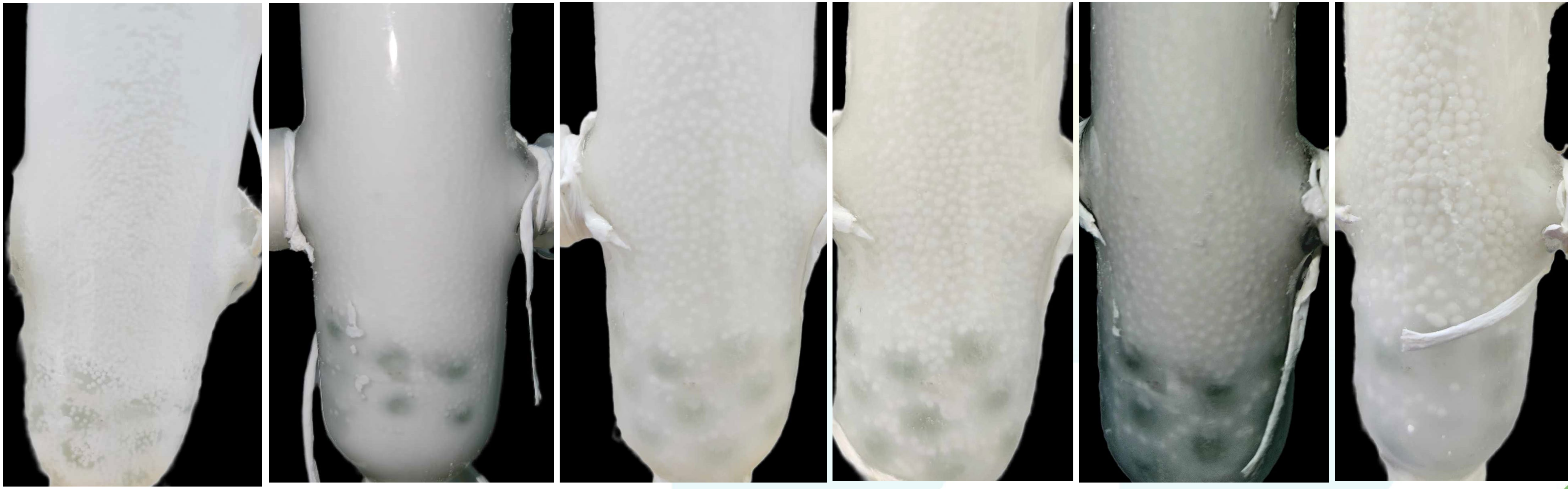
  At pH>10.5, $Ca(OH)_2$ formed

$$Ca(OH)_{2(aq)} \leftrightarrow Ca^{2+} + 2OH^-;$$

$$K_{sp} = \frac{\gamma_{Ca^{2+}}[Ca^{2+}] \times \gamma_{OH^-}[OH^-]^2}{[Ca(OH)_{2(aq)}]} = 7.9 \times 10^{-6}$$

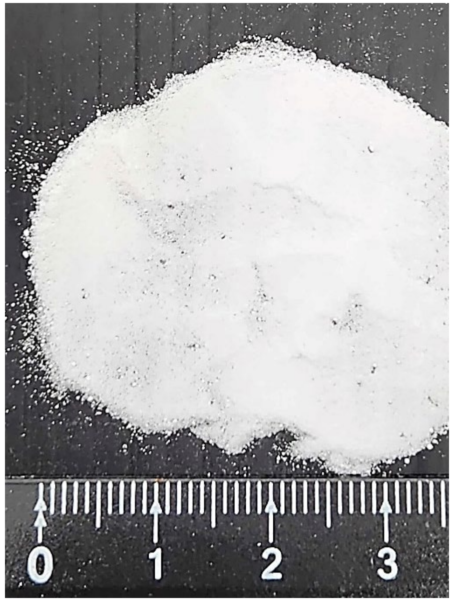
- Operation range: pH 8.0-10.0





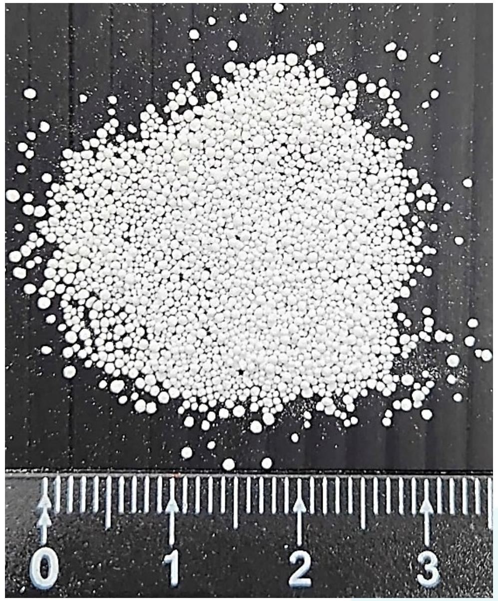
Day 1 Day 2 Day 3 Day 4 Day 5 Day 6

x < 0.38mm



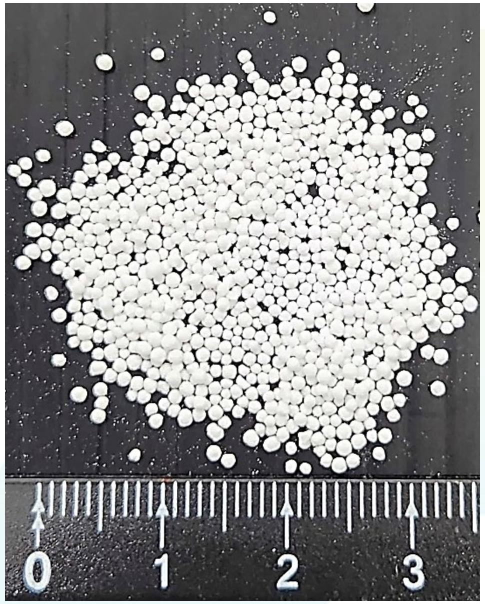
57.3%

0.38mm < x < 0.7mm



14.7%

0.7mm < x < 1mm



20.2%

1mm < x

7.8%

pH=9, MR=1, $[CO_3^{2-}]$ =0.120, $CaCl_2$

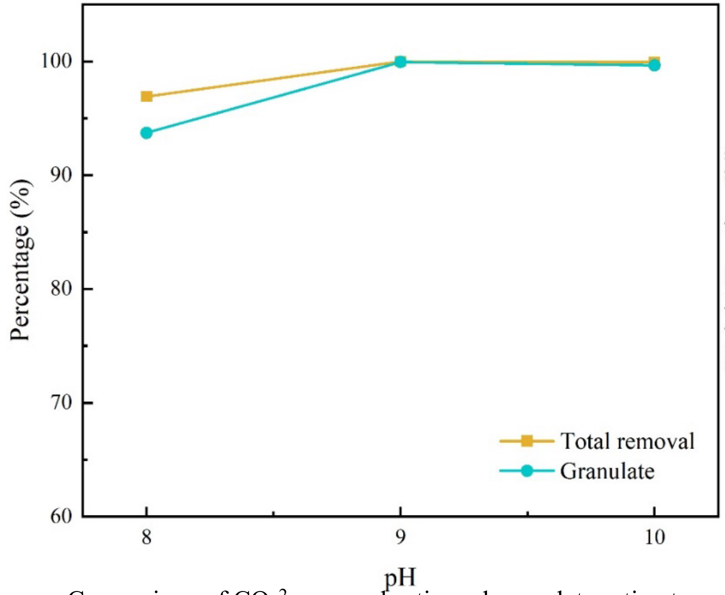
Effect of pH

Removal efficiency

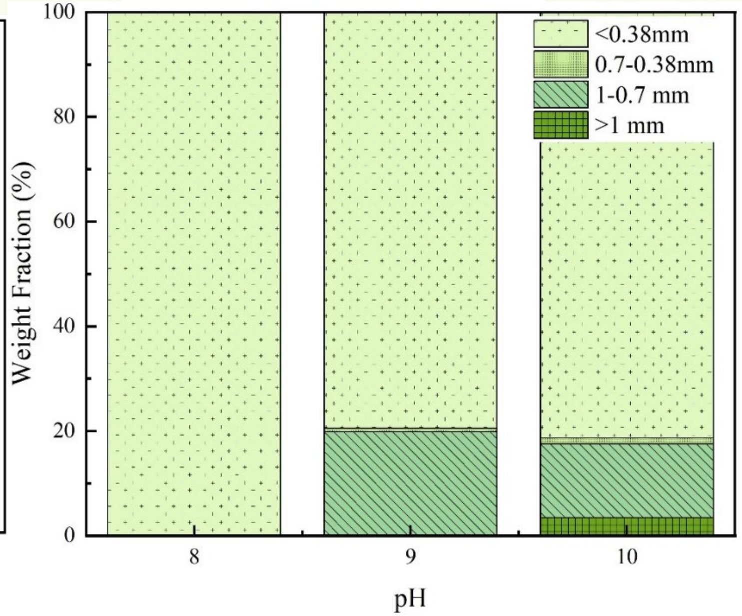
At pH 8, the removal and crystallization efficiencies were 96.9 and 93.7%, respectively, and those are 99.5% at pH 9, indicating that pH 9-10 was the optimum operating condition.

Size analysis

At a pH of 9, about 20% of the calcium carbonate particles were close to 1 mm in diameter. The granulation effect is significantly improved.

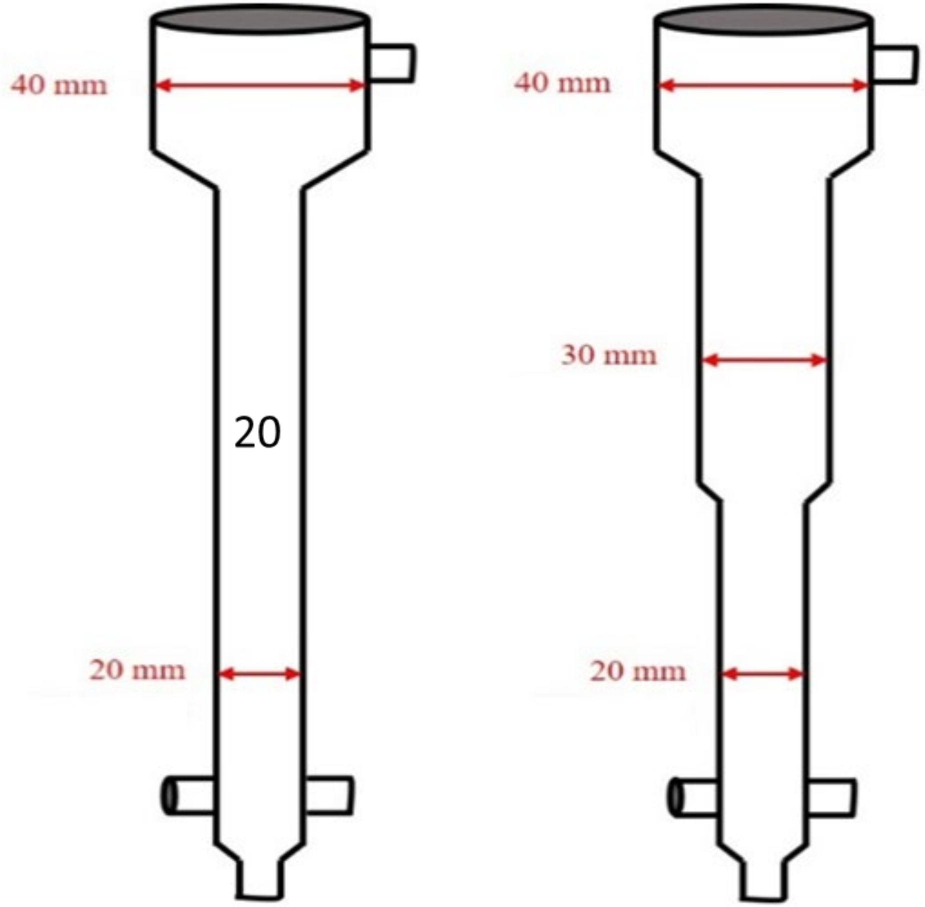


Comparison of CO_3^{2-} removal ratio and granulate ratio at different pH values .($[CO_3^{2-}]$=0.096, $[CO_3^{2-}]/[Ca^{2+}]$=1)



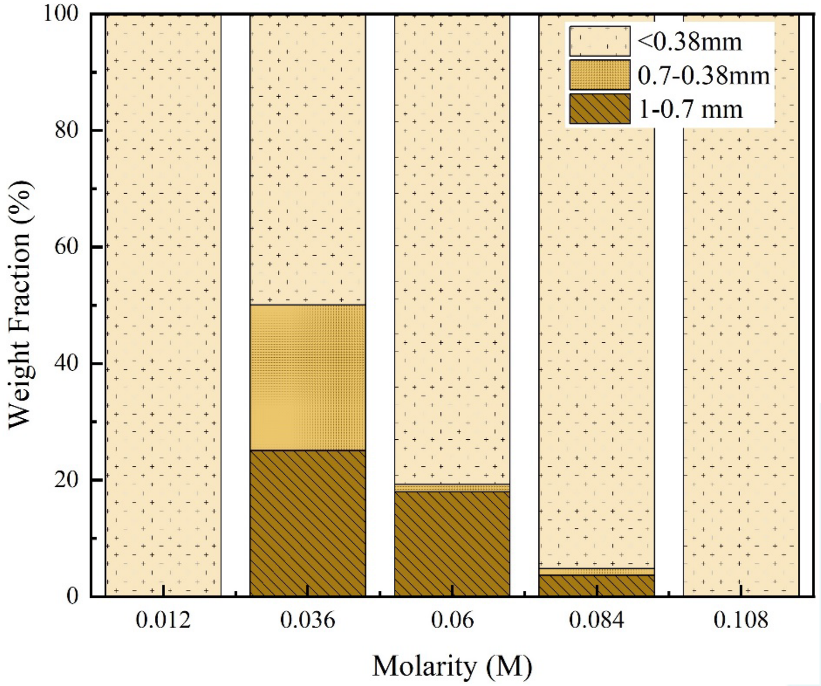
Comparison of $CaCO_3$ size distribution at different different pH values.($[CO_3^{2-}]$=0.096, $[CO_3^{2-}]/[Ca^{2+}]$=1)

■Reactor type



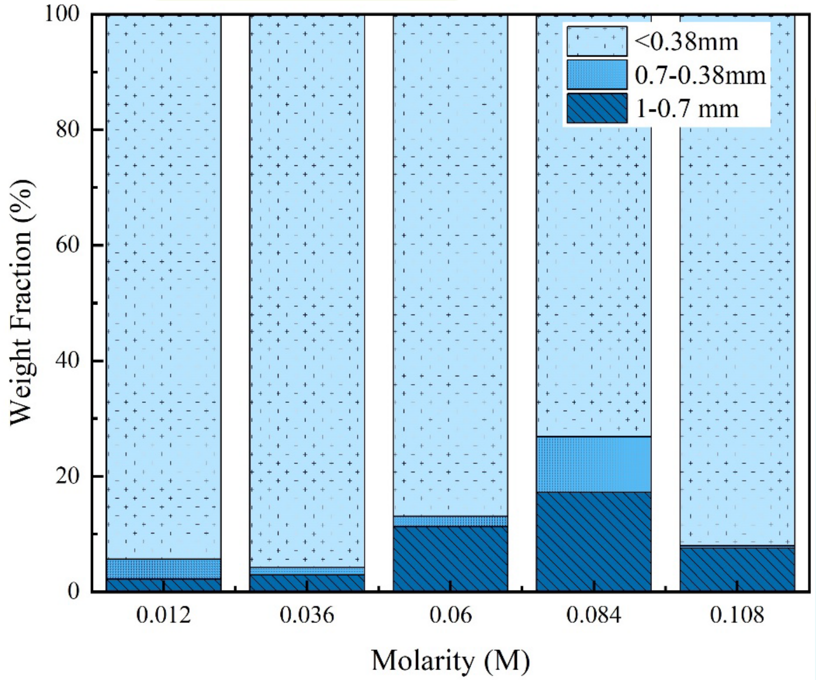
Effect of reactor type on granule size

- **One-stage reactor**



Comparison of $CaCO_3$ size distribution at different concentration.
($[CO_3^{2-}]/[Ca^{2+}]=1$, pH 9.0±0.3)

- Two-stage reactor



Comparison of $CaCO_3$ size distribution at different concentration.
($[CO_3^{2-}]/[Ca^{2+}]=1$, pH 9.0±0.3)

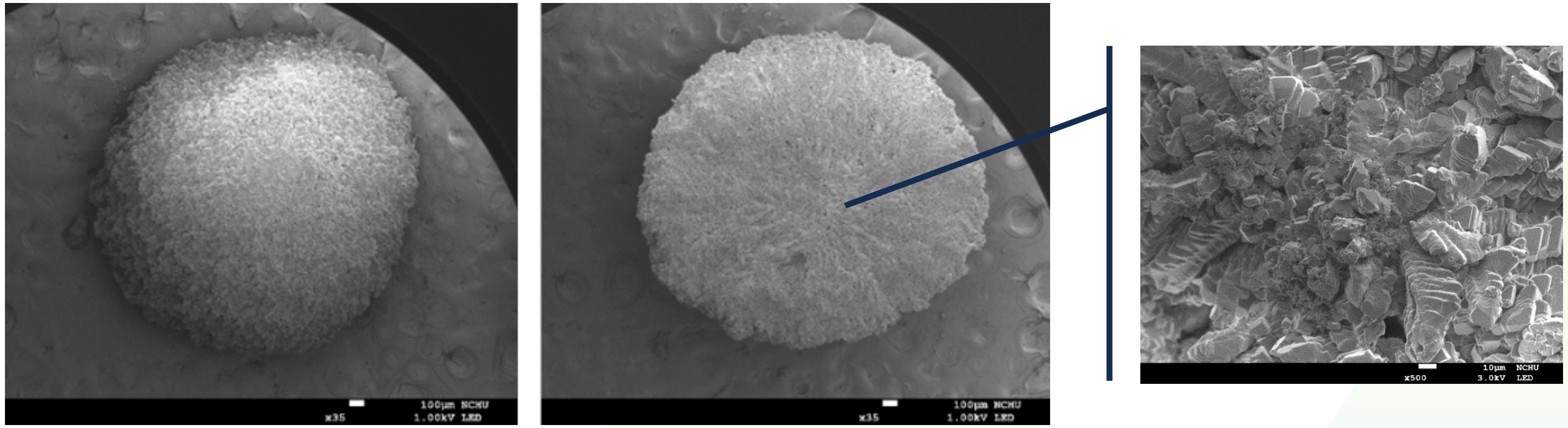
- **One-stage reactor**

  Composed of relatively fine crystals and the density is approximately 2.06 g/cm^3

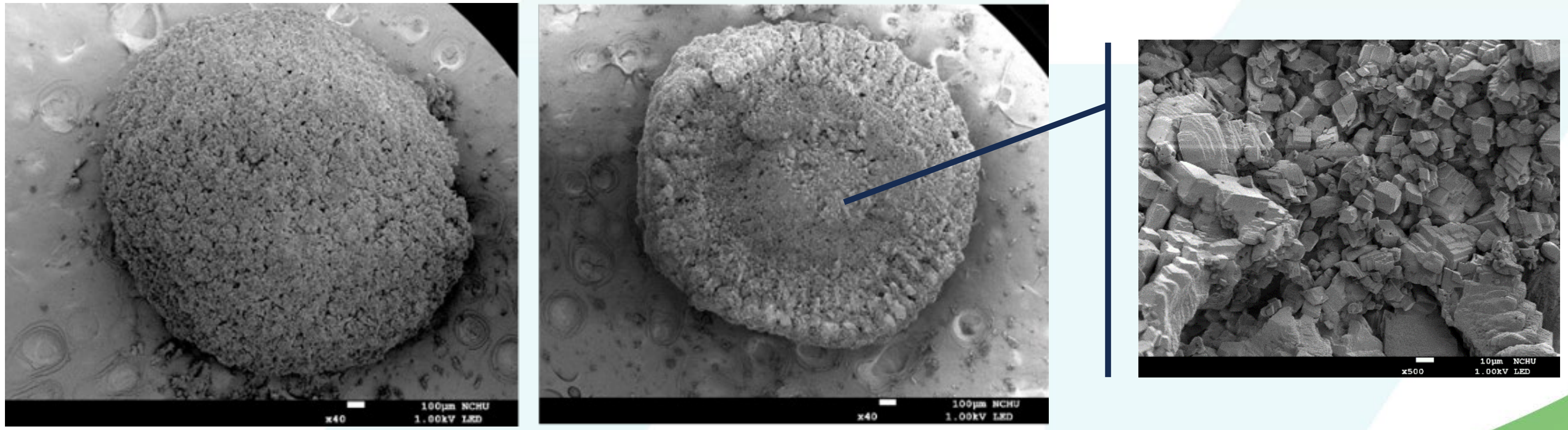
- **Two-stage reactor**

  The center of the granule is composed of larger crystal particles, and the density is approximately 1.68 g/cm^3

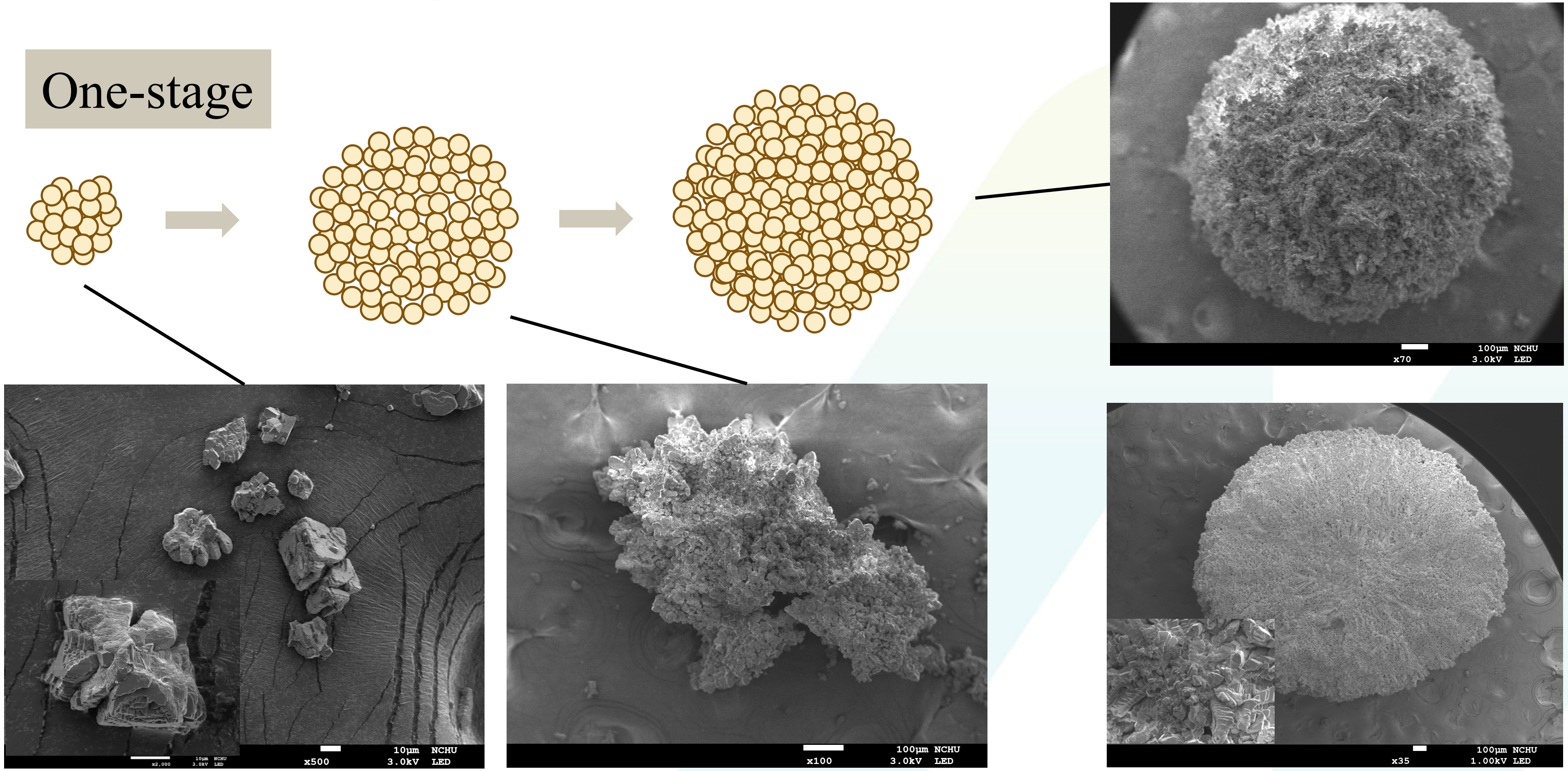
one-stage



two-stage

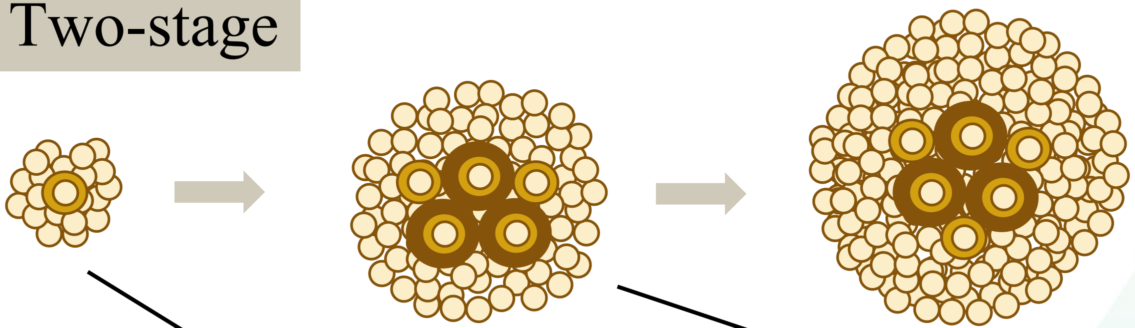


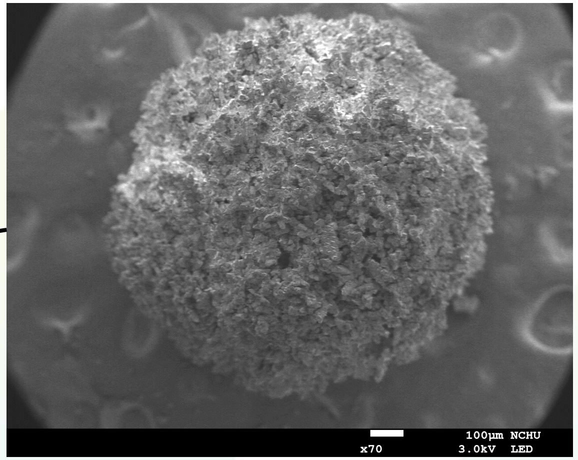
Mechanism of granulation

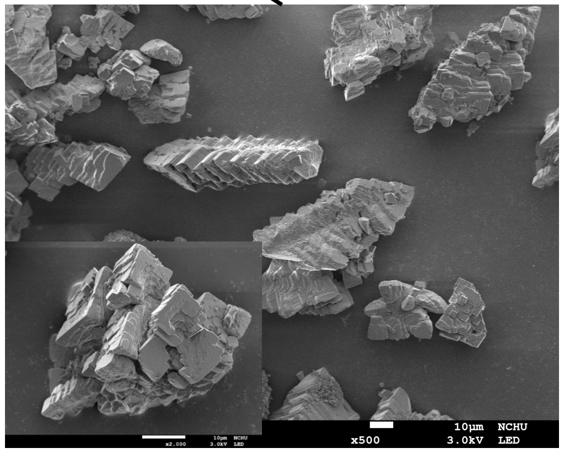


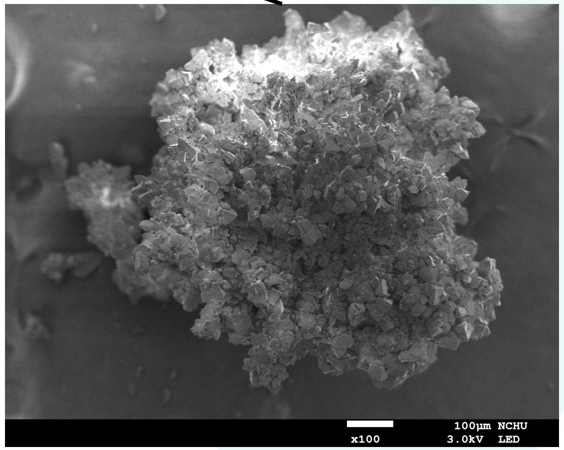
Mechanism of granulation

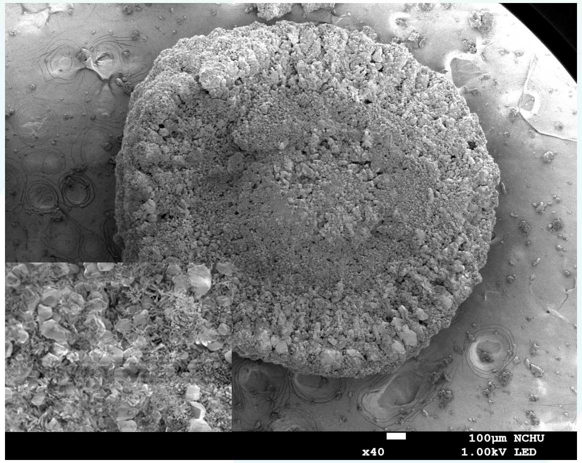
Two-stage

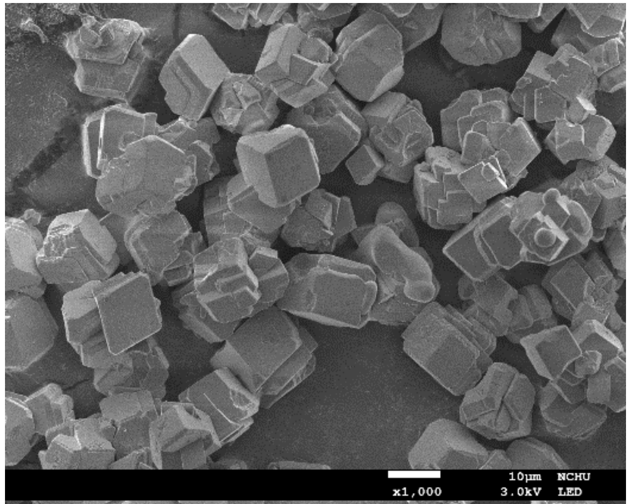


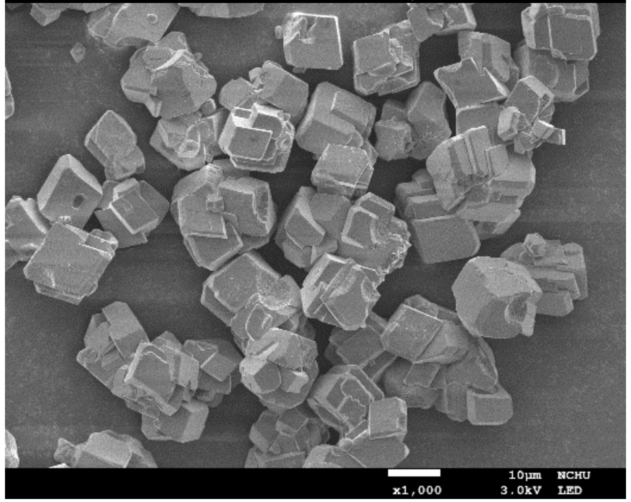


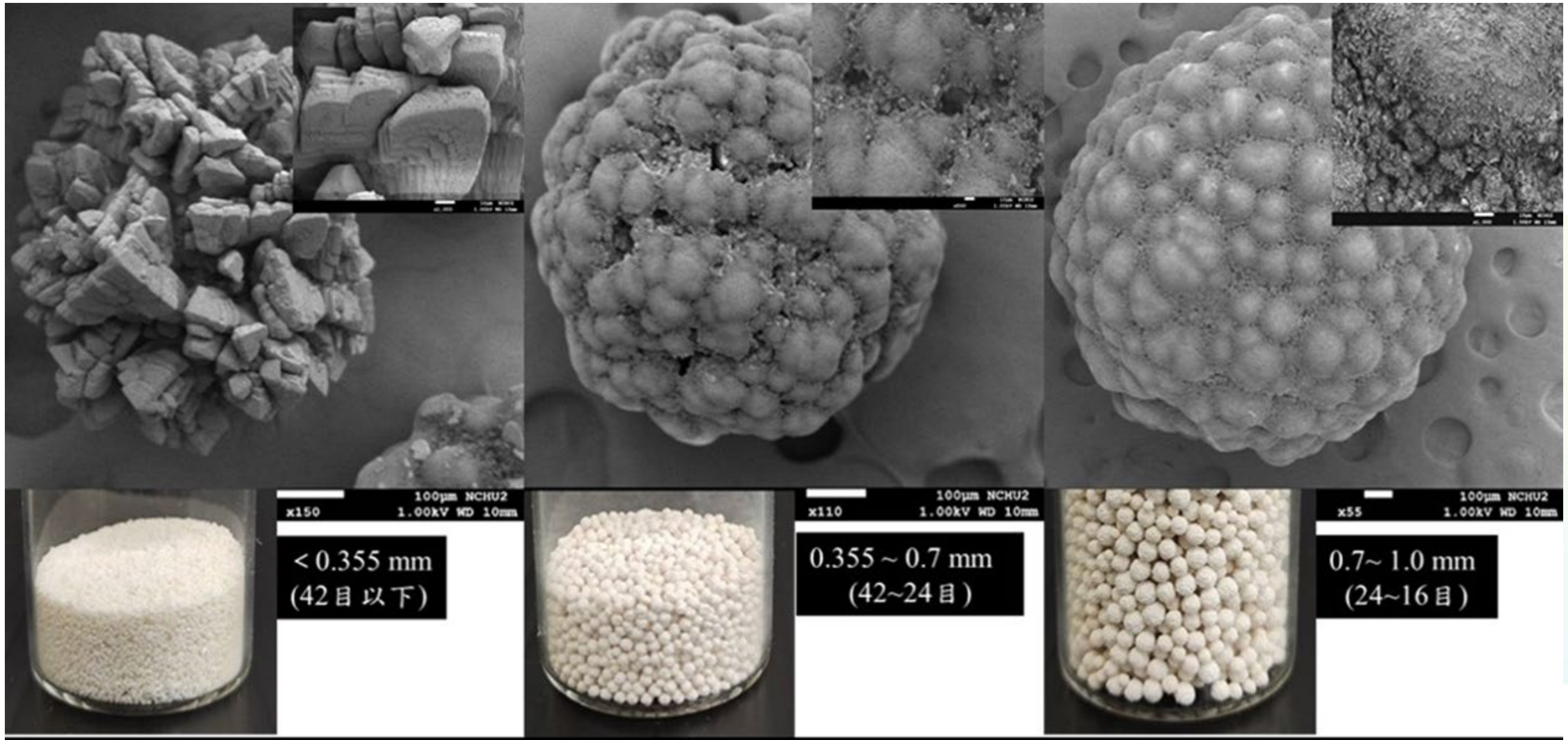




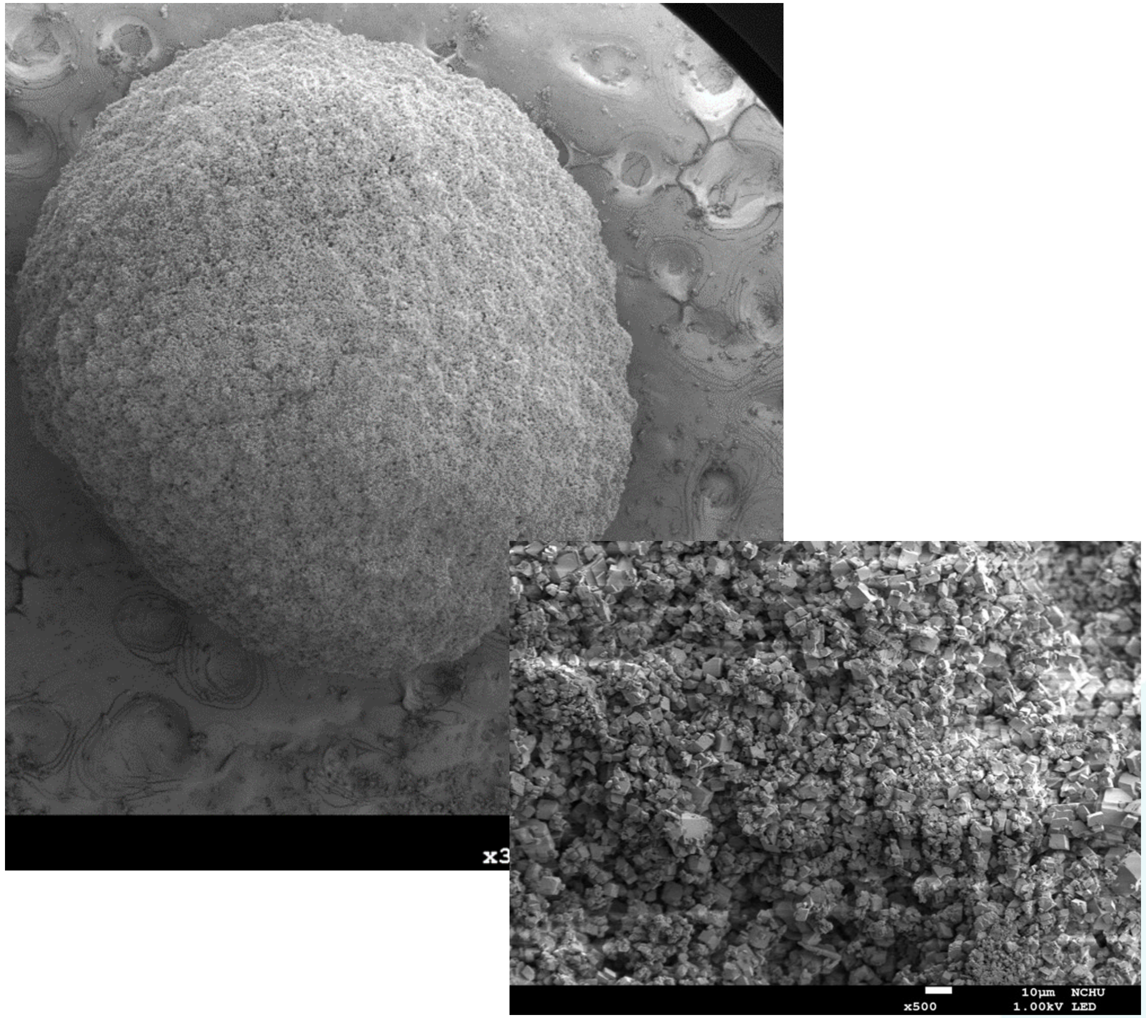


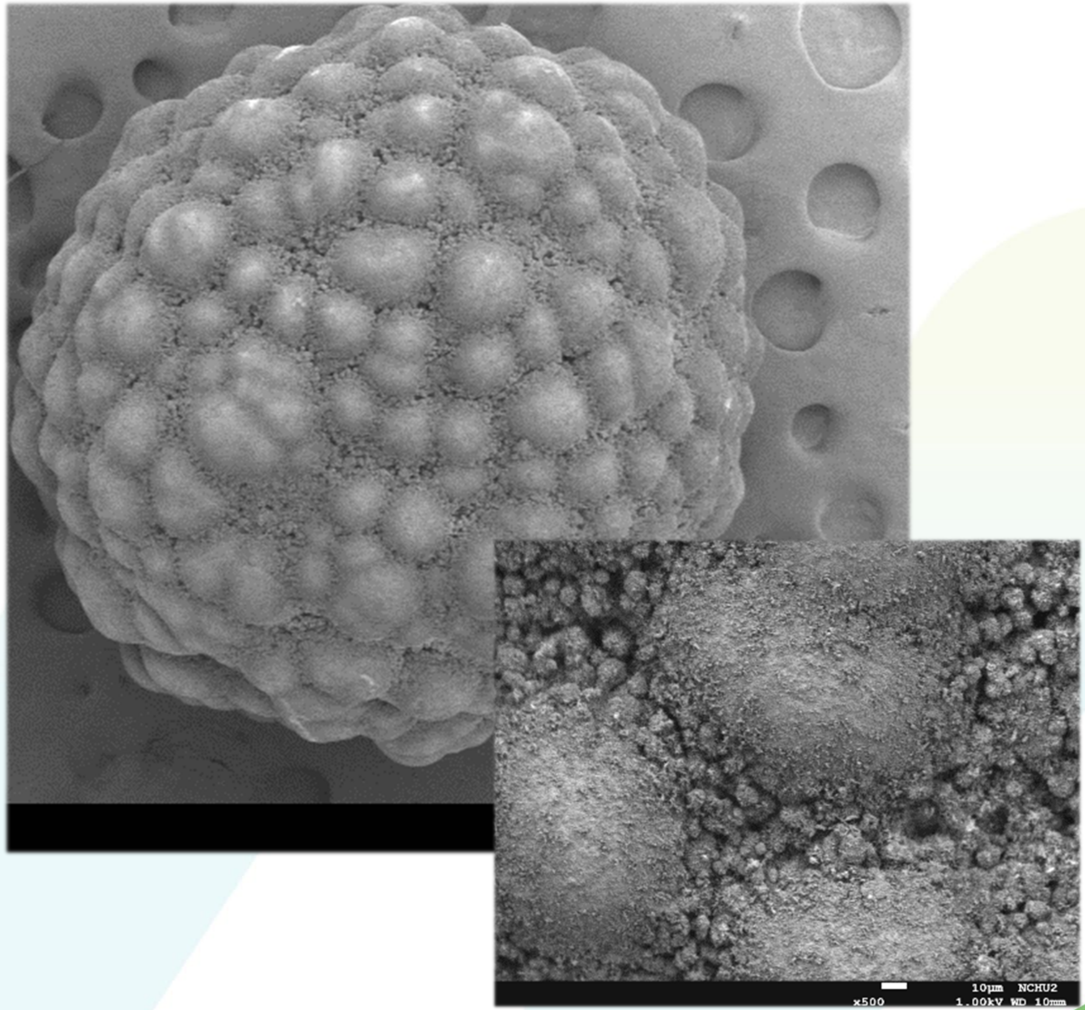






Growth of calcium carbonate crystal grains

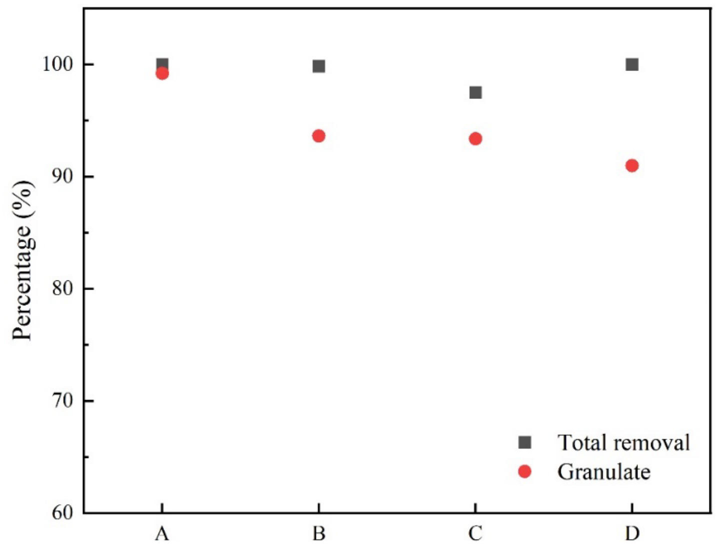

x500
10μm NCHU
1.00kV LED

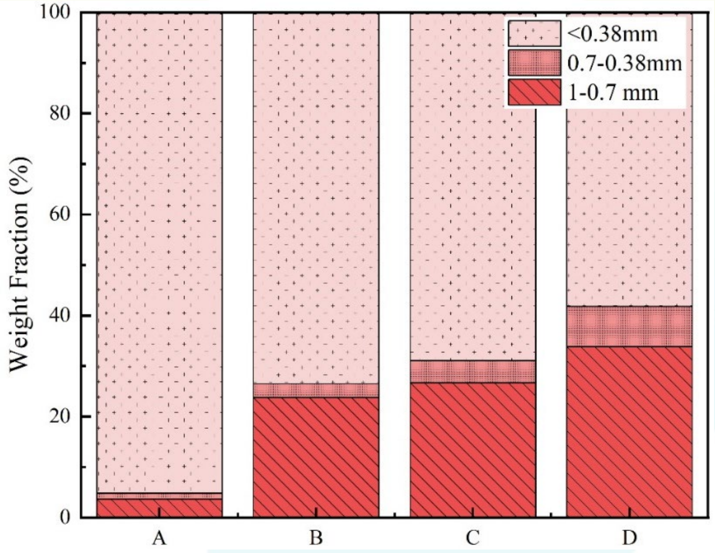

x500
10μm NCHU2
1.00kV WD 10mm

Effect of different chemicals on granulation

	A	B	C	D
Carbonate	K_2CO_3	K_2CO_3	Na_2CO_3	Na_2CO_3
Calcium	$Ca(NO_3)_2$	$Ca(OH)_2$	$Ca(NO_3)_2$	$Ca(OH)_2$

Operation condition	
pHe	9.0±0.3
CO_3^{2-} loading (kg/m^2hr)	61.8





Comparison of $CaCO_3$ size distribution at different different ion sources.($[CO_3^{2-}]$=0.096 M, $[CO_3^{2-}]/[Ca^{2+}]$=1,pH 9.0±0.3)

Cost evaluation of carbon dioxide capture and resource recovery from flue gas

	Item	Cost (TWD/kg or TWD/Kwhr)	Consumption or Production (kg reactant or product/kg CO_2)	CO_2 removal cost or benefit (TWD/ kg CO_2)		Remark
Expense	$Ca(OH)_2$	2.0-5.4	1.68	3.4-9.1	0	If recycled Ca is used, the cost is 0.
	Electricity	3.38		1.09-1.27	1.09-1.27	
	Capital			0.5-0.75	0.5-0.75	The amortization period is 10 years
Subtotal				4.99-11.12	1.59-2.02	
Income	$CaCO_3$	1.7-4.9	2.27	3.9-11.1	3.9-11.1	
	Carbon fee	0.3-3.0		0.3-3	0.3-3	
Subtotal				4.2-14.1	4.2-14.1	
Total				**-0.79 ~ +2.98**	**+2.61~+12.1**	If recycled calcium is used, there is definitely profit.

RESOURCE RECOVERY FROM BRINE

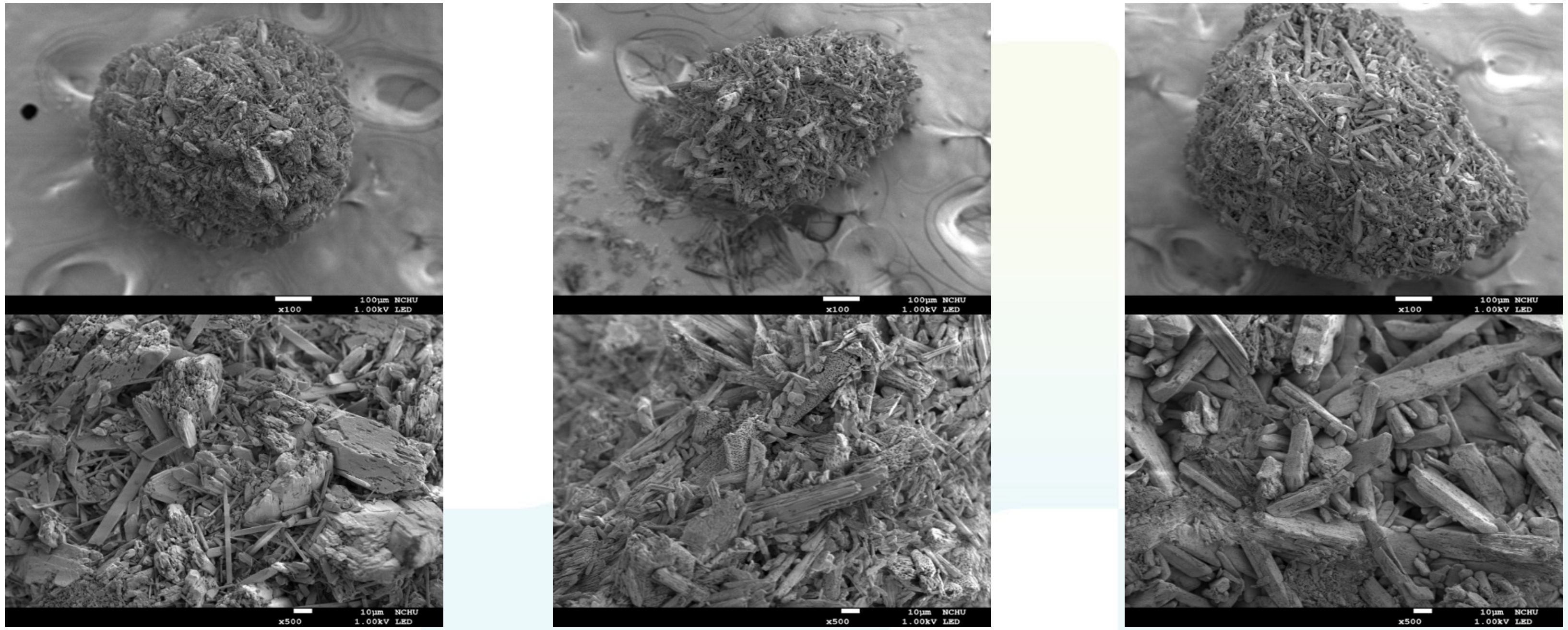
TABLE 1 | Physicochemical composition of the desalination brine.

Desalination	Oman RO	Emirates RO	Qatar RO
Calcium (mg/L)	417 - 1020	220 -1 180	1350
Magnesium (mg/L)	260 - 1980	311 - 2660	7600
Sodium (mg/L)	1670 - 15,300	311 - 17,700	NR
Potassium (mg/L)	43.1 - 668	34.1 - 950	NR
Strontium (mg/L)	11.4 – 28.2	4.56 -21.10	NR
pH	3.07 -7.94	6.38 - 7.87	NR
Carbonate (mg/L)	NR	NR	NR
Bicarbonate (mg/L)	37 -859	100 - 656	3900
Chloride (mg/L)	1964 - 77,335	2,933 -34,839	29,000
Sulphate (mg/L)	1143 - 6139	756 -4602	3900
Nitrate as NO_3 (mg/L)	5.2– 46.7	3 – 47.2	NR
Fluoride (mg/L)	–	<0.1 -2.3	NR
E.C (mS/cm)	9870 -	10,850 – 81,100	NR
S.A.R (me/L)	15.51 -64.65	6.8 – 67.25	NR
S.E.R (me/L)	61.77 -75.012	31.1 – 74.29	NR
Langelier Index (me/L)	-0.33 -	-0.28 – 1.2	NR
Ryzner Index (me/L)	4.38 – 9.27	4.47 – 7.69	NR
TDS (ma)	8,747 – 48,510	3700 – 61,587	NR
Total ions (mg/L)	8,765 – 48,618	33,765 – 61,645	NR
Total alkalinity (mg/L)	30 - 704	82 - 538	NR
Total hardness (mg/L),	2,211 – 9,951	1,730-12,872	NR
Iron (mg/L)	<0.05 -	<0.05 -0.33	NR
Manganese (mg/L)	<0.05 – 0.07	<0.05 – 0.07	NR
Copper (mg/L)	<0.05	<0.05 - <0.5	NR
Zinc (mg/L)	<0.05	<0.05 - <0.5	NR
Chromium (ma)	<0.02	<0.05	NR
reference	(Ahmed et al., 2001)	(Ahmed et al., 2001)	(Bello et al., 2021)

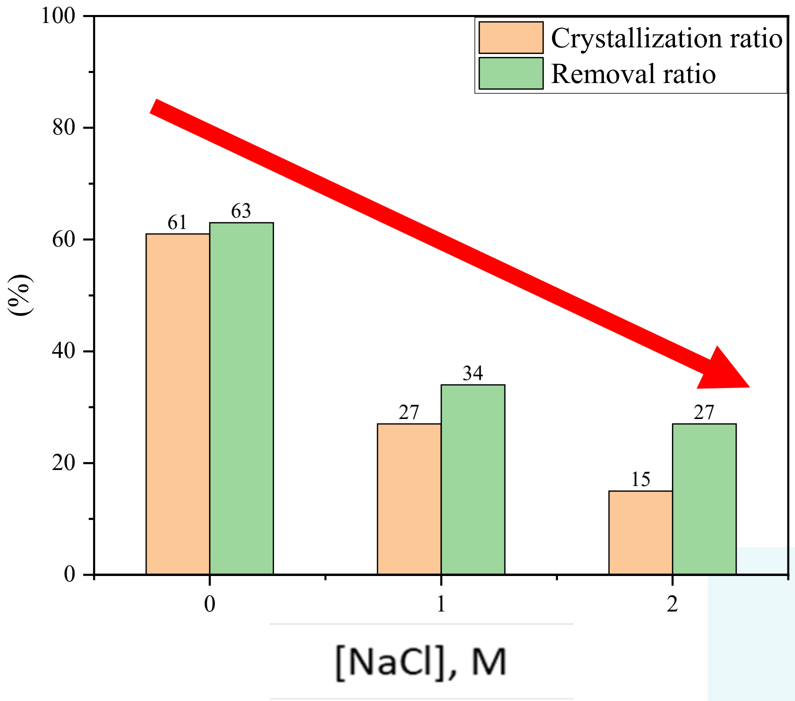
NaCl

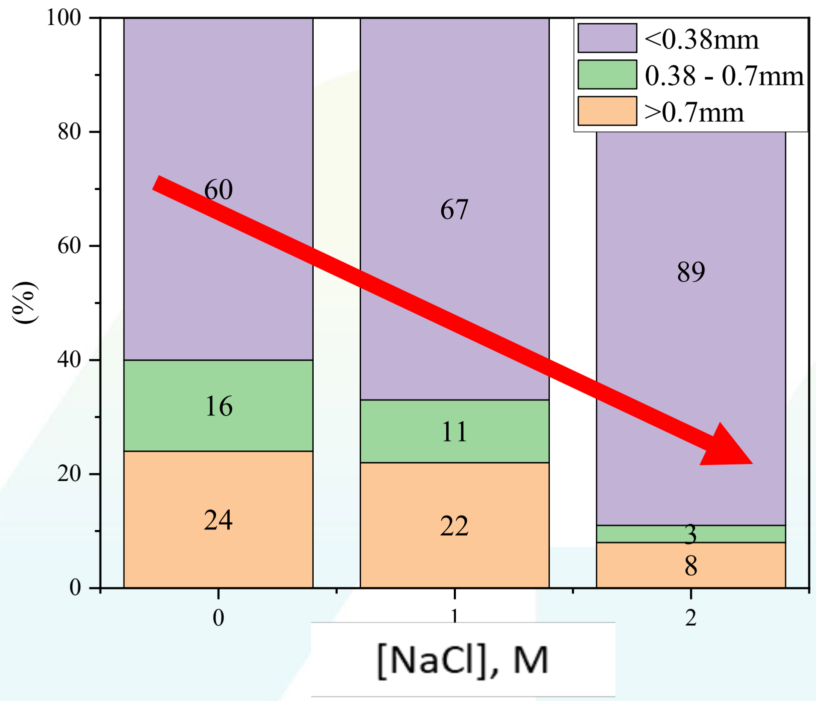
Ca^{2+} = 6,000 mg/l
SO_4^{2-} = 11,527 mg/l
pH = 7.5

Cl^- free	Cl^- = 35,450 mg/l	Cl^- = 70,900 mg/l

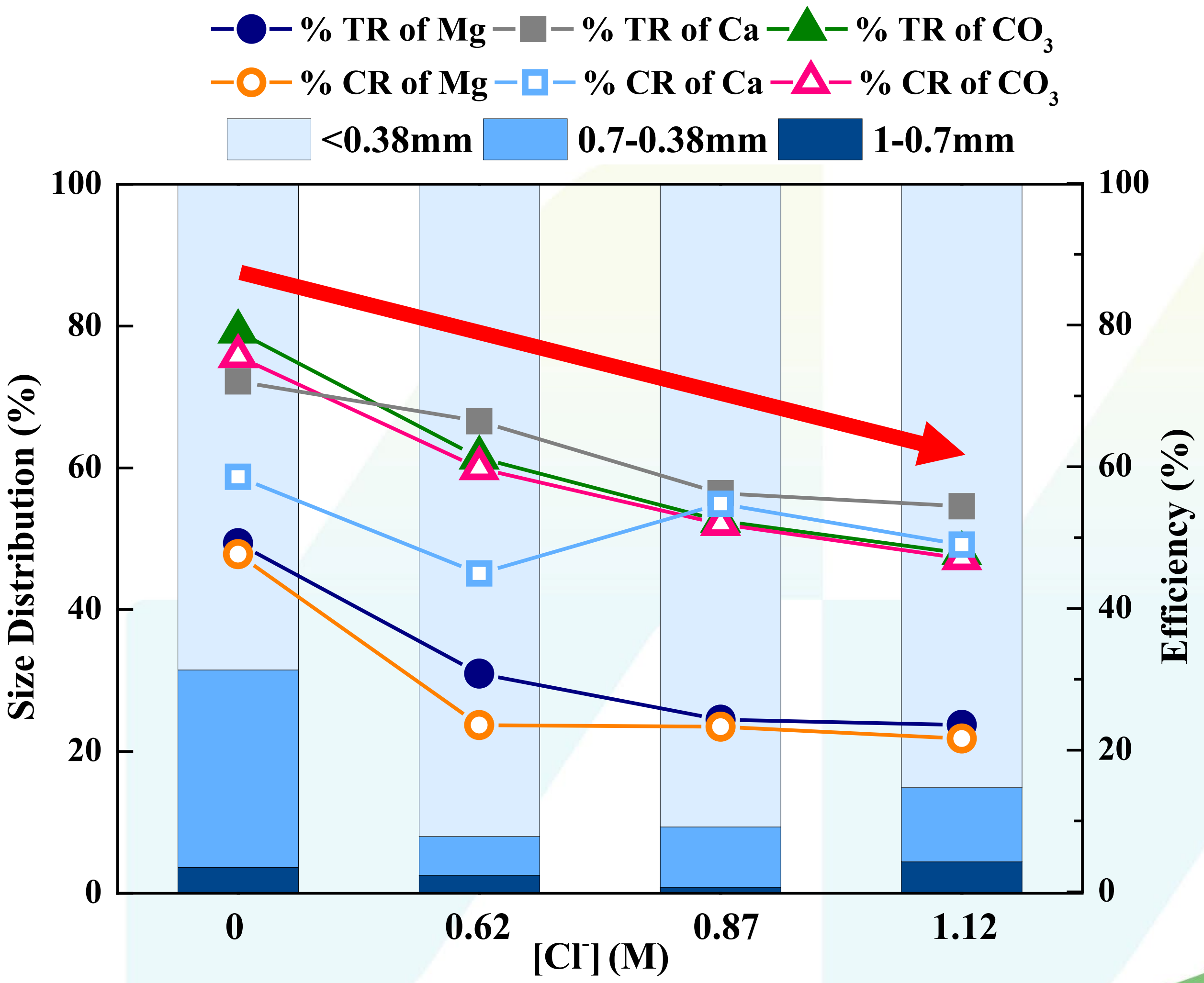


Cl^- free	Cl^- : 0.2 %	Cl^- :1.31 %


Crystallization ratio
Removal ratio
(%)
61
63
27
34
15
27
0
1
2
[NaCl], M


<0.38mm
0.38 - 0.7mm
>0.7mm
(%)
60
16
24
67
11
22
89
3
8
0
1
2
[NaCl], M

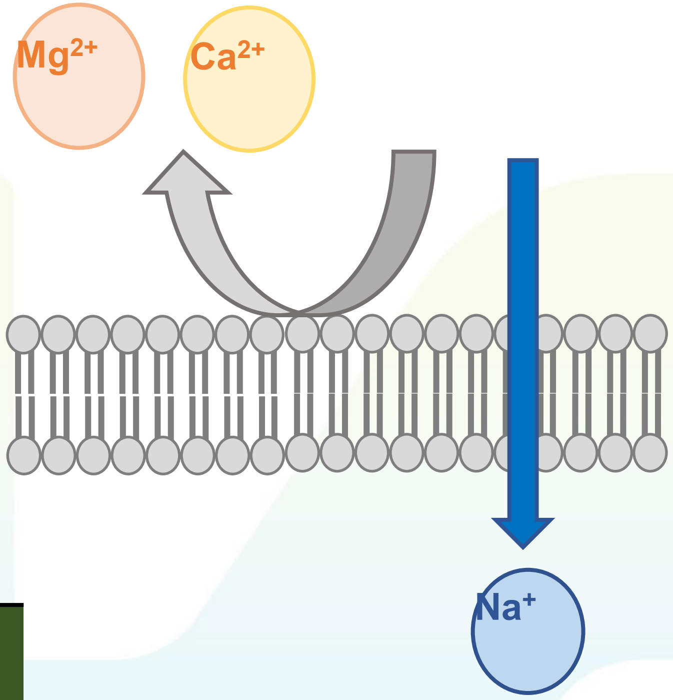
$[CO_3^{2-}]$=0.096M, pH=10.0±0.3,
$[Mg^{2+}]/[CO_3^{2-}]$=1.0,
$[Mg^{2+}]/[Ca^{2+}]$=10



A POSSIBLE SOLUTION

Nanofiltration (NF) Mechanism

- NF is a pressure-driven separation process based on principles of size exclusion, charge, and polarity.
- This process selectively removes divalent ions, small organic molecules, and viruses from aqueous solutions.
- NF is promising for precision separation, with advantages like low energy use for ion and small molecule removal.



Nanofiltration

Nanofiltration membrane technology features and advantages

Membrane pore size	Driving force	Mechanism	Applications	Advantage
0.1–10 nm	Pressure difference (10–25 bar)	Solution diffusion	• Treatment of wastewater and brackish water desalination • Chroma removal	• Less energy for treatment • Easy operation • Better efficiency • High water permeability

Take-home messages

- FBHC can recover both metal and non-metal resources from water at normal temperature and pressure
- FBHC can reduce by two-thirds of sludge amount
- FBHC is an technology with high treatment efficiency and flexibility
- FBHC could be a carbon negative technology for CCUS
- Technology application must consider technological feasibility, economic feasibility, and carbon emission feasibility.
- FBHC has the potential to recover resources from brines but NaCl has to be removed first.

Thank you very much for your kind attention

TAIWAN INT'L WATER WEEK

Sep. 10 ▸ 11
TICC台北國際會議中心

Water Towards Safety、Sustainable Environment and Prosperity

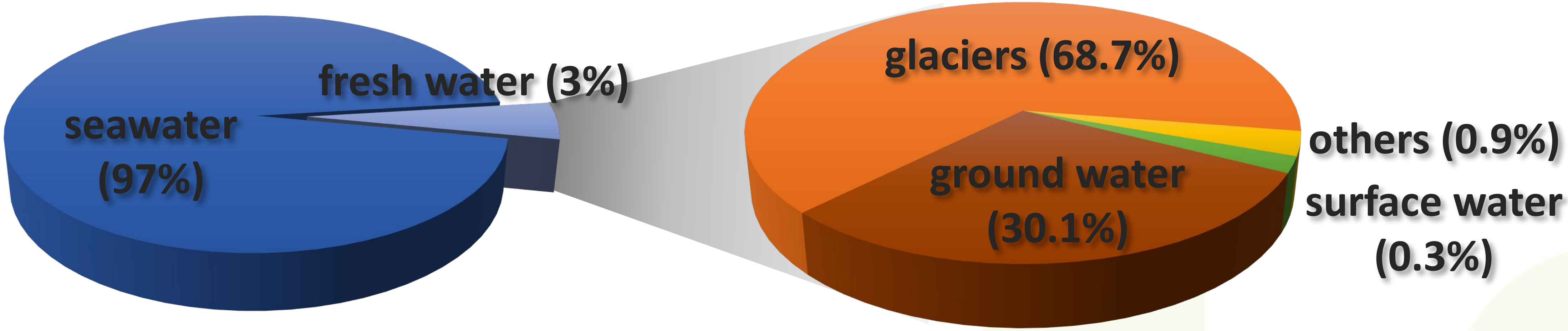
水與安全、環境、發展

Sustainable high-performance energy free desalination

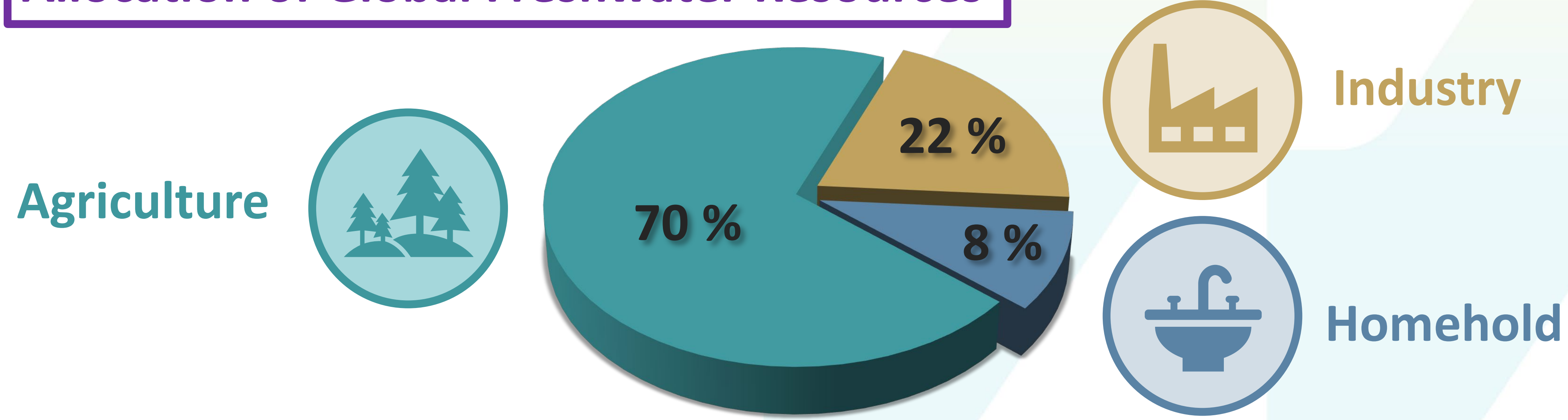
Sheh-Yi Sheu

Department of Life Sciences and Institute of Genome Sciences
National Yang Ming Chiao Tung University, Taipei, Taiwan

Water Resources on Earth



Allocation of Global Freshwater Resources



https://www.aslo.org/what-is-aquatic-science/earths-water-resources/

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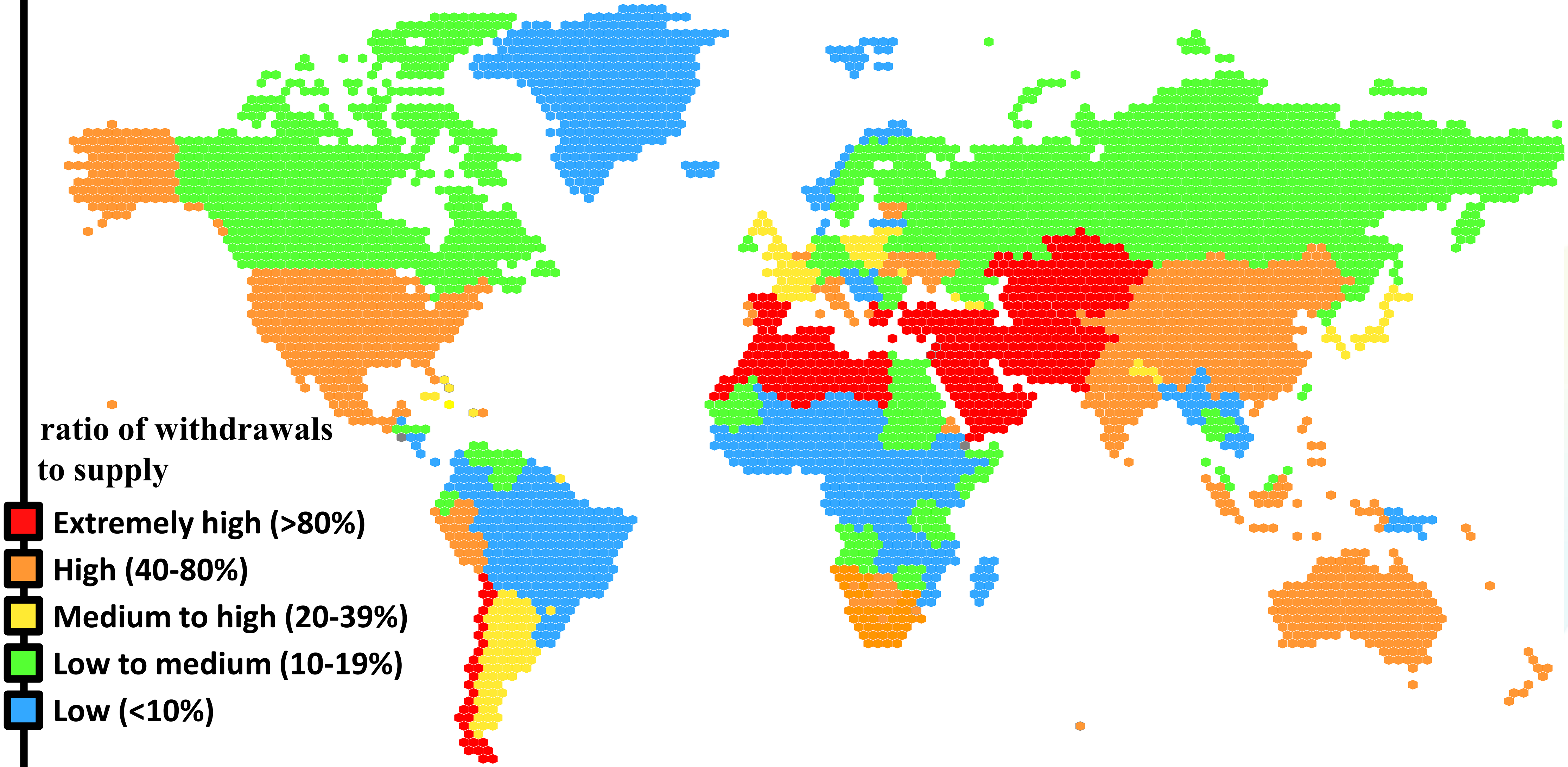
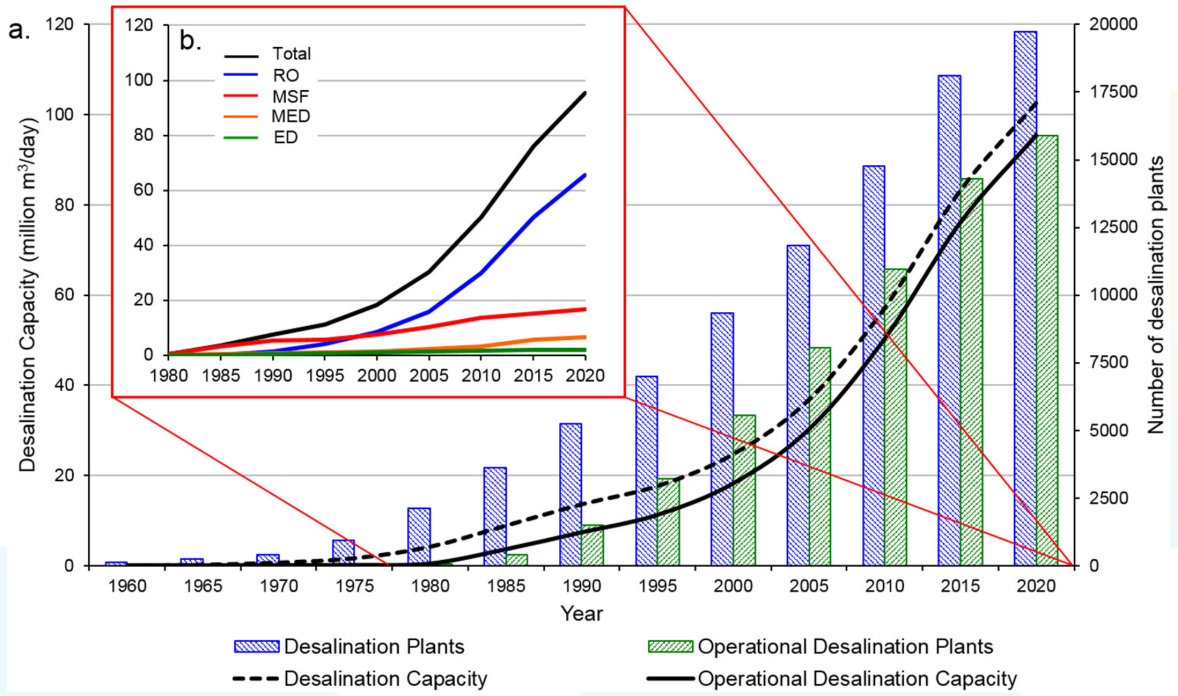
Water Stress by Country - 2040



Data source: World Resources Institute via The Economist Intelligence Unit

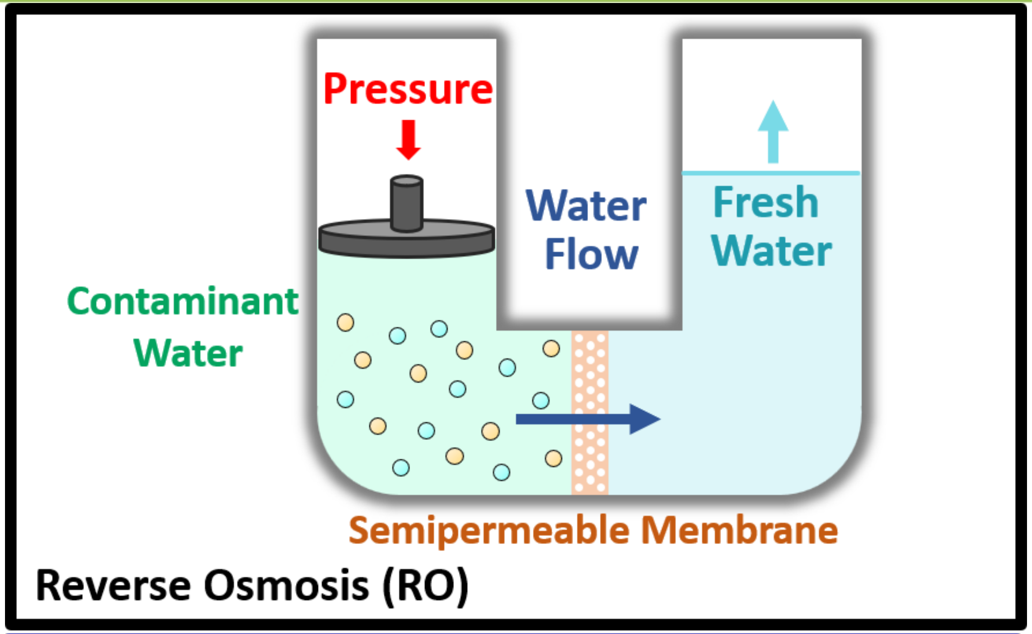
Desalination Methods

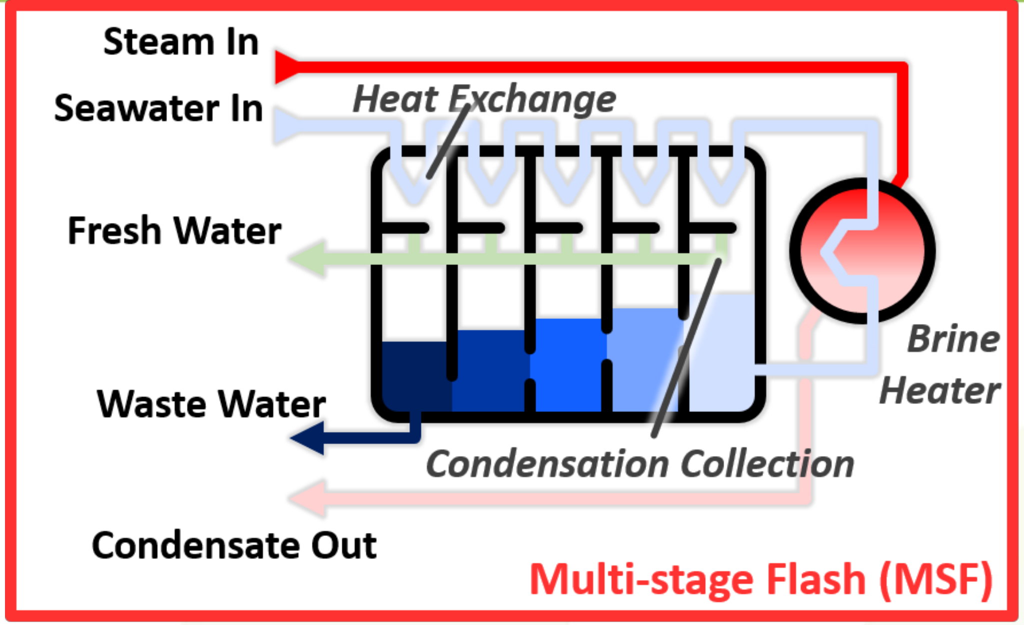
- Reverse osmosis (RO)
- Thermal Distillation
  - Multi-stage flash distillation (MSF)
  - Multi-effect distillation (MED)
  - Vapor compression distillation (VC)
  - Solar-powered desalination
- Electrodialysis (ED)
- Nanofiltration (NF)
- Gas hydrate formation

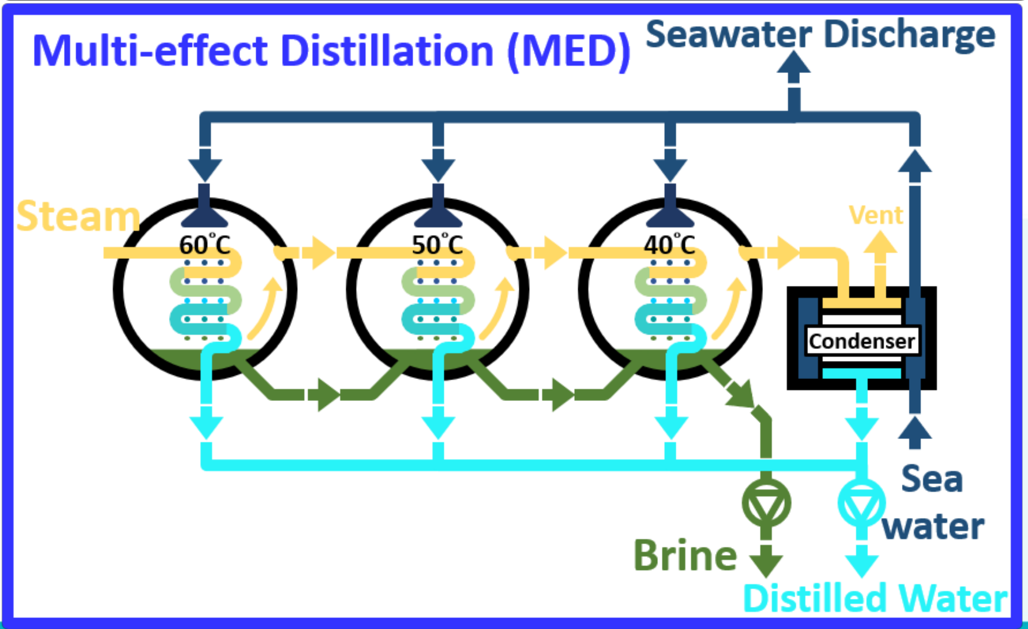


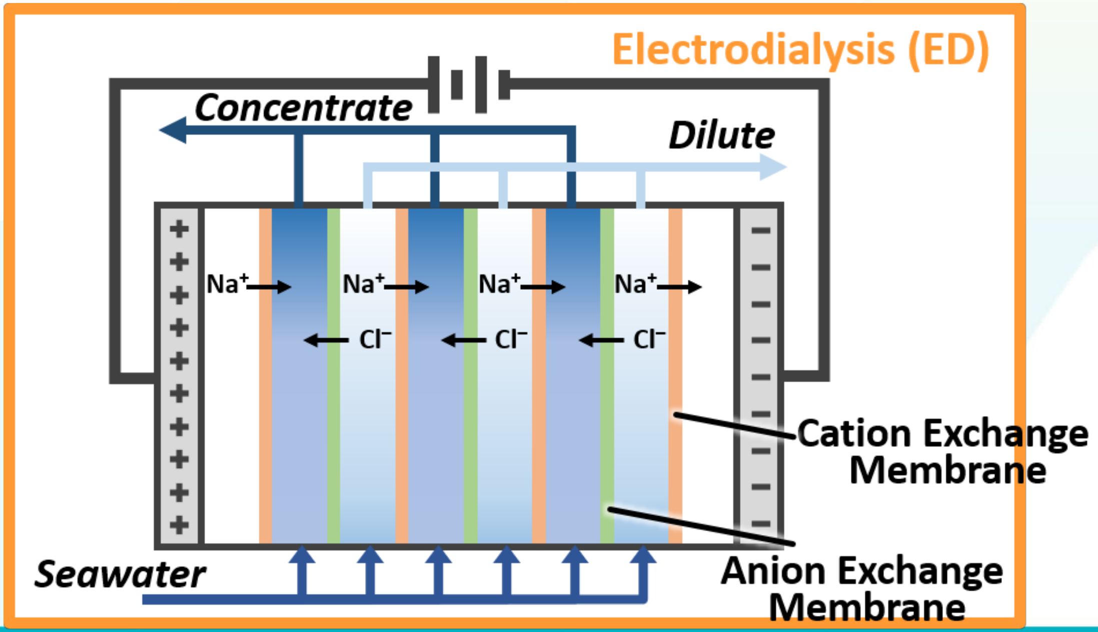
high pressure = energy

E Jones et al. Sci. Total Environ. 657, 1343 (2019)

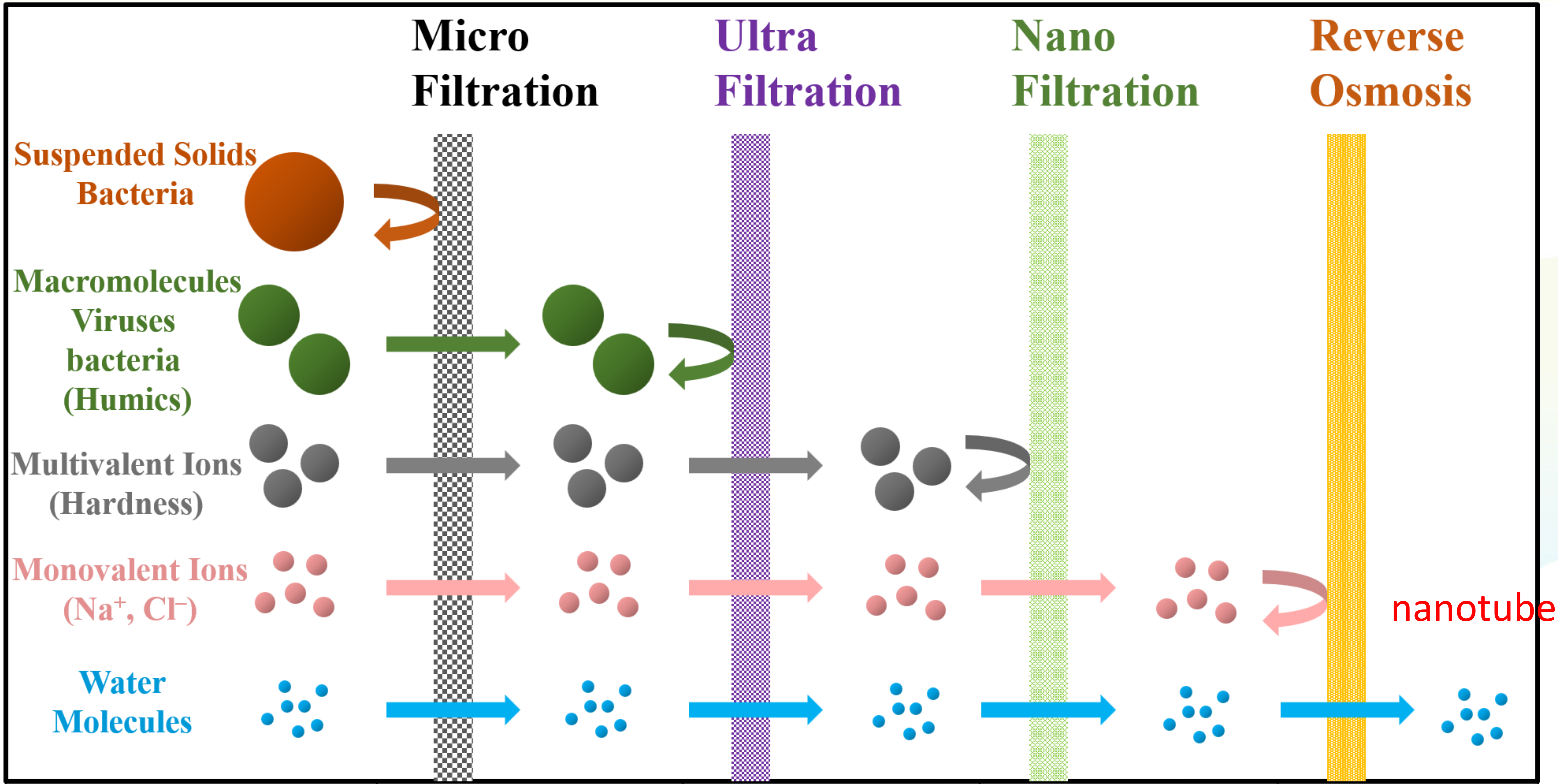

Pressure
Water Flow
Fresh Water
Contaminant Water
Semipermeable Membrane
Reverse Osmosis (RO)


Steam In
Seawater In
Heat Exchange
Fresh Water
Waste Water
Brine Heater
Condensation Collection
Condensate Out
Multi-stage Flash (MSF)


Multi-effect Distillation (MED)
Seawater Discharge
Steam
60℃
50℃
40℃
Vent
Condenser
Sea water
Brine
Distilled Water


Electrodialysis (ED)
Concentrate
Dilute
Na⁺
Cl⁻
Cation Exchange Membrane
Anion Exchange Membrane
Seawater

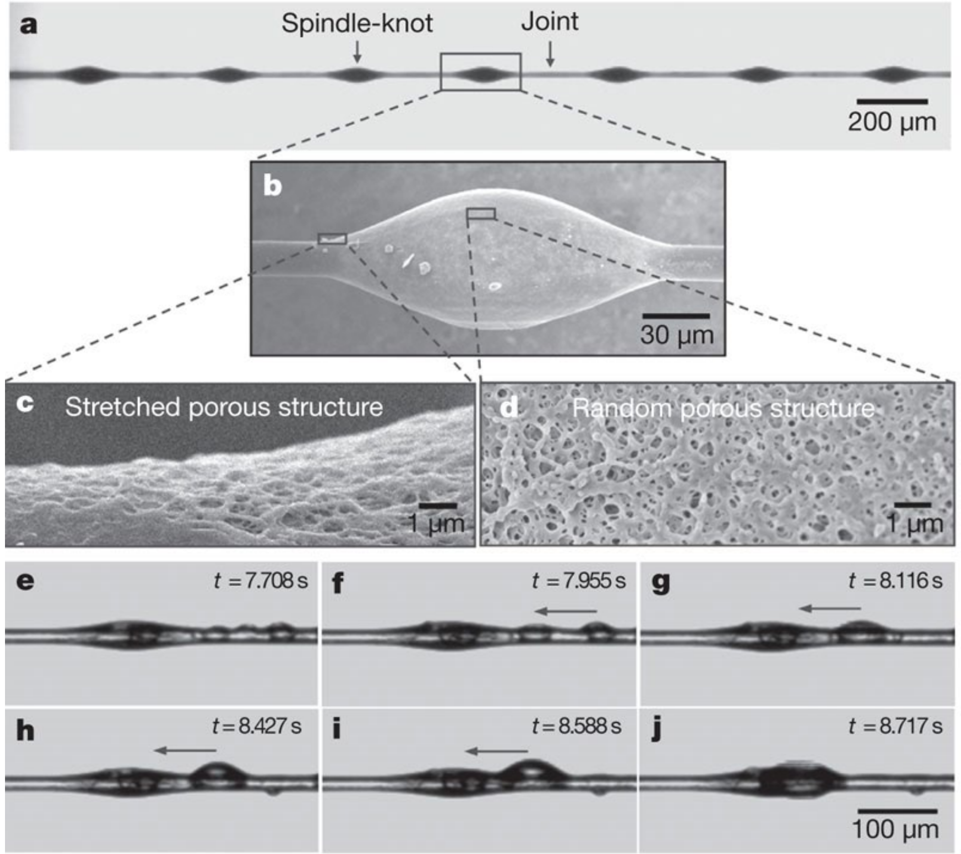
Pressure-Driven Membrane Process



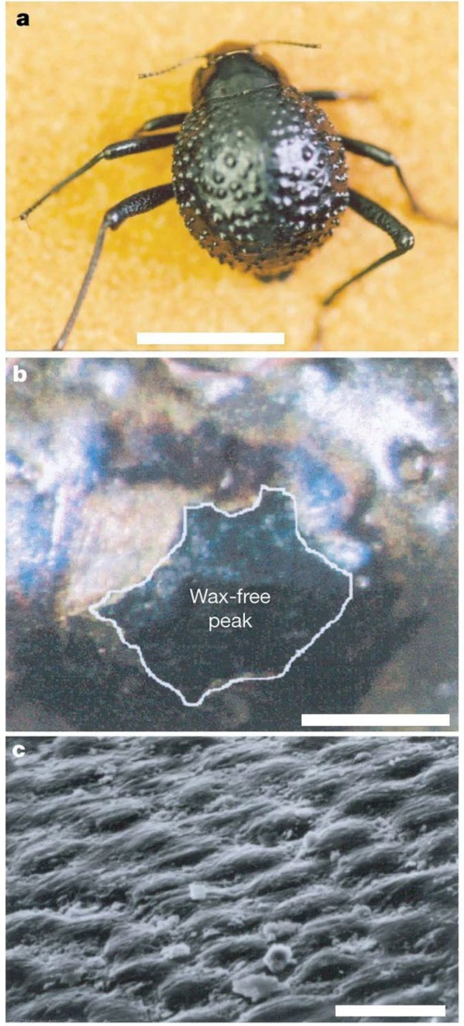
Pore Size	0.1 µm - 10 µm	0.01 µm - 0.1 µm	0.001 µm - 0.01 µm	0.0001 µm

Bioinspired By nature

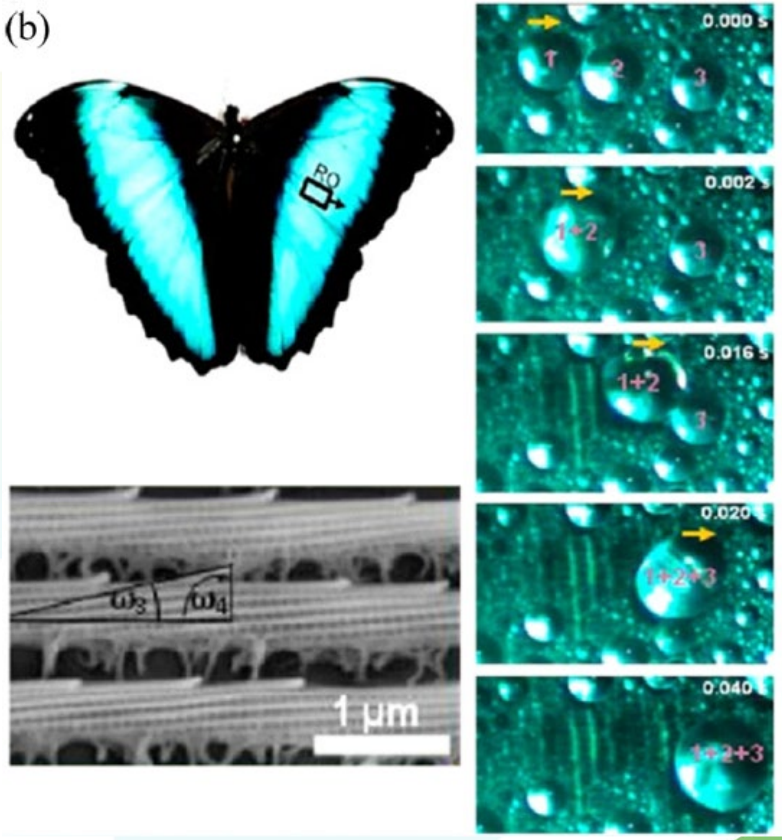
Unidirectional motion → Dissipationless



YM Zheng *et al. Nature* 463, 640 (2010)



AR Parker *et al. Nature* 414, 33 (2001)

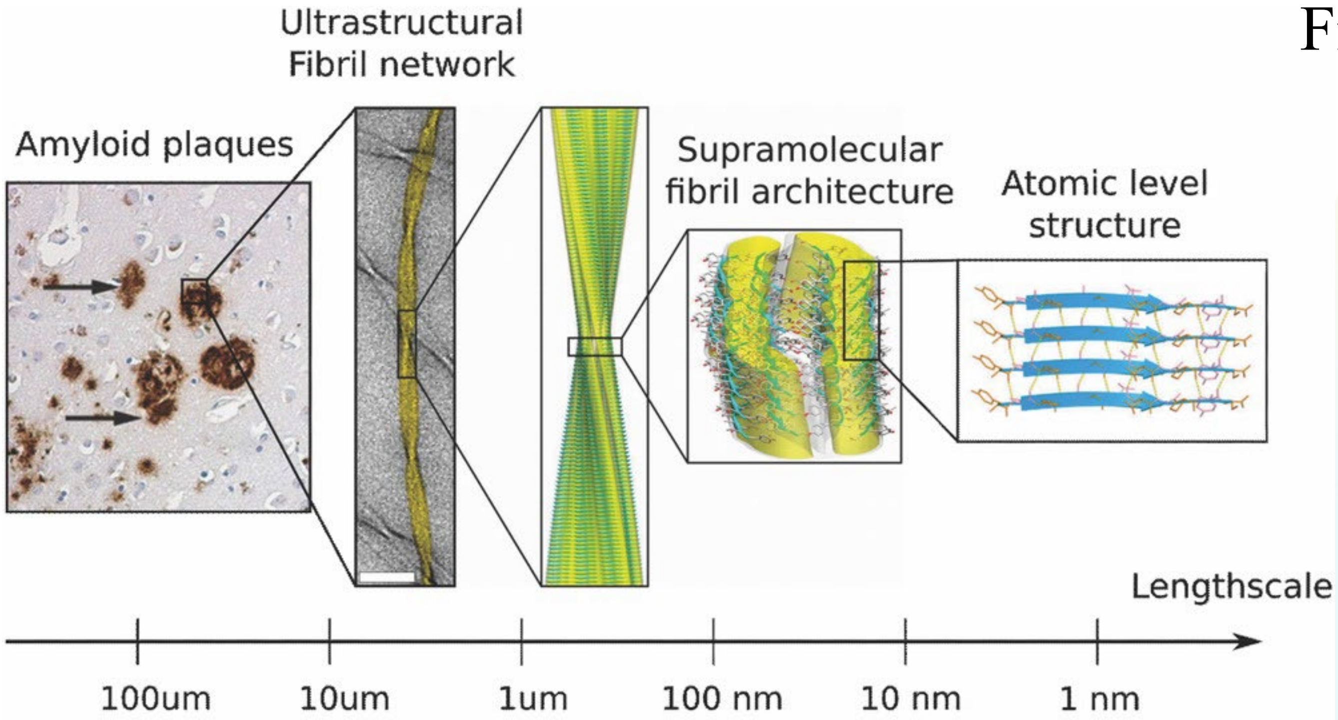


CC Liu *et al.* ACS Nano, 8, 1321 (2014)

Unidirectional Liquid Flow

Wettability and Liquid spread under nanoscale confinement are universal in biology — Asymmetric structures, Heterogeneity, and Surface roughness.

Amyloid Fibrils as Functional Materials



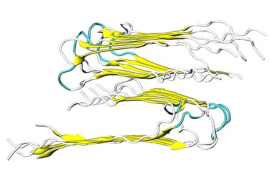
The physical nature of Amyloid Fibrils:

- Polyelectrolytes
- Hydrogen bonding network
- Chirality and polarity
- High Elastic moduli and Rigidity
  (Compared to actin, tubulin, collagen, keratin, and silk)
- It is an Irreversible assembly process.

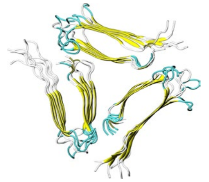
TP Knowles, *et al.* Adv. Mater. 28, 6546 (2016)

TAIWAN INT'L WATER WEEK

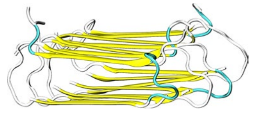
Structures of Aβ fibrils



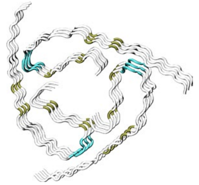
2lmn (NMR) $A\beta_{17\text{-}40}$



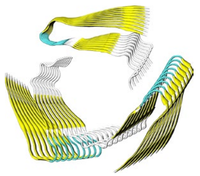
2lmp (NMR) $A\beta_{9\text{-}40}$



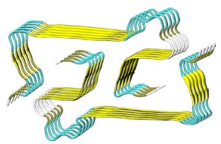
2lnq (NMR) $A\beta_{15\text{-}40}$ (D23N)



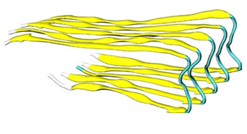
2m4j (NMR) $A\beta_{1\text{-}40}$



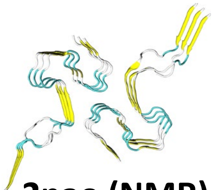
2mpz (NMR) $A\beta_{15\text{-}40}$ (D23N)



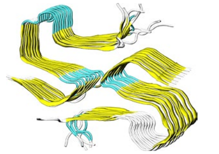
2mvx (NMR) $A\beta_{1\text{-}40}$ (E22 deletion)



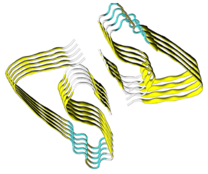
2beg (NMR) $A\beta_{17\text{-}42}$



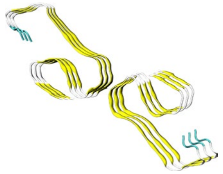
2nao (NMR) $A\beta_{1\text{-}42}$



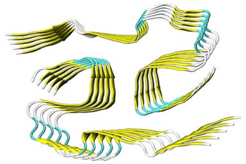
5kk3 (NMR) $A\beta_{11\text{-}42}$



5oqv (cryo-EM) $A\beta_{1\text{-}42}$

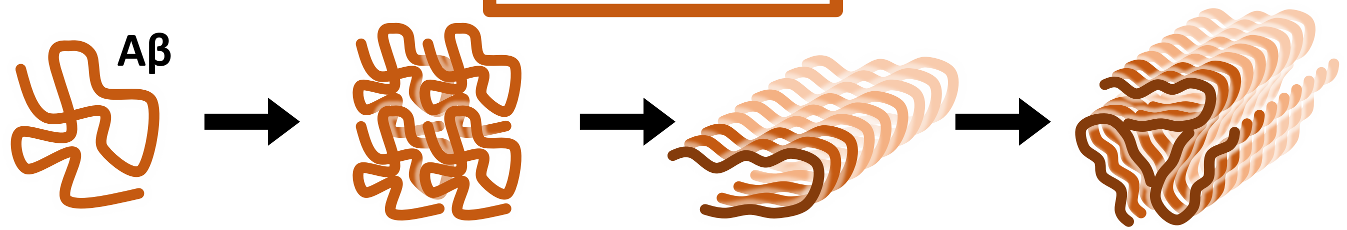


7f29 (cryo-EM) $A\beta_{6\text{-}42}$



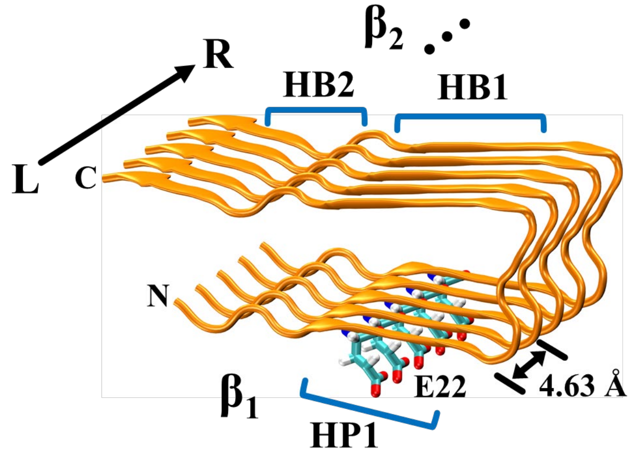
7q4b (cryo-EM) $A\beta_{9\text{-}42}$

Self-assembly

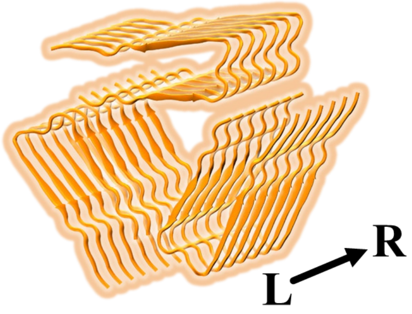


Monomer → Oligomers → β-sheet (Flat) → Fibrils (Tube)

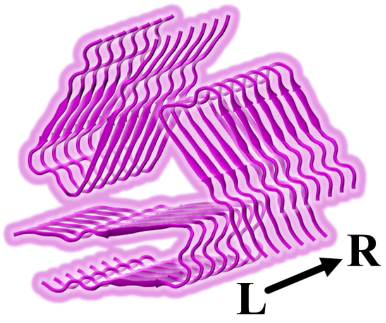
Structures of Aβ β-sheet and Nanotube



PDB ID: 2beg ($A\beta_{17\text{-}42}$)



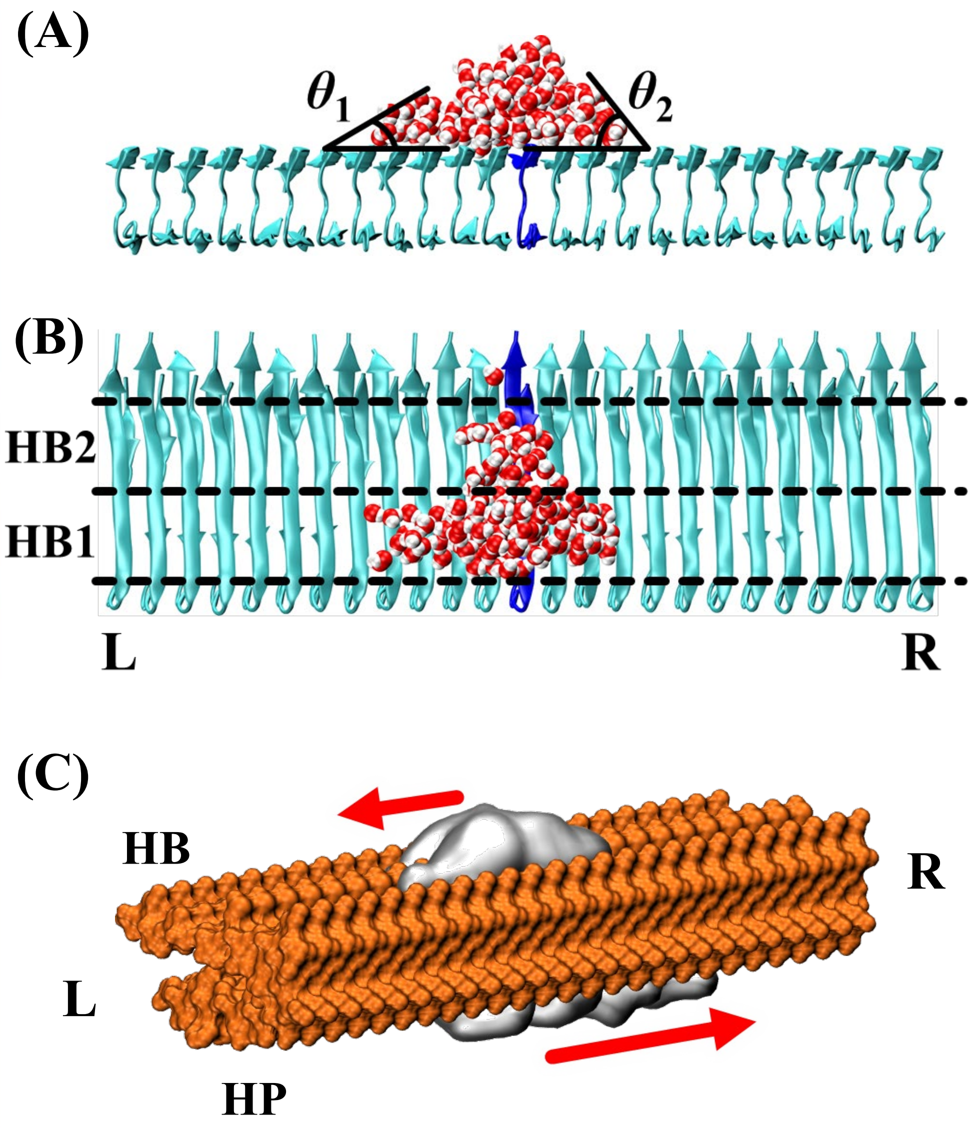
T(HP-WT)



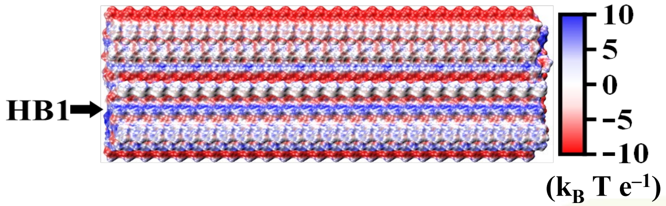
T(HB-WT)

Aβ-Nanotubes (ABNT)

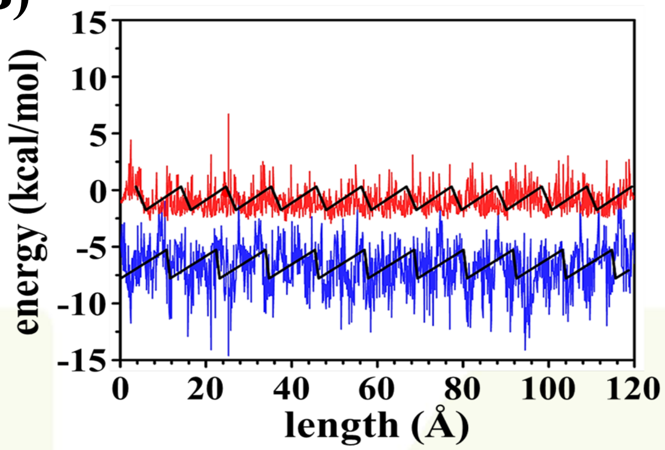
Unidirectional Motion



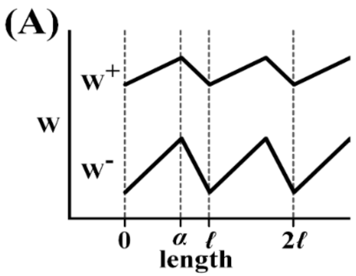
Asymmetric Periodic Ratchet Potential



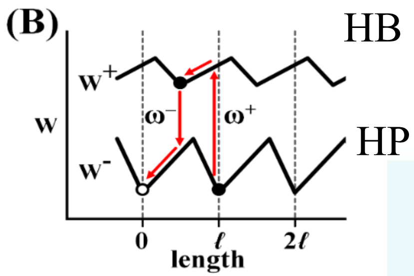
Heterogeneous periodic structure



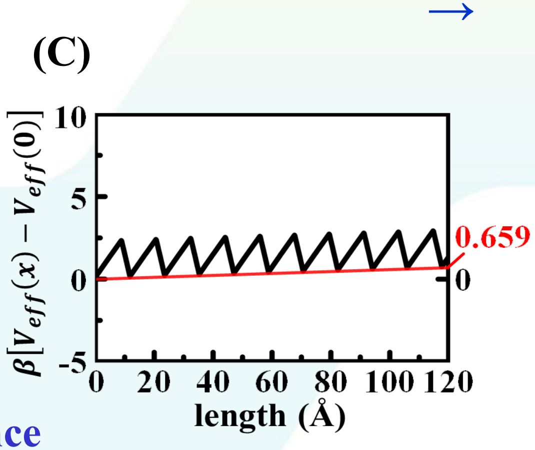
Two-domain Model



Ratchet potential

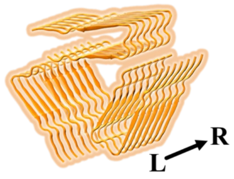


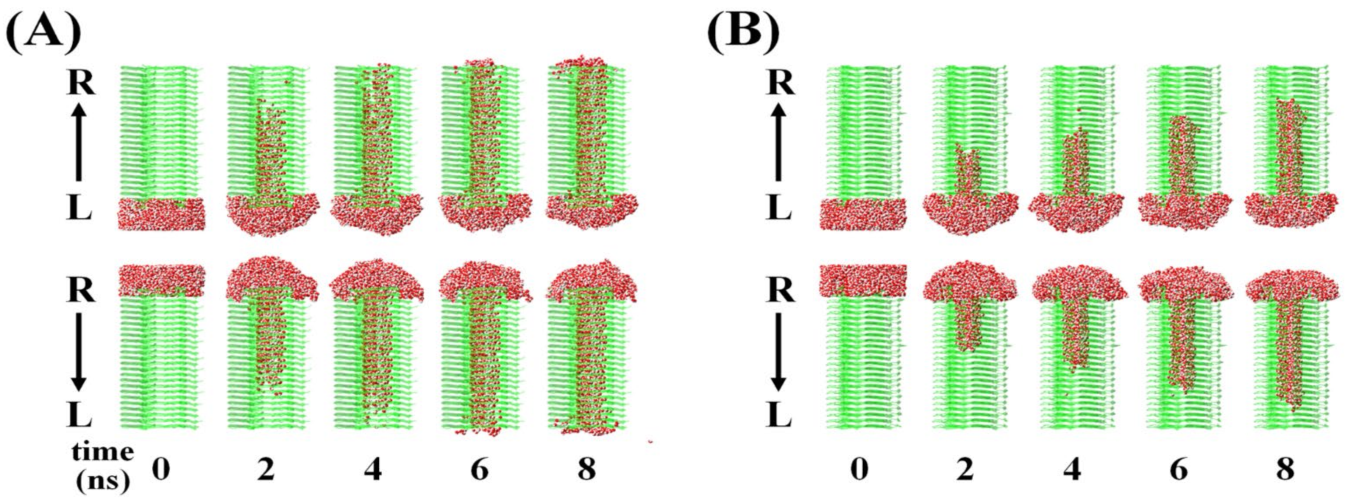
Ratchet potentials mismatch
Broken detailed balance

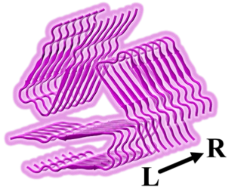


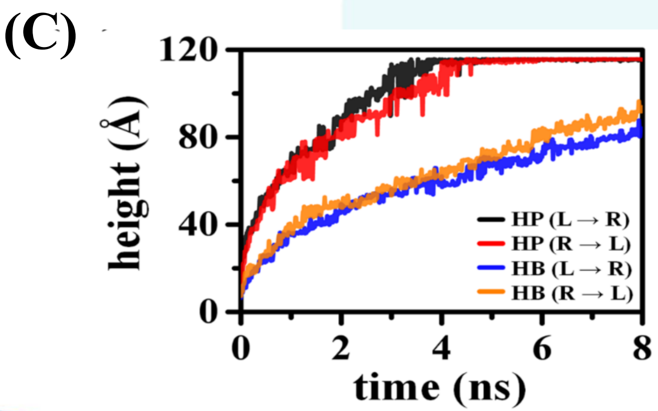
→ **Unidirectional flow**

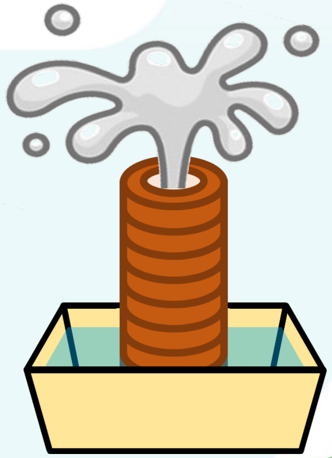
Water Pump — Fountain Effect



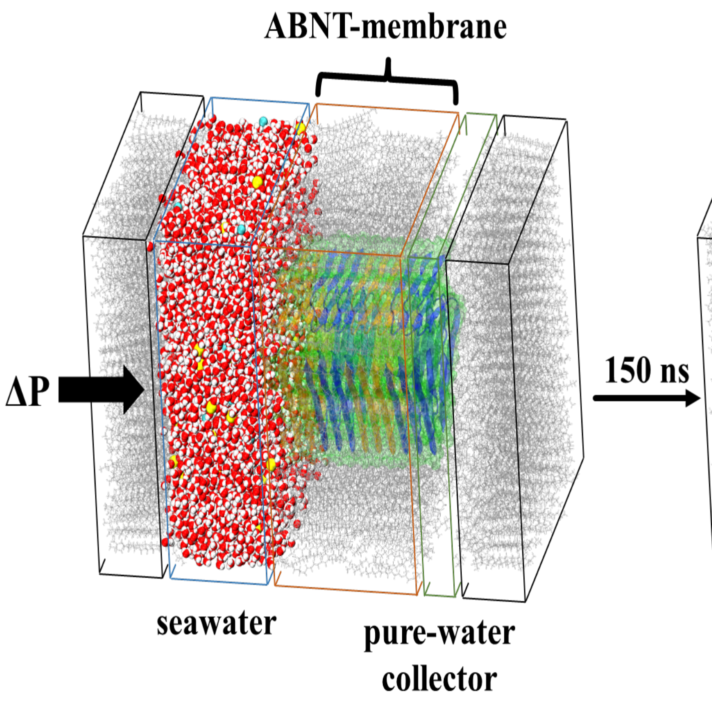




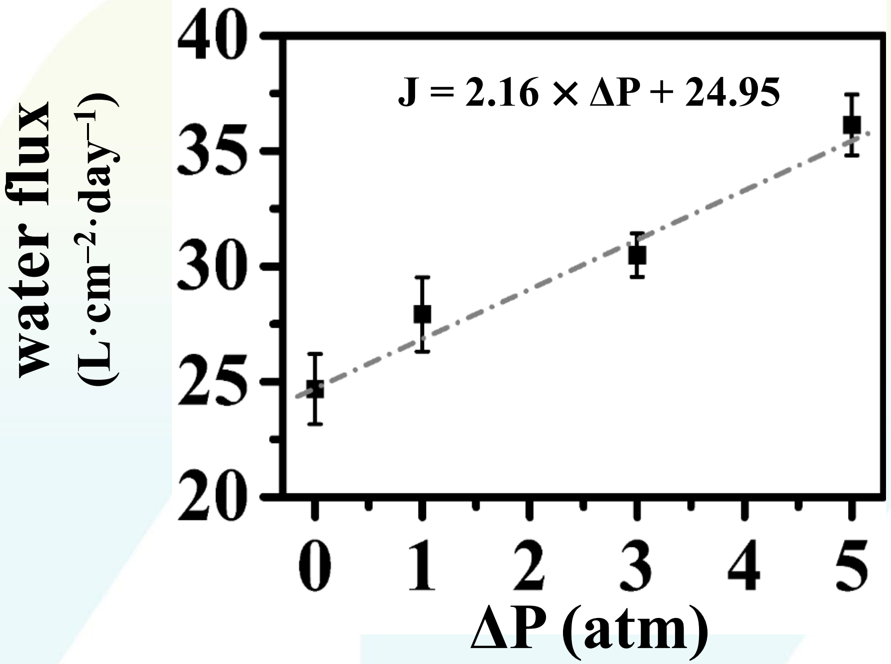




Pressure-Driven Nanofiltration



T(HP-3E3K)$_{12}$-DPPC



Desalination performance

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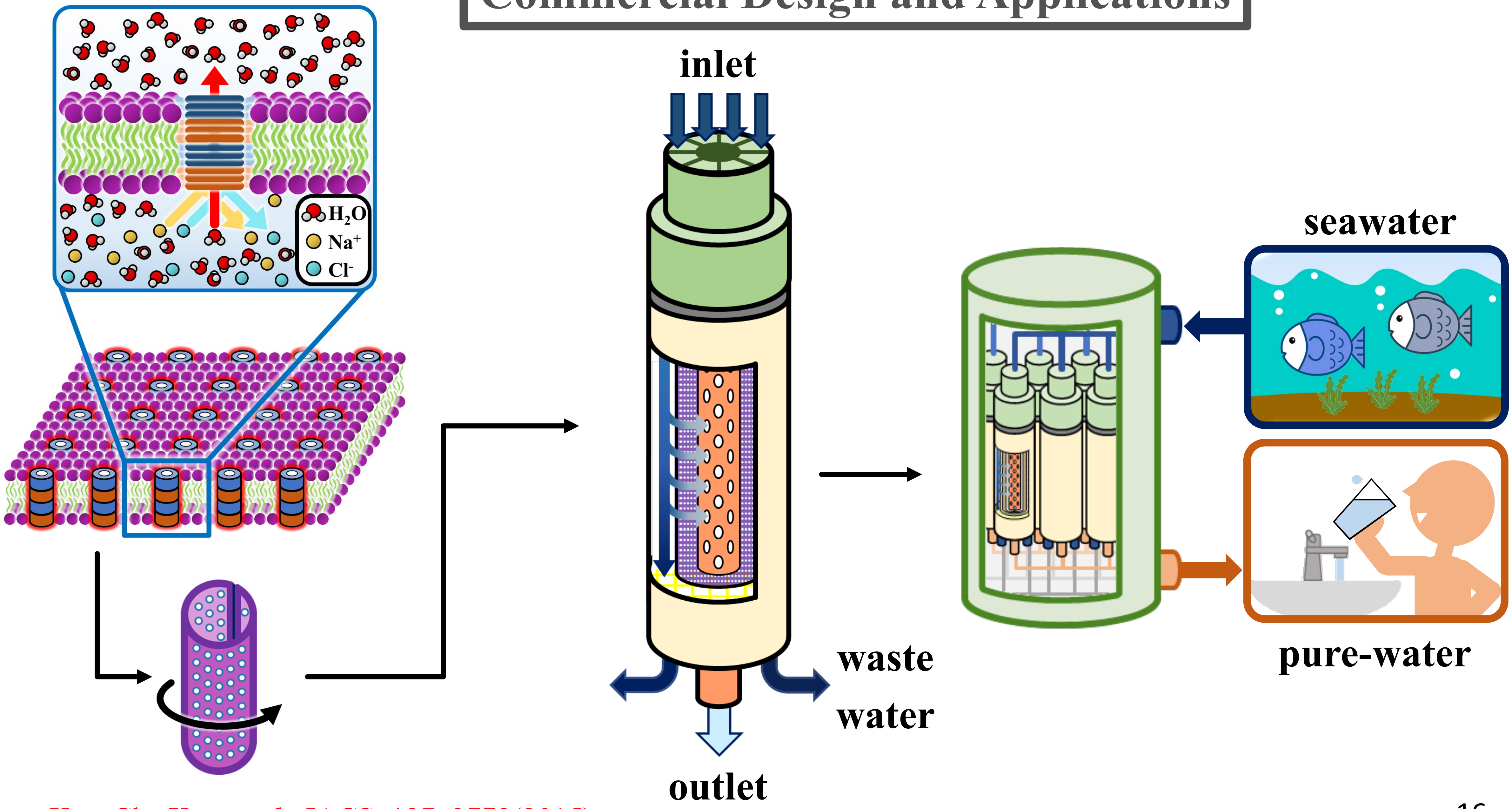
Type	Materials**	Methods*	Water flux ($L\cdot cm^{-2}\cdot day^{-1}$)	Salt Rejection
Pressure-driven	PA	MD(RO)	0.3868 at 9.9 atm	100.0 % (NaCl)
	CNT (6,6) CNT (7,7)	MD(RO)	0.27 (6,6) 0.42 (7,7) at 54.3 atm	100.0 % (6,6) (Na^+) 95.0 % (7,7) (Na^+)
	Mxene (Ti_3C_2)	MD(RO)	1.1532 per atm	> 99.0 % (NaCl, KCl)
	ZFCNT	MD(RO)	0.1153 at 36.0 atm	98.6 % (NaCl)
	GOQD	RO	0.090 at 15.8 atm	98.8 % (NaCl)
	rGO/TiO_2	NF-RO	0.1229 at 14.8 atm	99.5 % (NaCl)
	AqpZ-DOPC/DOTAP biomimetic	NF-RO	0.053 at 4.0 atm	75.0 % (NaCl) 97.0 % ($MgCl_2$)
Thermal-driven	Al membrane	DCMDL	0.0458	99.5 % (NaCl)
	Tubular ceramic	VMDL	0.0723	99.5 % (NaCl)
Commercial		**RO**	**0.0017 – 0.0054 per atm**	**> 99.6 – 99.9 % (NaCl)**
Our work	**ABNT-DPPC**	**MD**	**24.68 at 0 atm** **27.92 at 1 atm** **30.49 at 3 atm** **36.13 at 5 atm**	**100 % (NaCl)**

Commercial Design and Applications



Kun-Che Kao *et al.*, JACS, 137, 3779(2015).

Conclusions

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1. Nano-dewetting facilitates the unidirectional motion of water molecules on the *Aβ* surfaces — the ratchet structure and the broken detailed balance.
2. Water overflows from ABNT — natural water pump.
3. The designed ABNT nanofilter shows 100% desalination efficiency with perfect NaCl rejection.
4. The production of ~ 2.5 tons (10 x 10 cm^2) of pure water per day without any energy input.
5. Peptide-based nanotubes should be able to provide a more biocompatible environment for implant materials, while also providing flexibility, disposability and environmental protection.

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National Science and Technology Council