新竹科學工業園區管理局

財團法人中興工程顧問社

低耗能水再生技術-電容脫鹽及相關案例介紹

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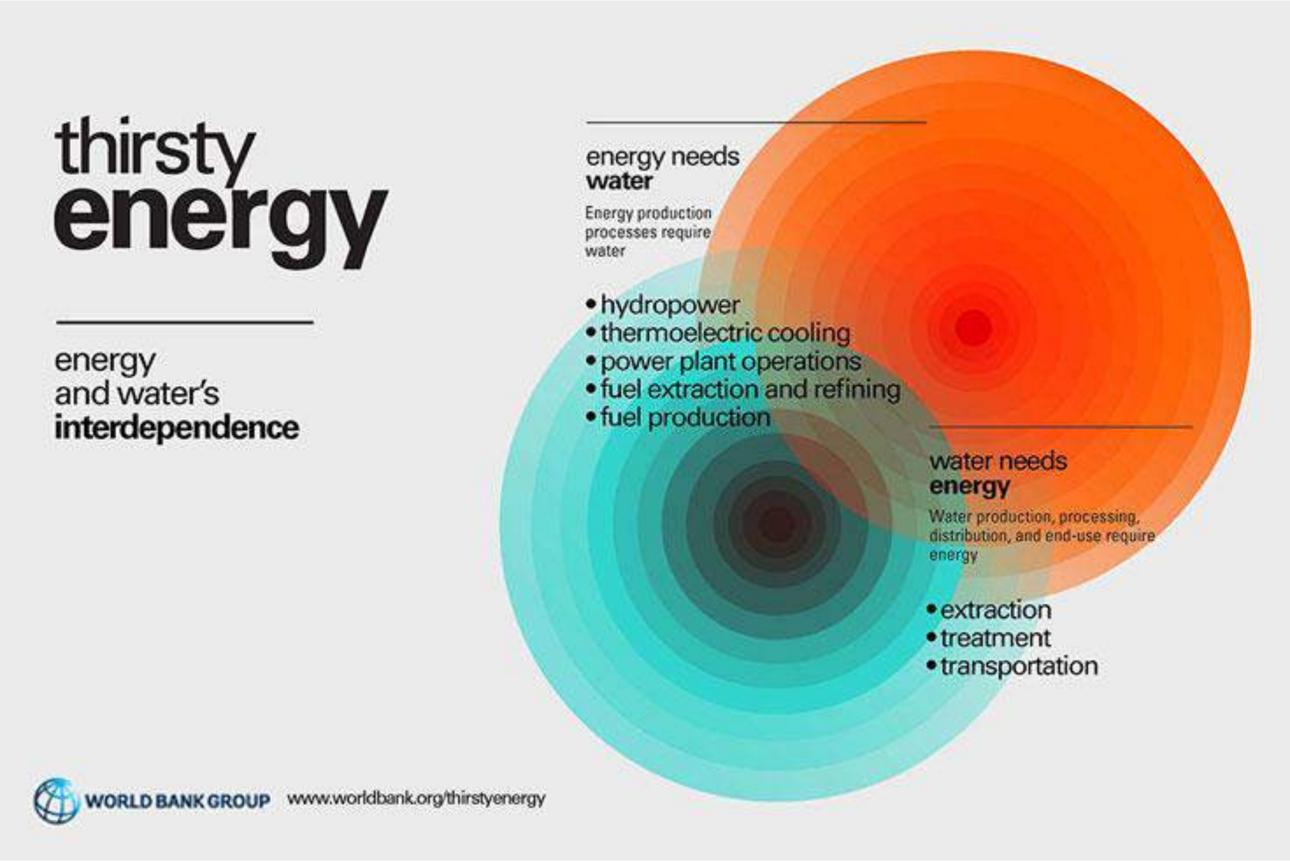
Outline: 電容脫鹽技術

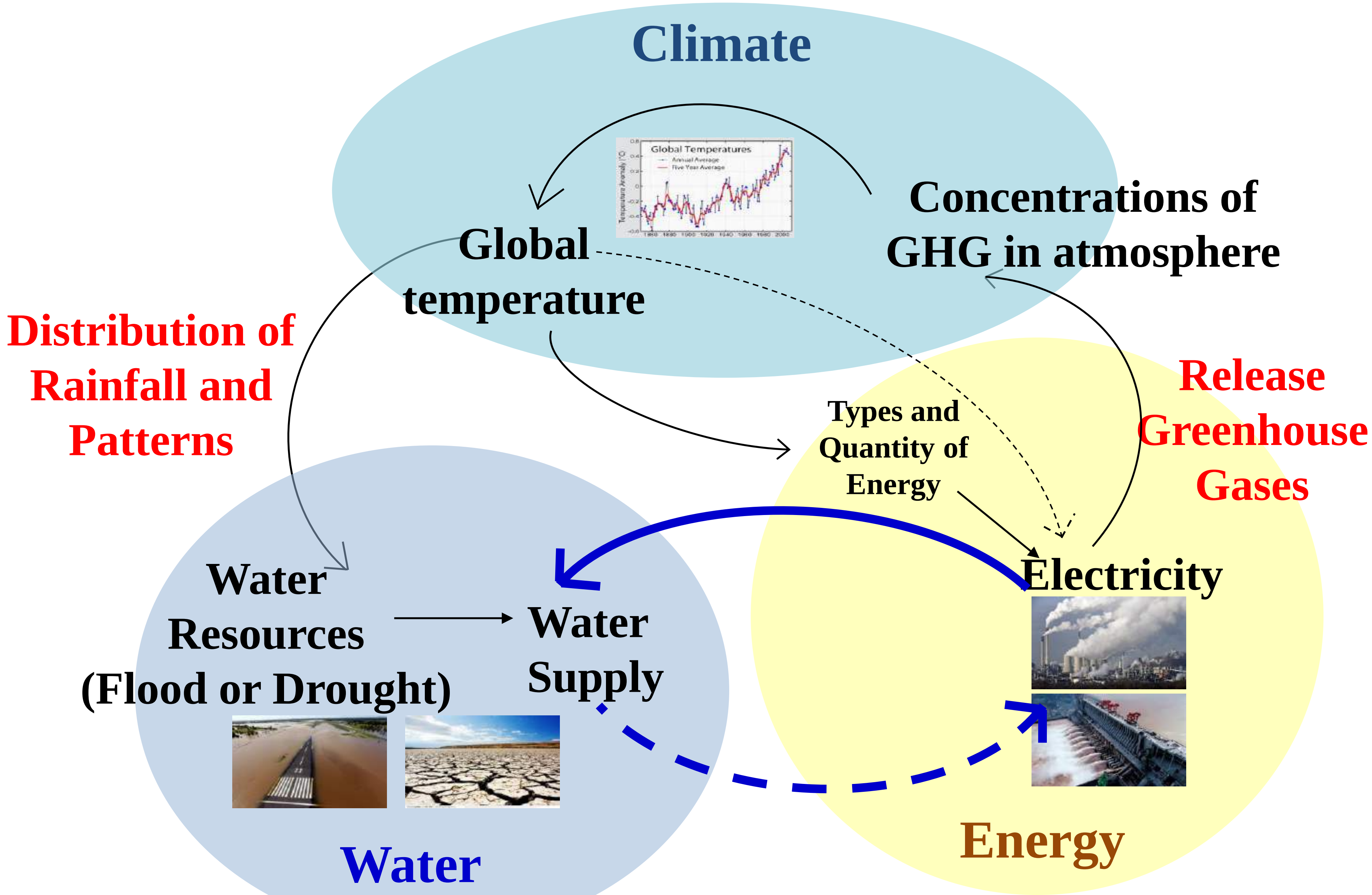
1. 水資源與能源之交互關係
2. 電容去離子技術之發展
3. 電容去離子技術之原理
4. 電容去離子技術之應用

水資源與能源之交互關係

聯合國：全球對能源的飢渴威脅水資源



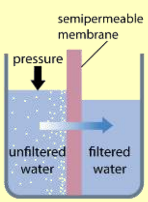
氣候變遷、能源、水資源之交互關係

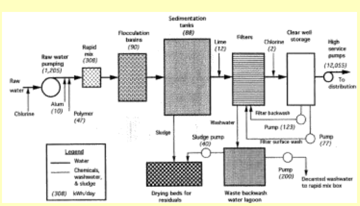


水資源與能源關係之思維

水資源之能源需求

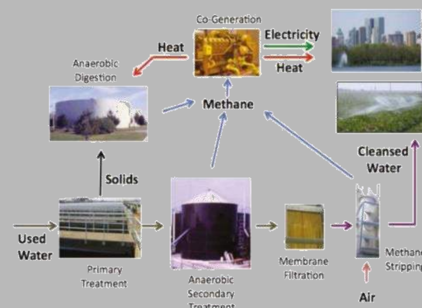
1.收集
2.飲用水處理系統
3.配給
4.廢水/水再生利用處理系統
5.其他相關能耗之使用 (如:海水淡化)

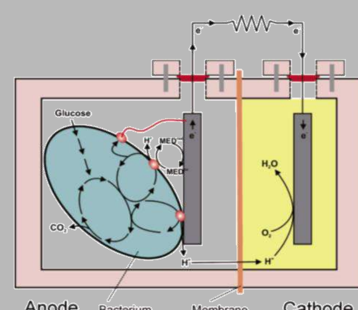




水資源之能源擷取

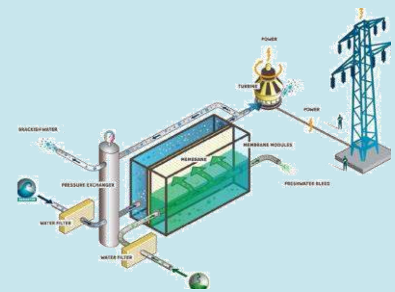
1. 厭氧處理程序
2. 微生物燃料電池

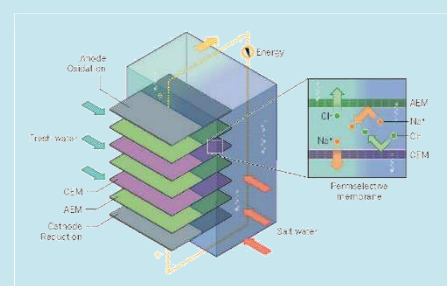




水資源之能源生產

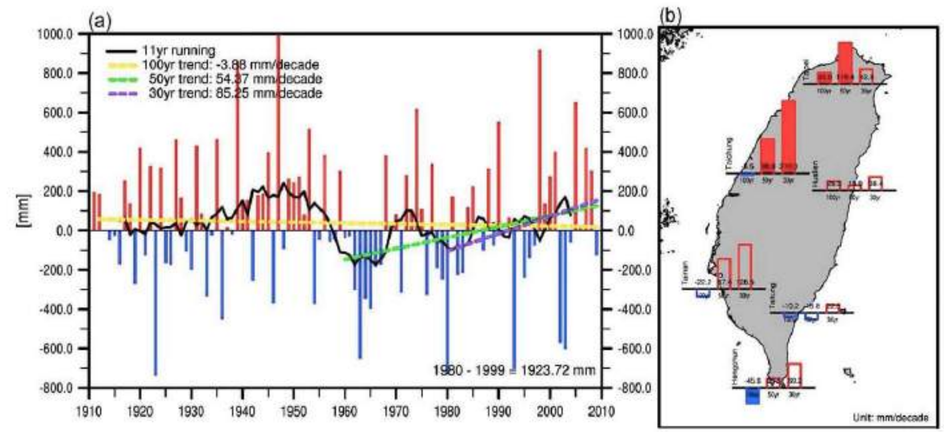
1.水力發電
2.壓力延遲滲 (PRO)
3.反向電透析 (RED)

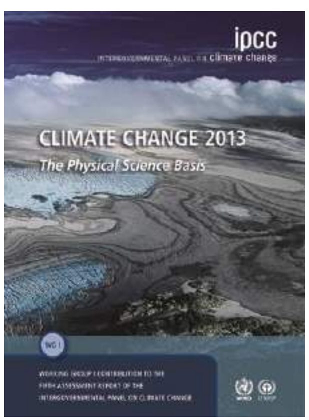




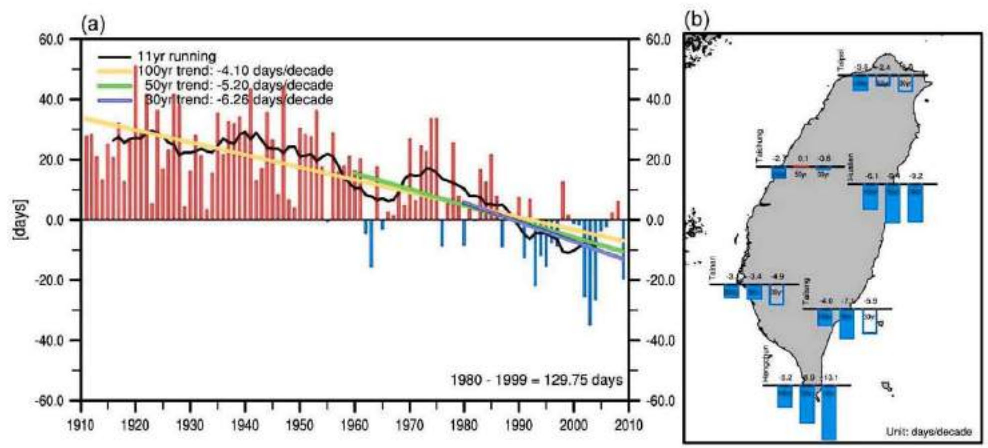
氣候變遷對臺灣水資源之影響

- Intergovernmental Panel on Climate Change (IPCC) Climate Change Assessment Report
  - Precipitation extremes
  - Increase in intense and heavy episodic rainfall events
  - Longer relatively dry periods





IPCC AR5, 2013



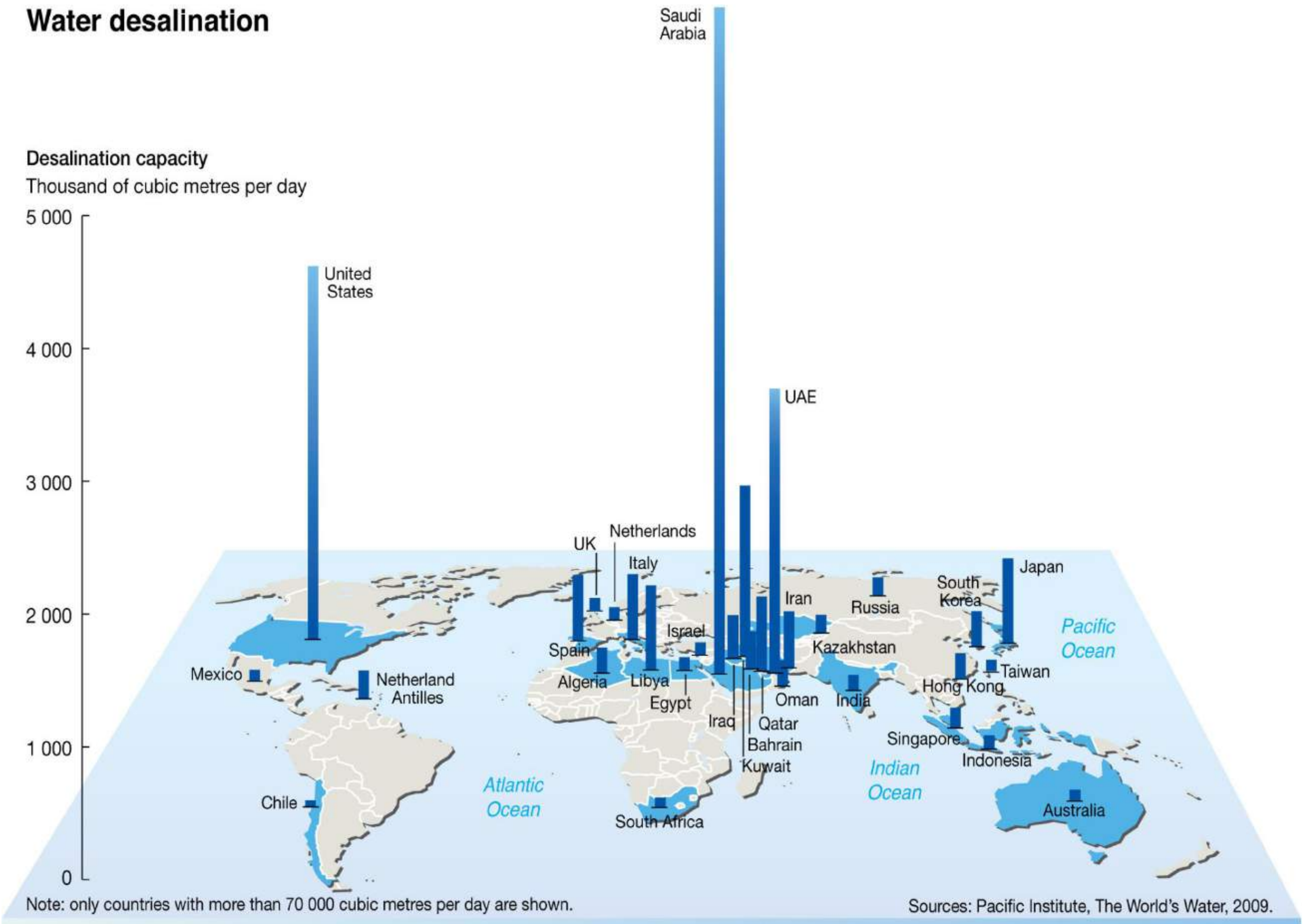
新興水資源之開發與推動(水利署)

水資源多元化

- **傳統水源**
  - 地面水(包含河川、湖泊、水庫蓄水範圍、排水設施、運河、滯洪池)
  - 地下水
- **新興水源**
  - 貯留雨水 → 提供生活次級利用
  - 海水 → 海水淡化 → 海淡水 → 工業與民生用水(台灣本島以供應高科技產業保險用水之用，離島則為主要的供水來源之一)
  - 生活污水、事業廢水 → 水再生利用技術 → 再生水 → 依水質提供不同使用用途，包含工業用水
生活次級用水、環境景觀用水、地下水補注、河川涵容維持利用等

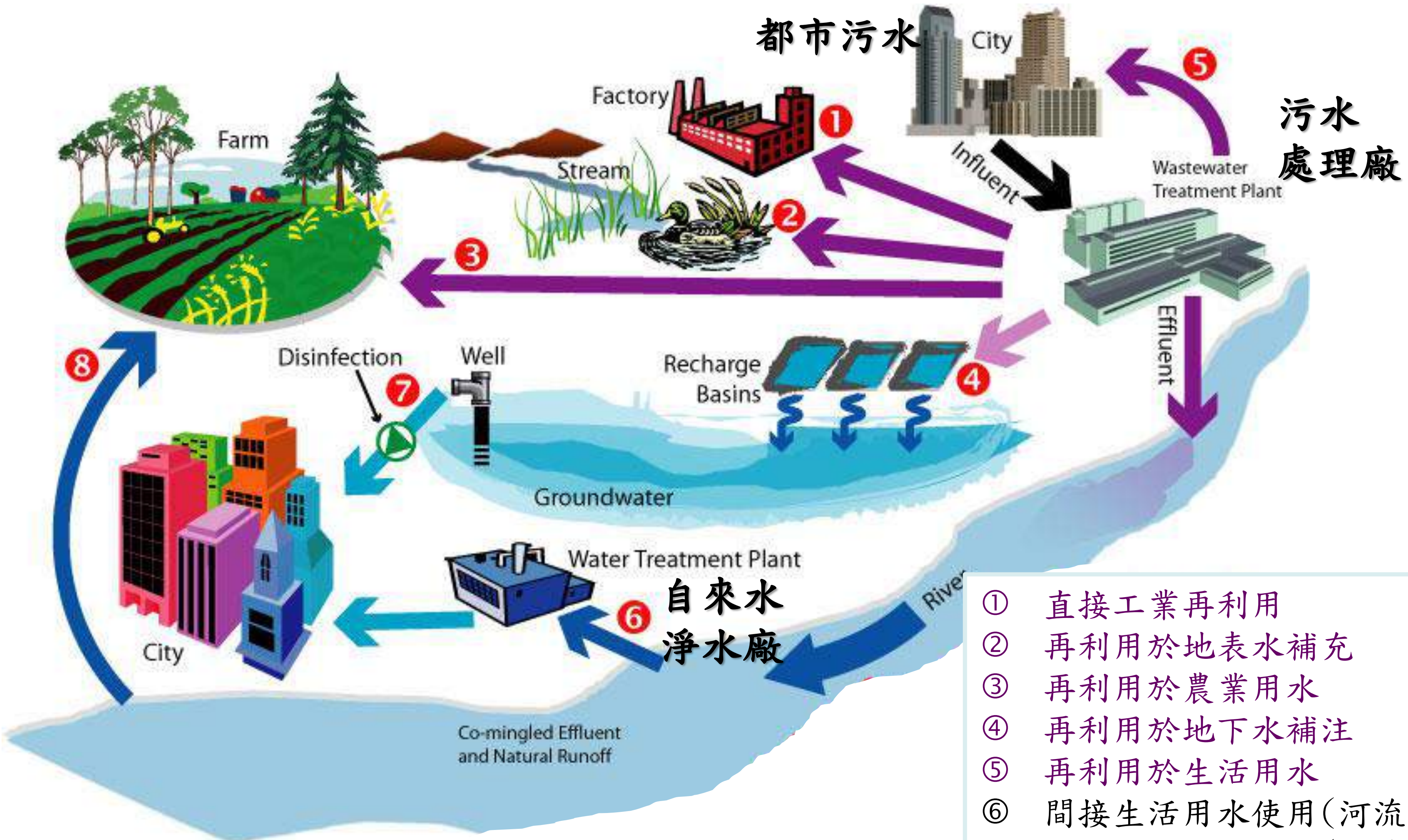
    *不得供人飲用、不得與人體直接接觸為原則

新興水資源：海水淡化



Water desalination
Desalination capacity
Thousand of cubic metres per day
5 000
4 000
3 000
2 000
1 000
0
United States
Saudi Arabia
UAE
Netherlands
UK
Italy
Spain
Algeria
Libya
Israel
Egypt
Iraq
Qatar
Bahrain
Kuwait
Iran
Oman
Kazakhstan
Russia
India
South Korea
Japan
Taiwan
Hong Kong
Singapore
Indonesia
Australia
Mexico
Netherland Antilles
Chile
South Africa
Pacific Ocean
Atlantic Ocean
Indian Ocean
Note: only countries with more than 70 000 cubic metres per day are shown.
Sources: Pacific Institute, The World's Water, 2009.

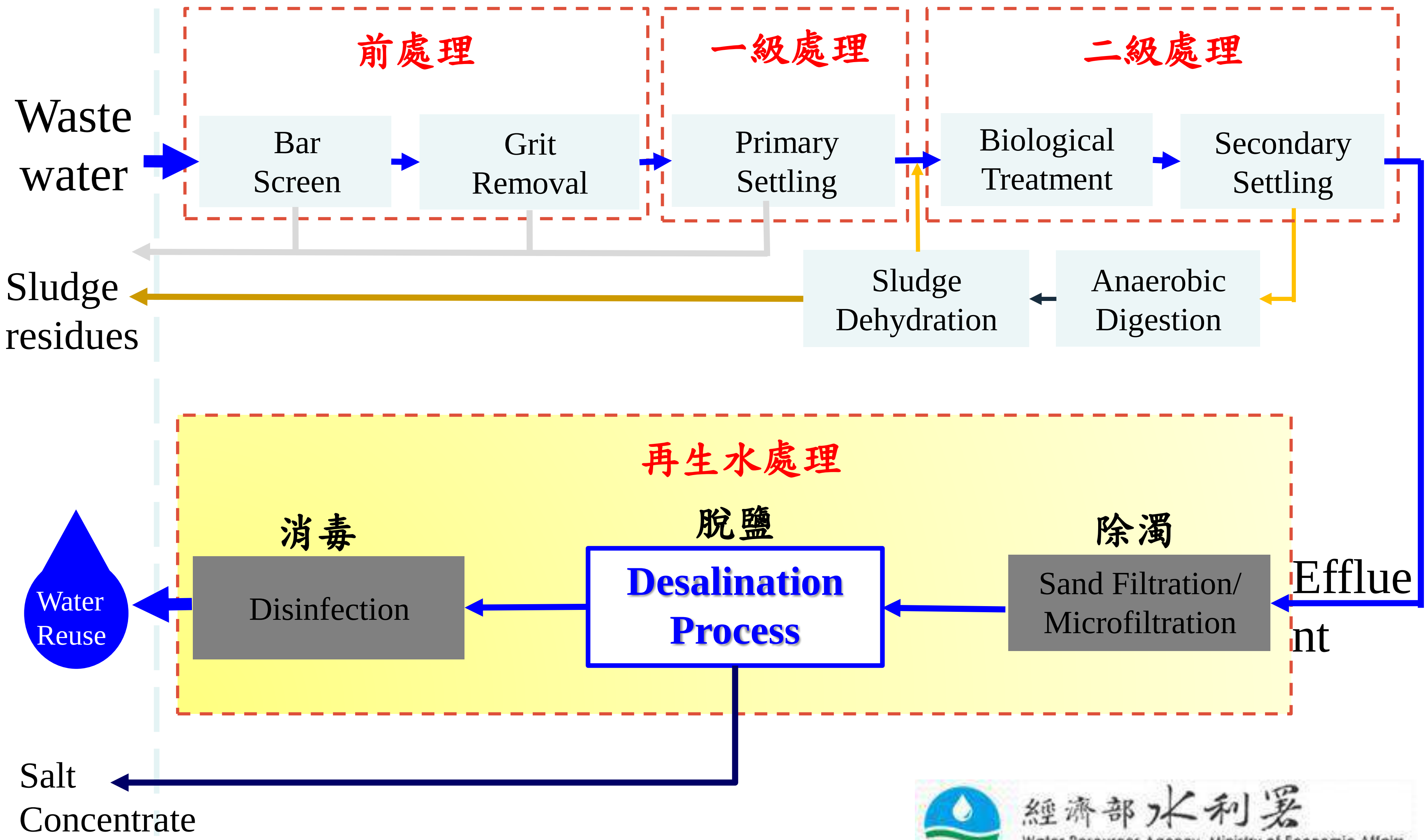
新興水資源：再生水在水循環扮演之角色



① 直接工業再利用
② 再利用於地表水補充
③ 再利用於農業用水
④ 再利用於地下水補注
⑤ 再利用於生活用水
⑥ 間接生活用水使用(河流)
⑦ 間接生活用水使用(水井)
⑧ 間接農業用水再利用

http://www.water.ca.gov/recycling/

低耗能脫鹽技術與現有污水處理場結合



經濟部水利署
Water Resources Agency, Ministry of Economic Affairs

脫鹽技術的發展與演變

1960 1970 2000 2006 2008 2010 2014 2016

Desalination

Thermal process — >10 kWh/m^3
- Multiple-Effect Distillation (MED)
- Multi-Stage Flash Distillation (MSF)

Membrane process — 2-8 kWh/m^3
- Reverse Osmosis (RO)
- Electrodialysis (ED)

Energy-efficient process — **<1 kWh/m^3**
- Forward Osmosis (FO)
- Membrane Distillation (MD)
- Capacitive Deionization (CDI)
- Hybrid Process

1st technological innovation

Next technological innovation

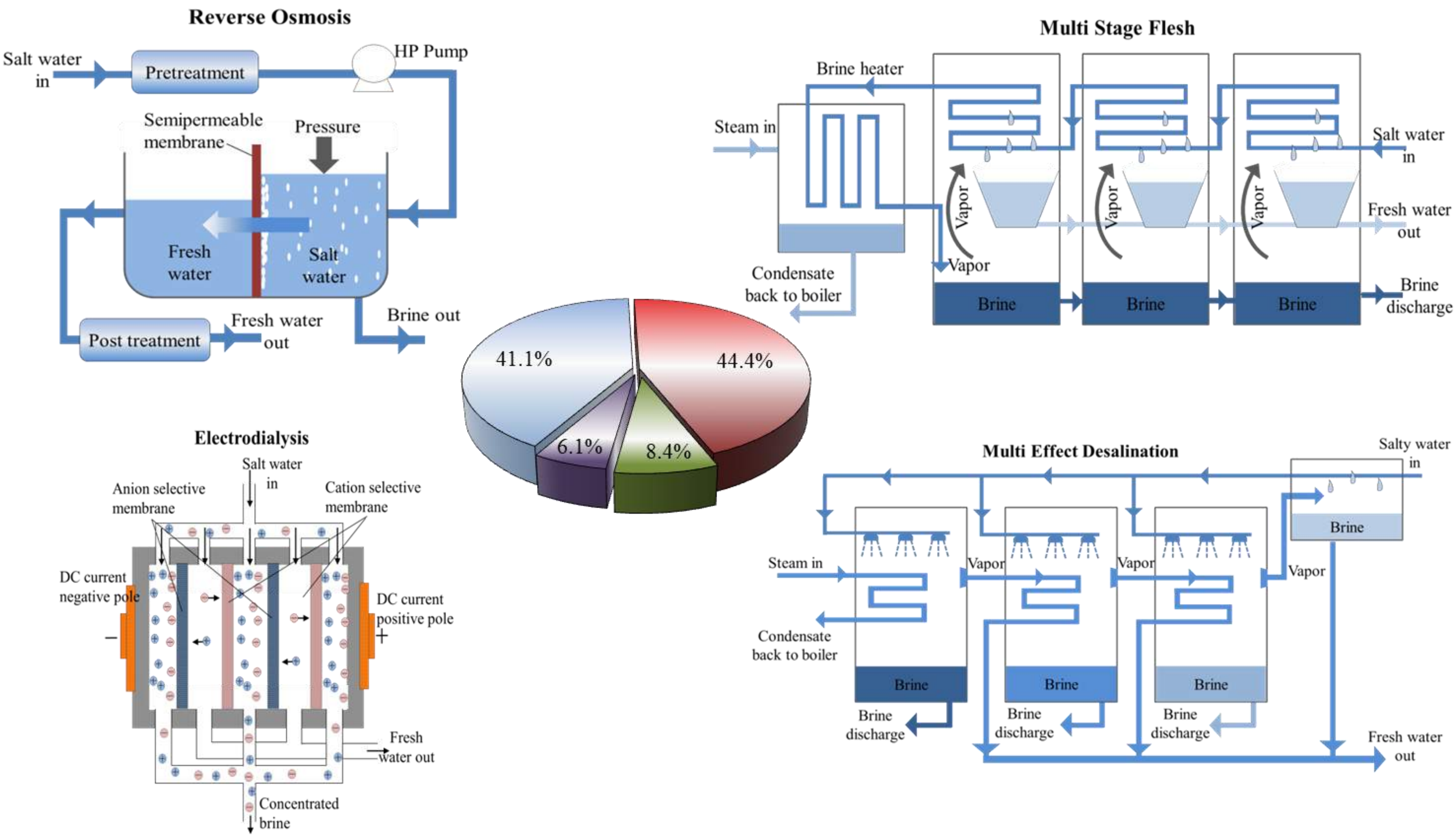
國立臺灣大學CDI研究

Fundamental
- EDL Theory
- Electrosorption of ions

Carbon Material
- High capacitive charge storage
- High desalination performance

Module Design and Scale-up
- Systemic integrated design
- Pilot test

常見的脫鹽技術



Schematic diagram of major desalination technologies and their relative contributions to worldwide installed capacity for seawater and brackish water desalination.

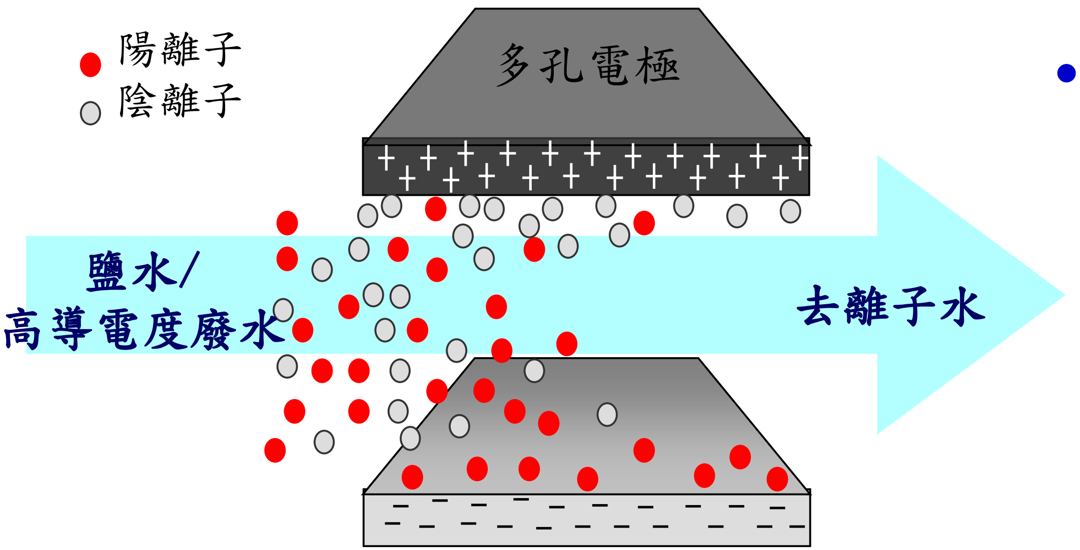
新穎(低耗能)脫鹽技術之現況分析

處理程序	正滲透(FO)	電去離子(EDI)	電容去離子(CDI)	薄膜蒸餾(MD)
技術原理 與 關鍵技術	利用選擇性半透膜兩邊溶液其溶質濃度差異所造成的滲透壓差做為驅動力，水分子自發地從低溶質濃度傳輸到高溶質濃度的過程	結合IEM以IER的複合型分離技術。EDI利用IEM對陰、陽離子的選擇性，以及IER的離子交換作用，在直流電場操作下進行離子分離程序	藉高比表面積及導電性之特性，以電吸附作用使帶電荷離子向帶有相反電荷的電極移動，在孔洞間形成電雙層，達到水體中移除離子的目的。	利用疏水性薄膜兩側水溫高低溫差，以薄膜兩側流體接觸面的蒸氣壓差為趨動力，將水蒸氣分子經薄膜孔洞，由高溫側傳輸到低溫側後凝結成液體，而達到分離水分子之目的。
目標 污染物	各類水溶性溶質	重金屬、 溶解性無機鹽	重金屬、帶電離子、 溶解性無機鹽	揮發性溶劑中離子、 巨分子、膠體、 以及非揮發性物質
技術特點	自發性驅動 高離子排除率、 不易發生積垢問題	改善傳統 電透析(ED)程序 增加對弱解離性物種 處理效果	不需使用薄膜 (無積垢) 低電壓操作、 可由綠能驅動運行	熱能可由廢熱驅動 較傳統蒸餾程序有低能量與空間需求、高離子排除率
關鍵技術	薄膜製造技術 & 提取液開發	薄膜製造技術 & 陰陽IER混合比例	碳電極材料製造技術 & 模組設計	薄膜製造技術 & 模組設計
主要應用	➢高營養鹽污泥 ➢濃縮脫水 ➢有機污染物去除 ➢二級放流水的處理	➢純水的製造 ➢重金屬離子的去除	➢海水淡化 ➢硬水軟化 ➢地下水整治 ➢重金屬離子去除	➢海水淡化 ➢非揮發性物質移除 ➢揮發性有機物質移除 ➢酸液濃縮
重要 參考文獻	(Holloway et al., 2007) (Zhang et al., 2013) (Zhang et al., 2012)	(Arar et al., 2014) (Strathmann, 2010) (Dermentzis et al., 2009)	(Farmer,1997) (Xu et al., 2008) (Seo et al., 2010)	(Lawson and Lloyd, 1997) (Khayet et al., 2003) (Zhang et al., 2015)

電容去離子技術 (Capacitive Deionization, CDI)

技術原理

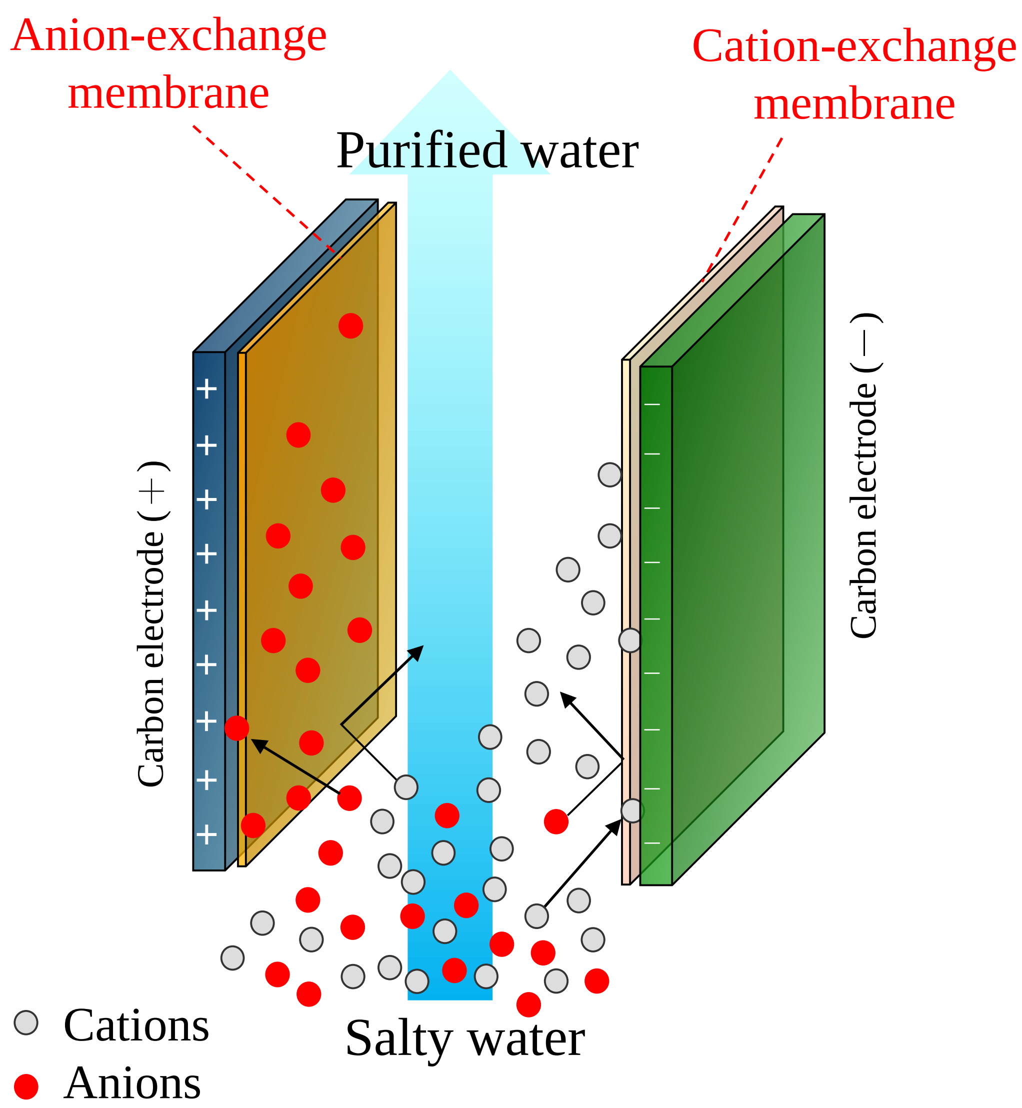
- 以電荷分離與超級電容器工作原理，從水體中移除離子。
- 基於奈米孔洞碳電極，施加低電壓(~ 1.2 V)產生正極和負極，使得水體中的陽離子、陰離子被庫倫作用力影響，電吸附於具相反電性的電極中，進而在孔洞中發展電雙層。

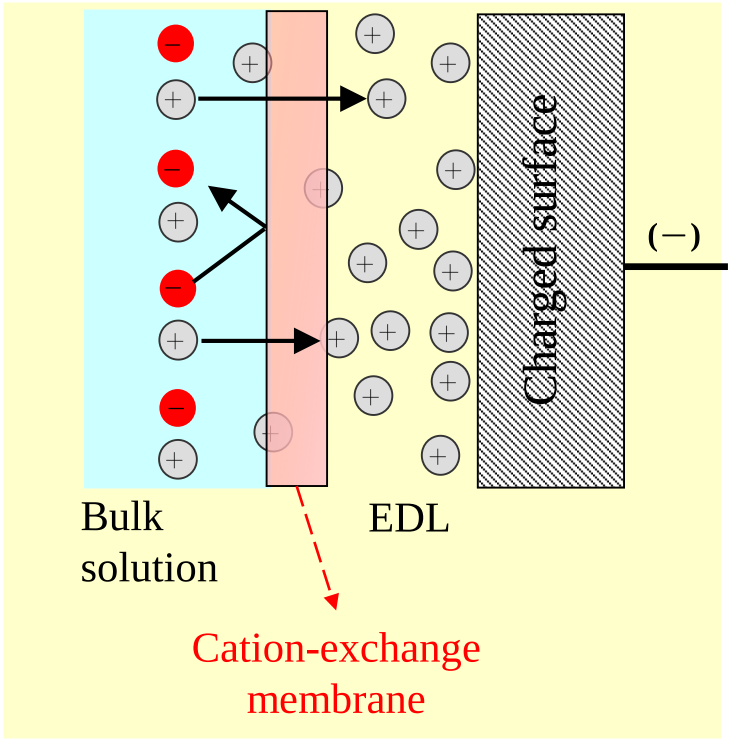


電容去離子技術的工作原理

- 研發動機
  - 電容去離子技術被OCED評估為未來最具發展潛力的脫鹽技術。
  - 低耗能、綠色分離的技術，可有效的去除水中的無機性離子，降低水體的導電度及總溶解固體濃度。

薄膜電容去離子技術
(Membrane Capacitive Deionization, MCDI)

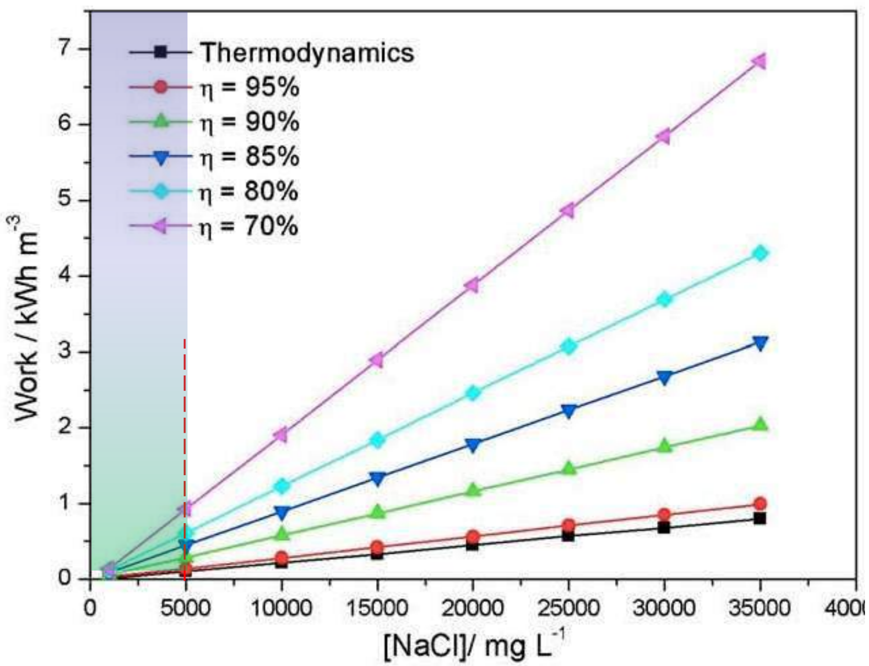


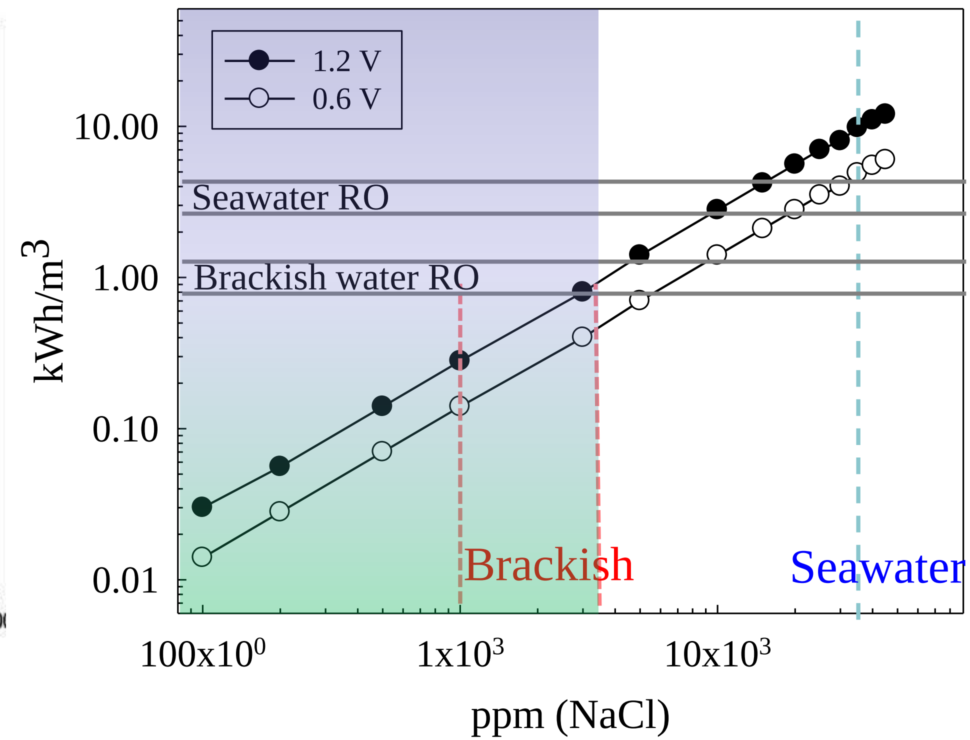


- ✓Without interference of Coions
- ✓Removal efficiency
- ✓Energy efficiency

電容脫鹽技術的低耗能優點

Energy Considerations in CDI





(Adapted from Oren *et al*., 2008)

CDI could be competitive technology at NaCl concentrations below 5000 mg/L. (M. M. Anderson et al., 2010)

*Energy consumption (2000 mg/L salty water):

RO: 2.25 kWh/m^3

EDR: 2.03 kWh/m^3

CDI : 0.59 kWh/m^3

(Welgemoed and Schutte, 2005)

電容去離子技術的特點

主要特點

- 低壓操作
- 低電壓、低耗能
- 通道式流道，不易堵塞
- 產水率高(>75%)
- 無二次汙染
  操作與維護簡便

應用範圍

- 半鹽水淡化
- 飲用水淨化
- 家庭/工業再生水脫鹽
- 微量污染物的去除
- 重金屬的去除

脫鹽技術	技術原理
逆滲透 (RO)	□**外加壓力與反滲透膜** □高壓下運行 □薄膜積垢與操作維護複雜 □能耗：2.3 ~ 5.7 kWh/m^3
電透析 (ED)	□**電驅動與陰陽離子交換膜** □薄膜極化與水解現象 □消耗化學藥品
電容去離子 (CDI)	□**電吸附與超級電容原理** □通道式結構 □OECD(2009)評估最具有取代現有脫鹽技術之潛力 □低耗能 0.5 ~ 1.0 kWh/m^3

電容脫鹽技術的主要特點

高脫鹽效率
> 90%

高產水率
> 80%

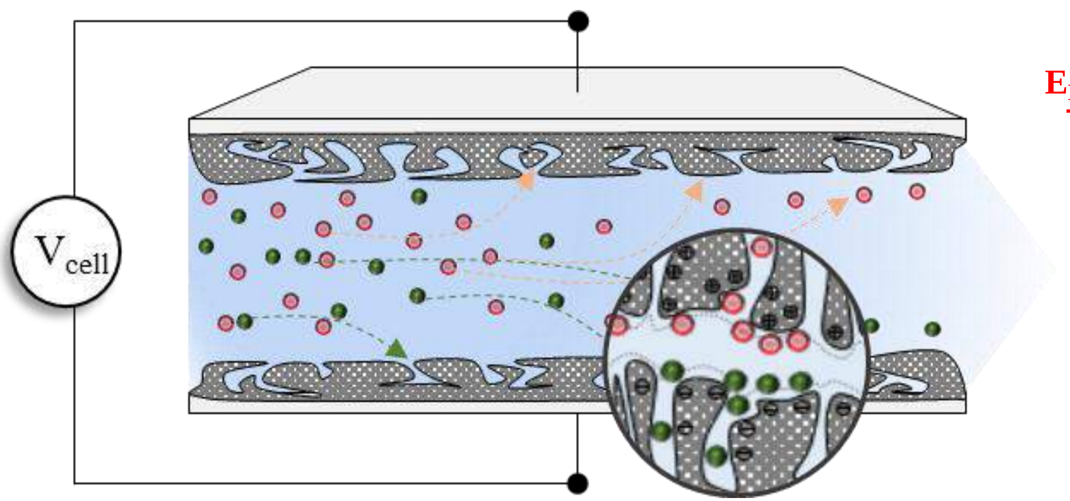
低能耗
< 1 kWh/m^3

環境
友善性

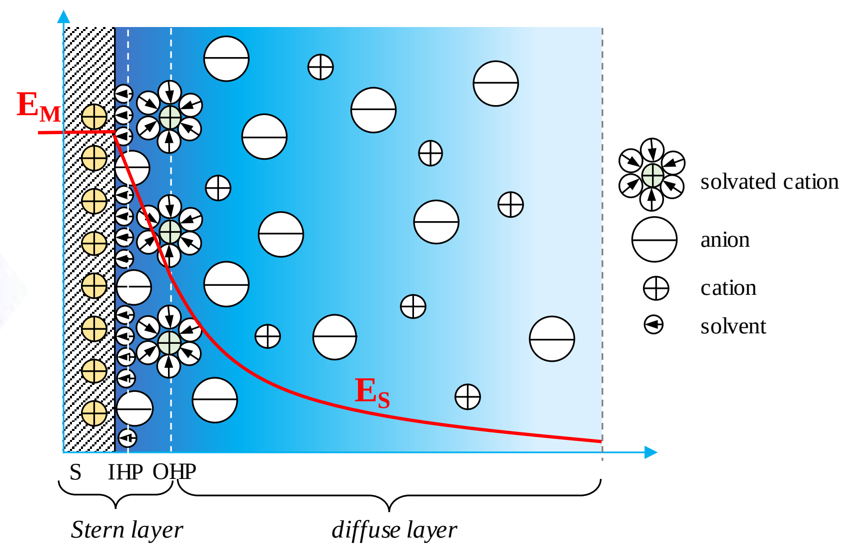
模組驗證與
商業化階段發展

降低積垢
問題

電容去離子技術之原理



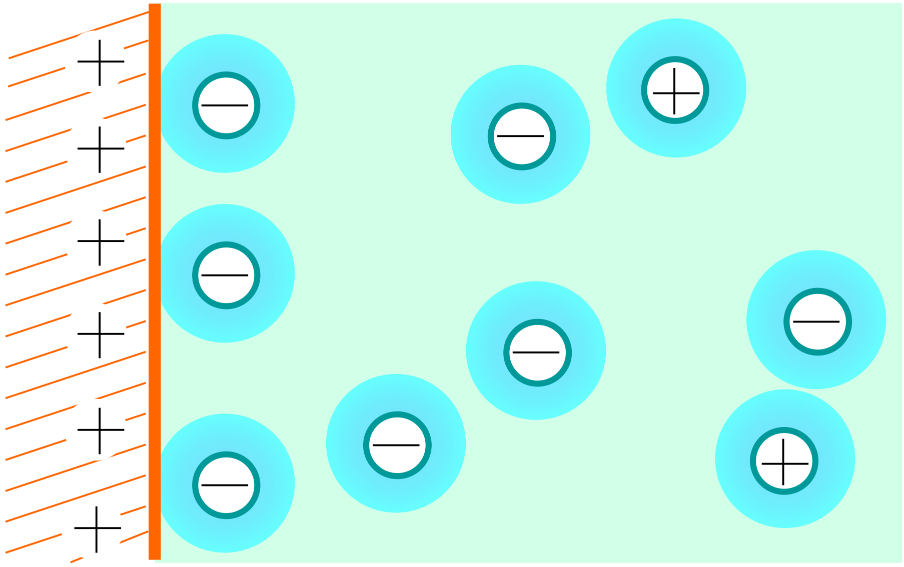
V cell



E M
E S
solvated cation
anion
cation
solvent
S
IHP
OHP
Stern layer
diffuse layer

電雙層(Electrical Double Layer)的形成

- A charged surface in an aqueous environment leads to a potential difference across the solid/electrolyte interface.
  - ✓ Neutralization of space charge: counterion accumulation
  - ✓ Electrical double layer (EDL) formation
  - ✓ Electrosorption of ions



EDL is a very important interfacial phenomenon to many physical, chemical, and biological systems.

電雙層的理論

Historical development

- ✓ **Helmholtz:**

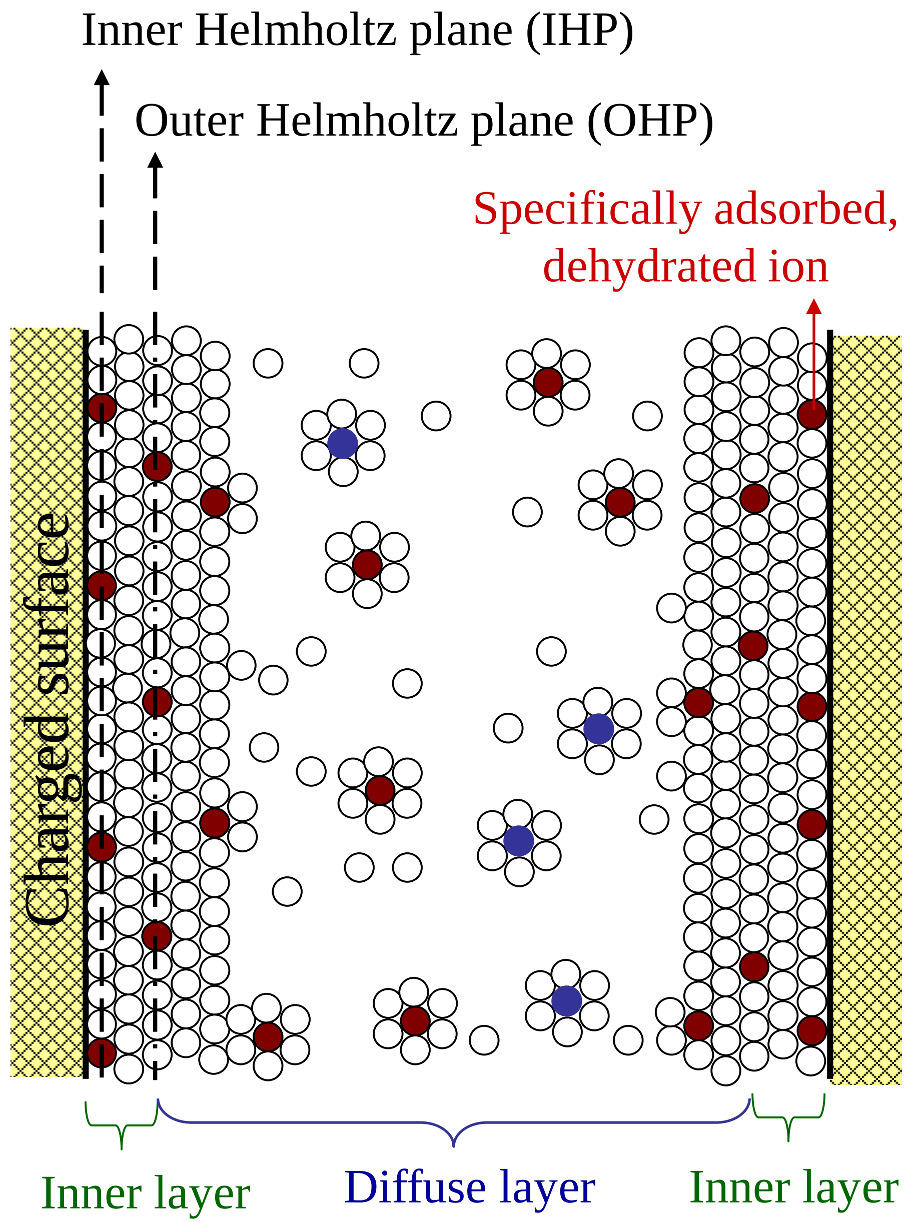
  A single-adsorption layer of ions with charge opposite to that of the surface

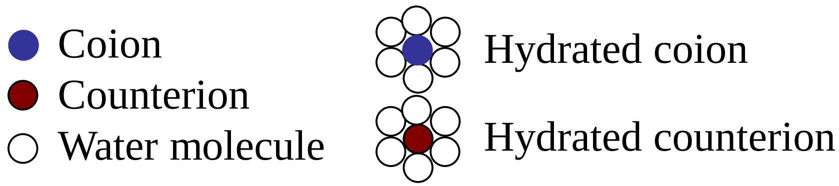
- ✓ **Gouy and Chapman:**

  A diffuse model of EDL, in which the potential decreases exponentially due to accumulation of counterions from the solution

- ✓ **Stern:**

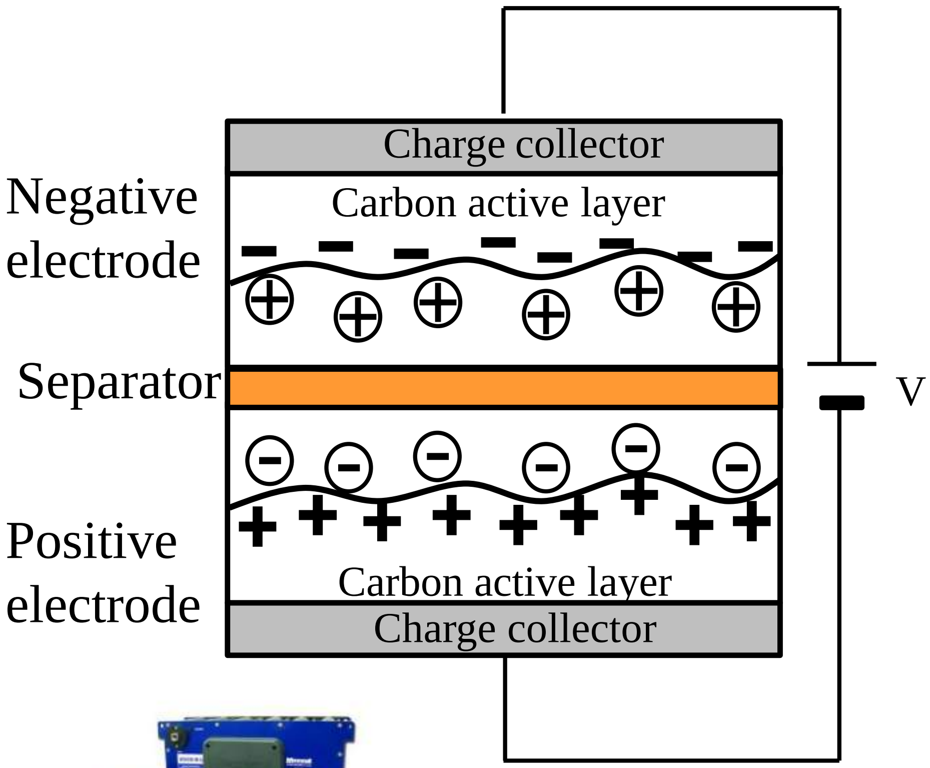
  Combination of the Helmholtz single-adsorption layer and Gouy-Chapman diffuse layer models

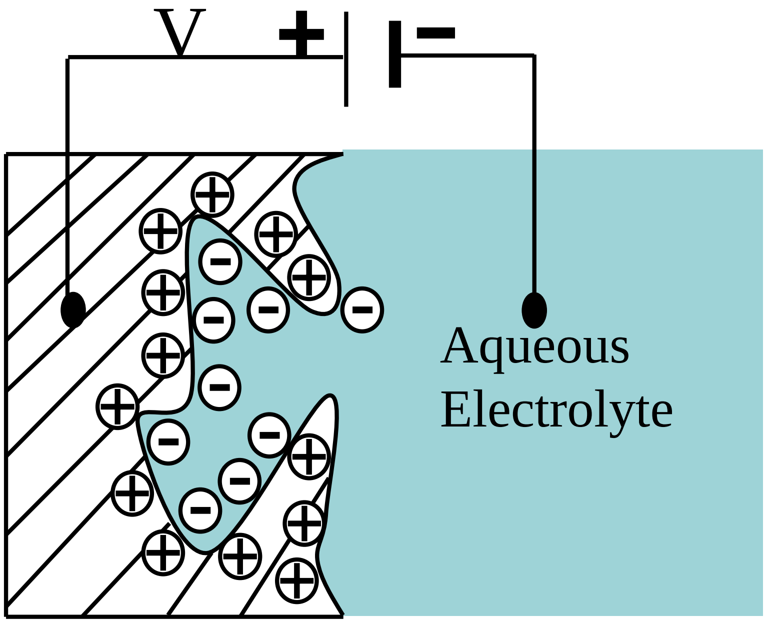




電雙層電容器/超級電容器 (Electrical Double Layer Supercapacitor)

- Energy storage by formation of double layer when a voltage is applied to an carbon electrode immersed in an electrolyte



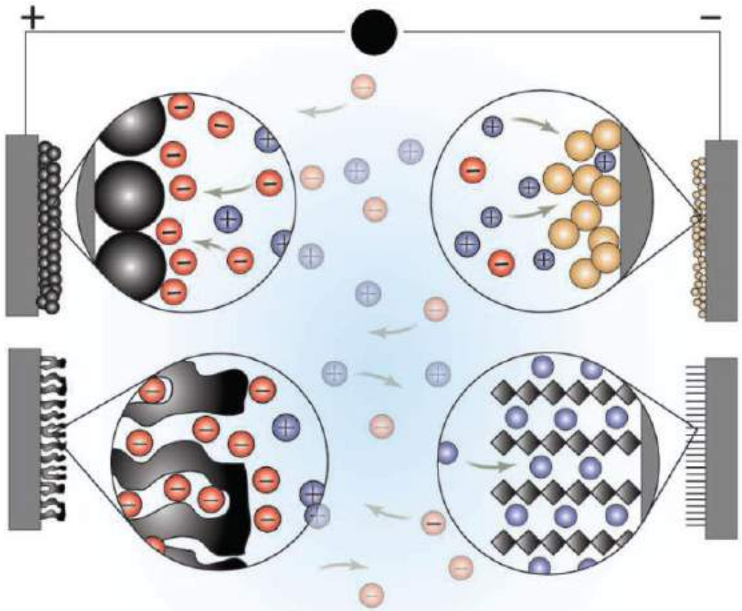


Pores in carbon electrode

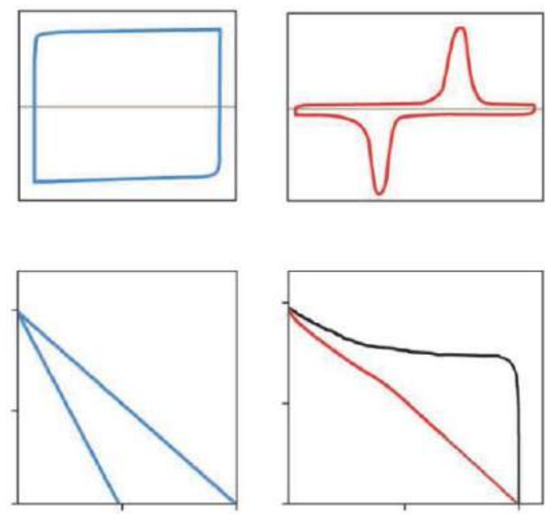
Porous electrode with double layer formed on the solid/electrolyte interface.

超級電容器的時代

Where Do Batteries End and Supercapacitors Begin?
Simon et al. (2014), *Science*



The mechanisms of capacitive energy storage

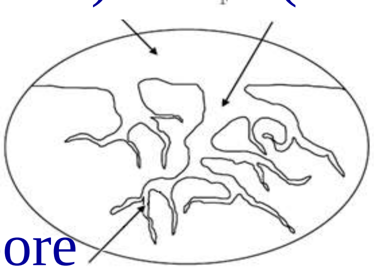


Electrochemical measurements can distinguish between different types of energy storage materials and their underlying mechanisms.

電容脫鹽技術的工作原理

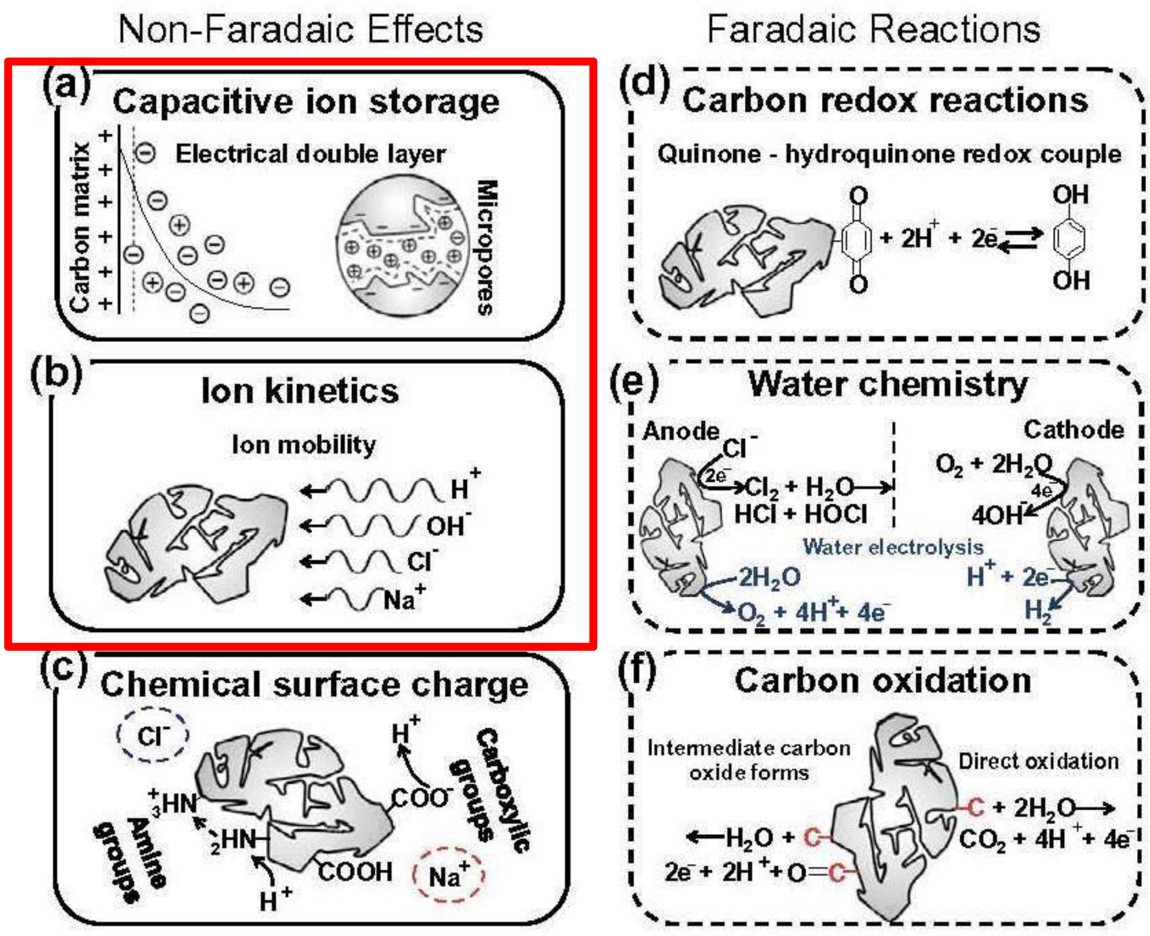
- Electrosorption process (電吸附)
  - Electric-field-driven separation
    transportation of ions from bulk solution to the electrode
  - Charge separation
    (capacitive ion storage as a supercapacitor)
    EDL formation

- Highly porous electrode (多孔電極材料)
  - High electrochemical stability
  - Good electrical conductivity
  - Good wetting behavior
  - Large specific surface area
  - Good pore accessibility for ion electrosorption



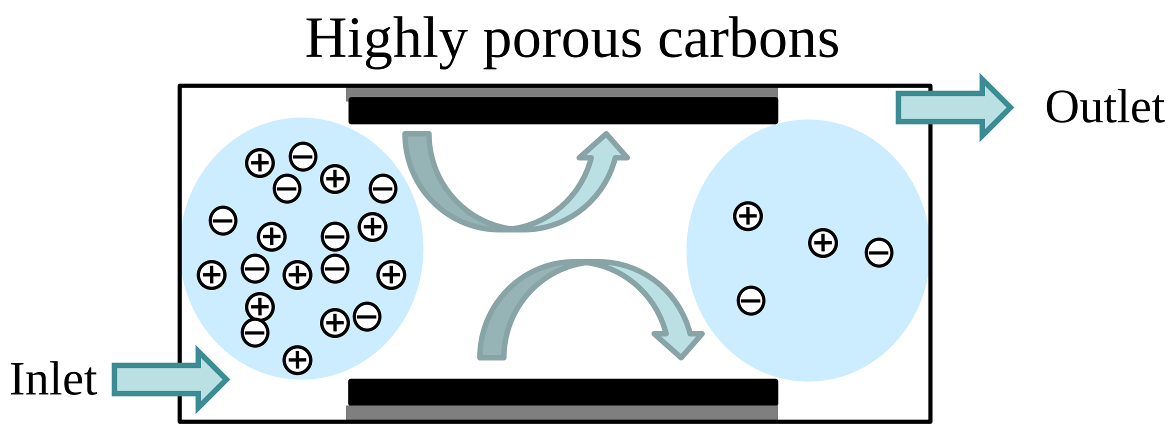
多孔電極之電化學反應

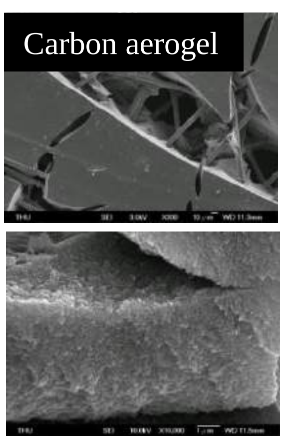
- Capacitive ion storage (EDL formation)/ and ion kinetics are the heart effects of CDI process.
- Other reactions need to be minimized.

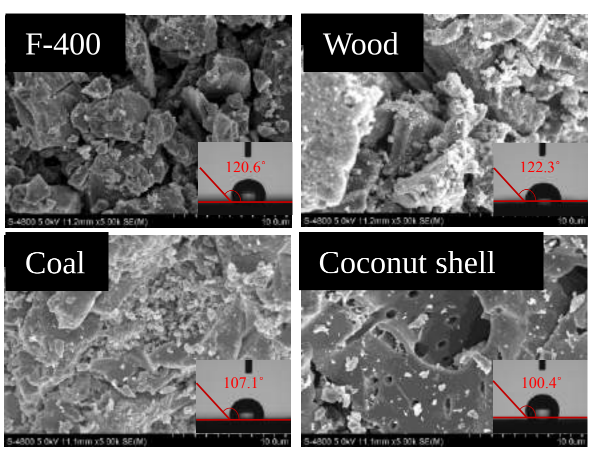


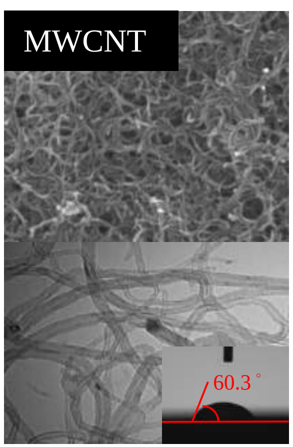
S. Porada et al. Progress in Materials Science (2013)

多孔電極材料


Highly porous carbons
Outlet
Inlet

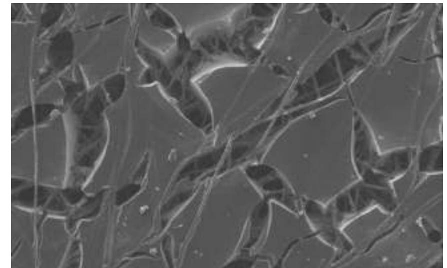

Carbon aerogel

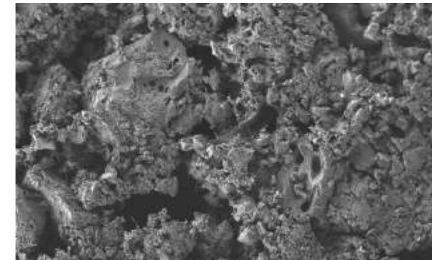

F-400
120.6°
Wood
122.3°
Coal
107.1°
Coconut shell
100.4°

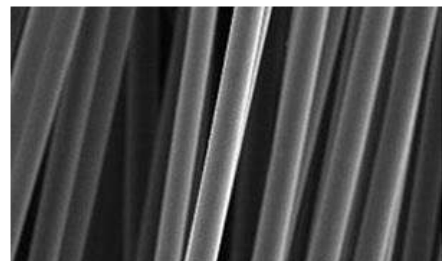

MWCNT
60.3°

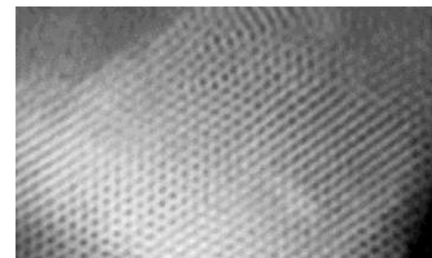
多孔電極材料在CDI的應用

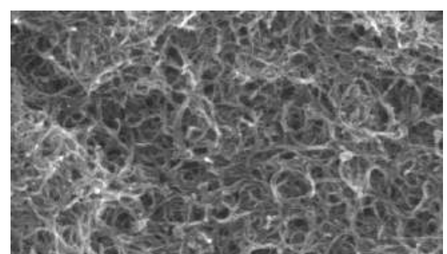
- Highly porous carbons as electrodes:
  - Carbon aerogel
  - Activated carbon
  - Carbon nanofiber
  - Activated carbon cloth
  - Carbon nanotubes
  - Graphene
  - Ordered mesoporous carbon
  - Hierarchical ordered carbon
  - Other composite electrodes
- Application to capacitive charge storage


Carbon aerogel


Activated carbon


Carbon fiber

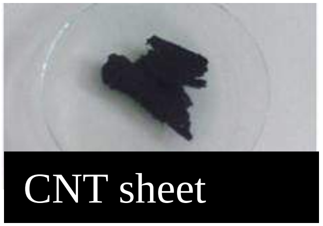

Mesoporous carbon


Carbon nanotube

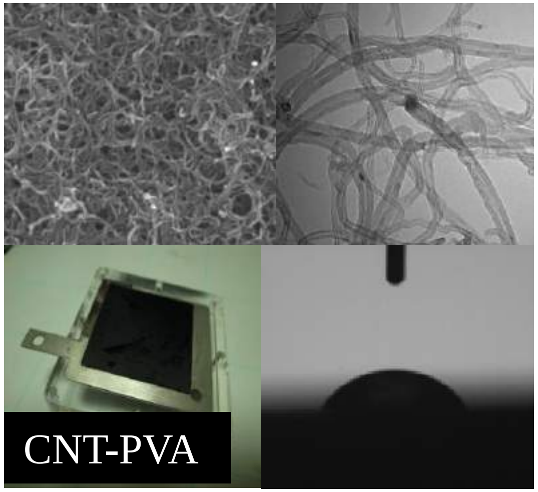

Graphene

奈米碳管 (Carbon Nanotubes)

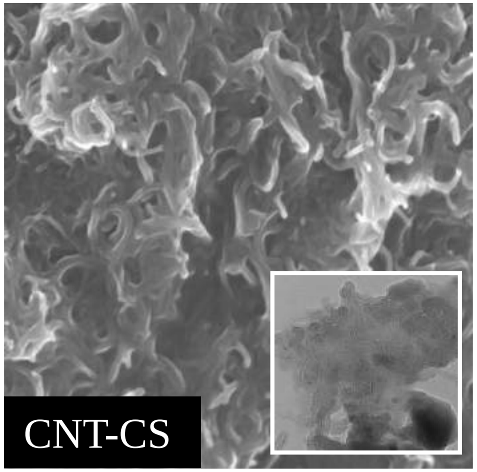
- Carbon nanotubes have superior conductivity, excellent chemical inertness, and large sorption capacity
  - Carbon nanotube sheets (by chemical vapor deposition)
  - Polymer composite
    - poly(vinyl) alcohol (PVA)
    - Chitosan (CS)
    - Polyaniline
  - AC-CNTs composite

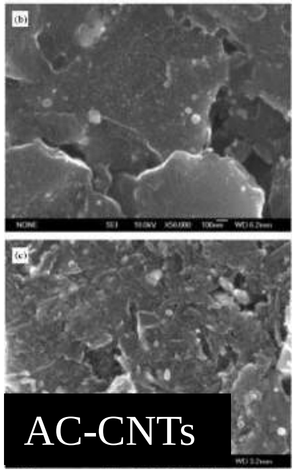


Tofighy and Mohammadi, 2010



Hou et al, 2013

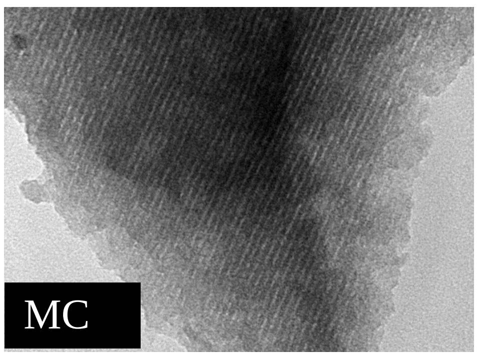


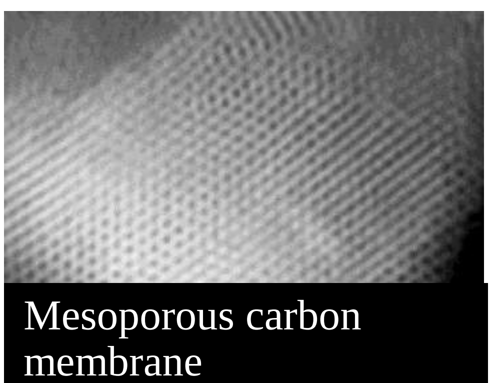


Dai et al, 2006

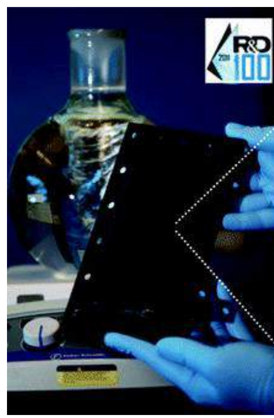
規則性中孔洞材料(Ordered Mesoporous Carbons)

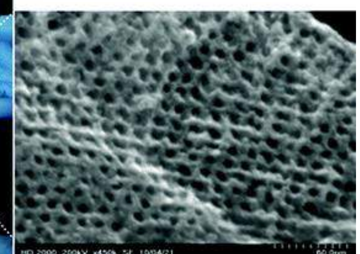
- Mesoporous carbon (MC) are less affected by double-layer overlapping to facilitate ion transport.
  - Synthesized using a self-assembly method via soft template
  - Good pore accessibility and ion selectivity


MC

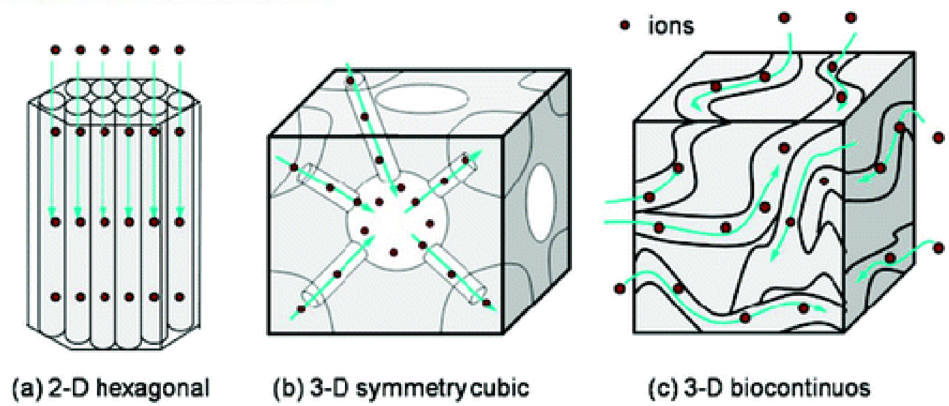

Mesoporous carbon membrane

Hou et al, 2008





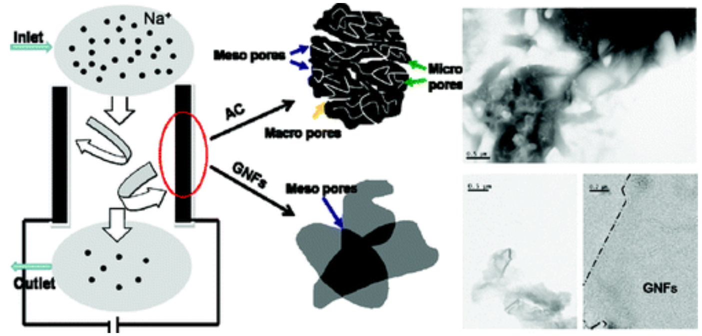
Tsouris et al, 2011



Peng et al., 2011

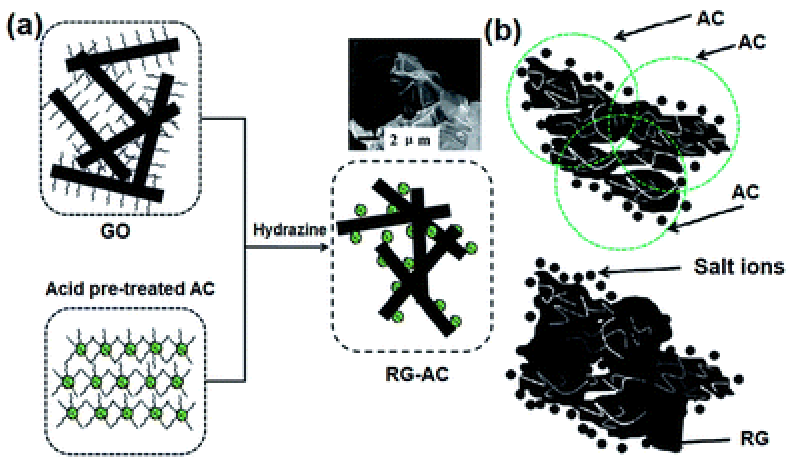
石墨烯 (Graphene)

- Graphene (GE) has an ideal two-dimensional (2-D) carbon nanostructure.
  - Graphene-like nanoflakes
  - Reduced graphene oxide-ACs
  - Graphene-CNTs
  - Graphene-mesoporous carbon



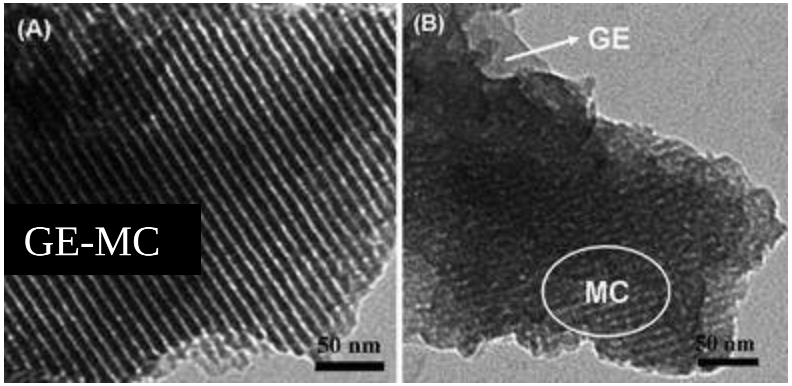
GE

Li et al., 2010



Reduced GE-ACs

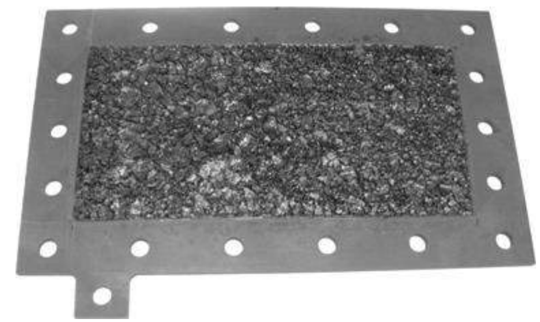
Li et al., 2012



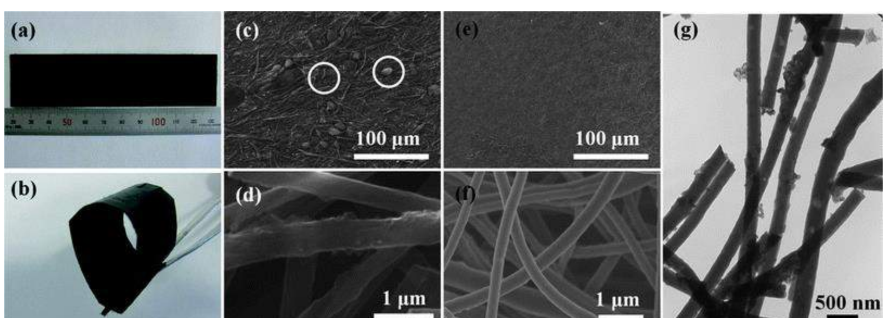
Zhang et al, 2012

階層孔洞碳電極 (Hierarchical Porous carbons)

- Hierarchical porous carbon (HPC) has a well-defined pore structure.
  - Macropores, mesopores, and micropores are well interconnected with a balanced ratio
  - Hierarchical activated carbon nanofiber
  - Hierarchical ordered mesoporous carbon
  - 3-D hierarchical porous carbon

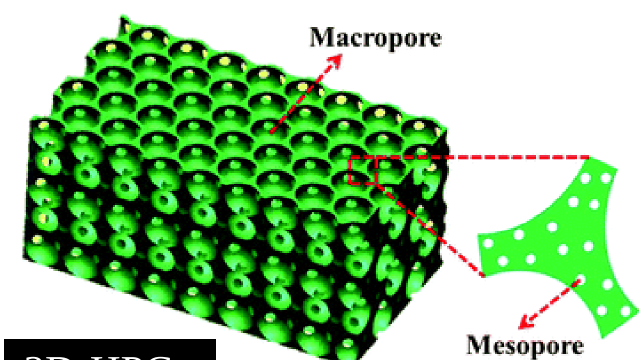


HPC-MC Maye et al., 2010



HPC-nanofiber

Wang et al., 2012

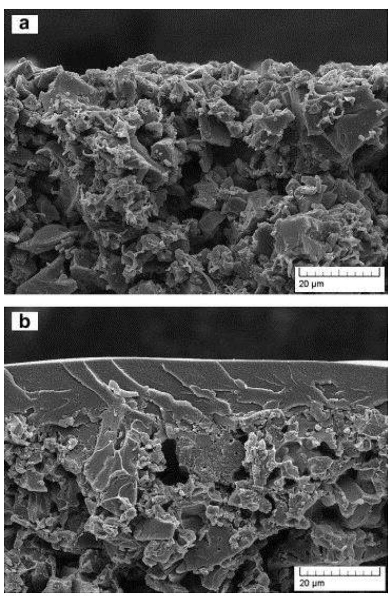


3D-HPC

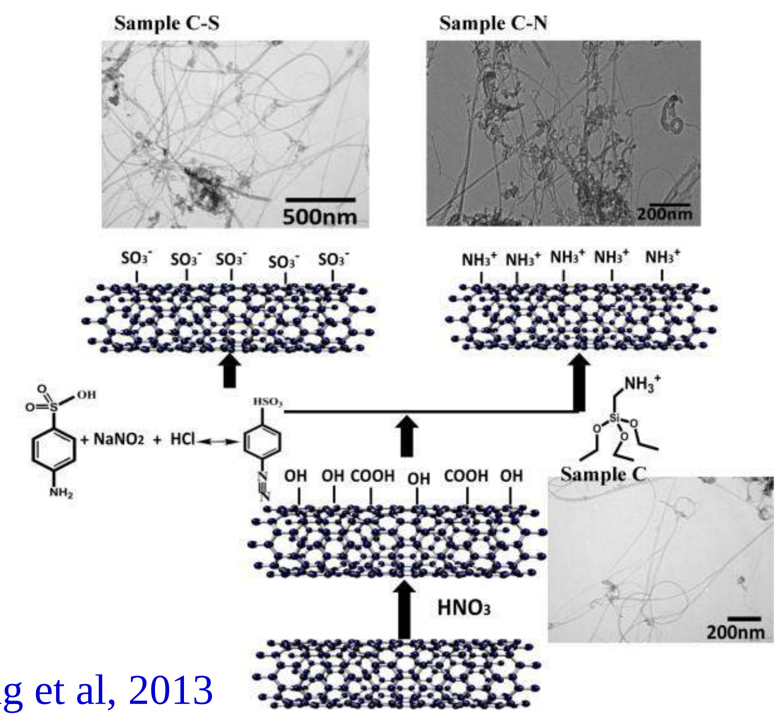
Wen et al., 2012

選擇性電極 (Ion-Selective Electrode)

- Improvement of desalination efficiency and selectivity
  - Carbon electrode coated with an ion-exchange polymer
  - CNTs with sulfonic and amine functional groups
- Born removal (activated carbon fiber, CDI)
- Selective removal of nitrate ions (MCDI)

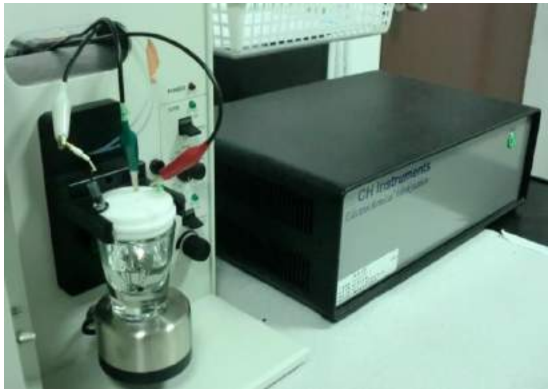


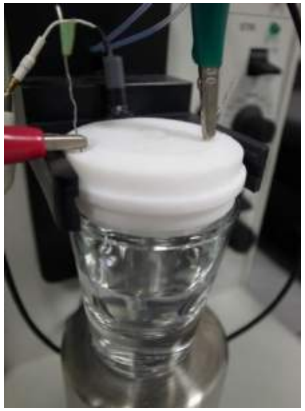
Kim and Chio, 2010



Yang et al, 2013

電極材料的電容特性



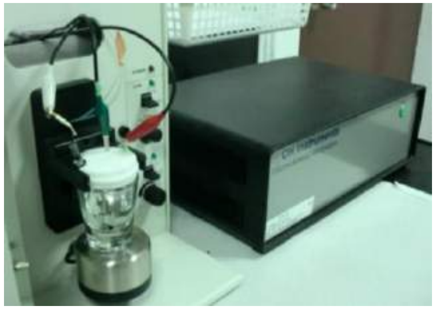


比表面積與孔洞分布

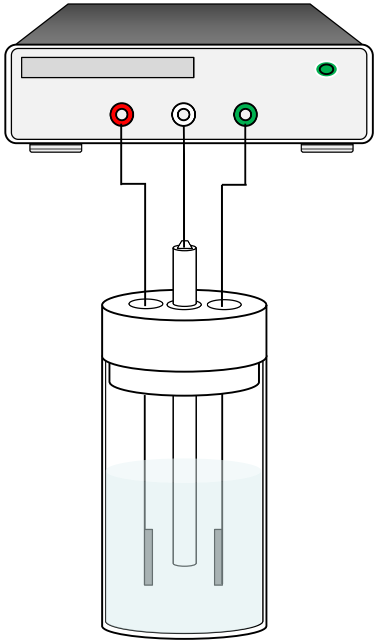
Carbon	S_{BET} (m^2/g)	S_{micro} (m^2/g)	S_{meso} (m^2/g)	V_{tot} (cm^3/g)	V_{micro} (cm^3/g)	V_{meso} (cm^3/g)	V_{meso}/V_{tot} (%)
Carbon aerogel	445	225	220	0.66	0.56	0.10	15.2
F-400 activated carbon	964	513	451	0.50	0.23	0.27	54.0
Wood activated carbon	662	457	205	0.43	0.21	0.22	51.1
Coal activated carbon	673	476	197	0.35	0.21	0.14	40.0
Coconut shell activated carbon	648	571	77	0.31	0.27	0.04	12.9
MWCNT/PVA	208	23	185	0.71	0.01	0.70	98.6
Highly mesoporous activated carbon	2105	850	1300	1.50	0.44	1.06	70.7
Highly microporous activated carbon	2162	1860	302	1.05	0.85	0.20	19.0

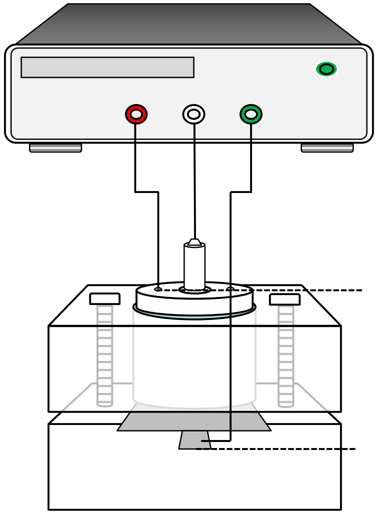
電容特性分析

- Electrochemical characterization:
  - Electrochemical impedance spectra (EIS)
  - Galvanostatic charge/discharge curve (GC)
  - Cyclic voltammetry (CV)

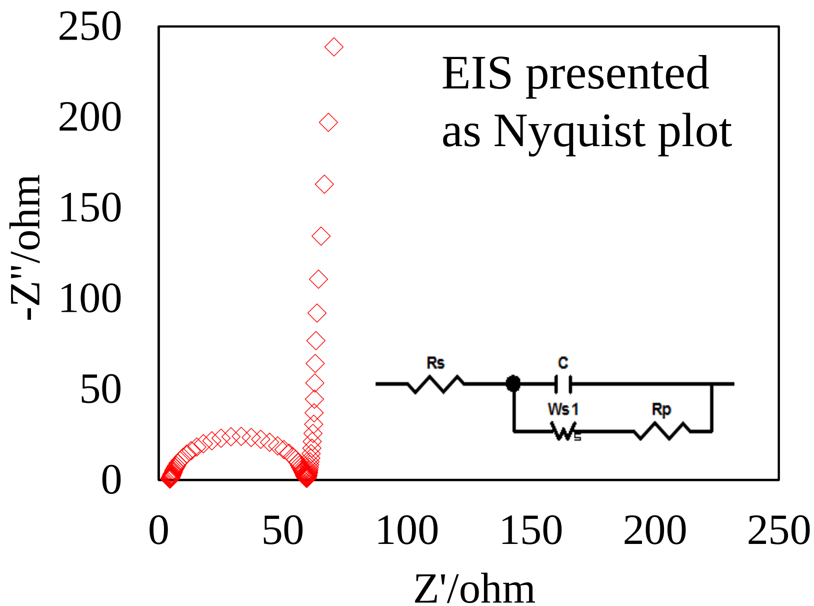


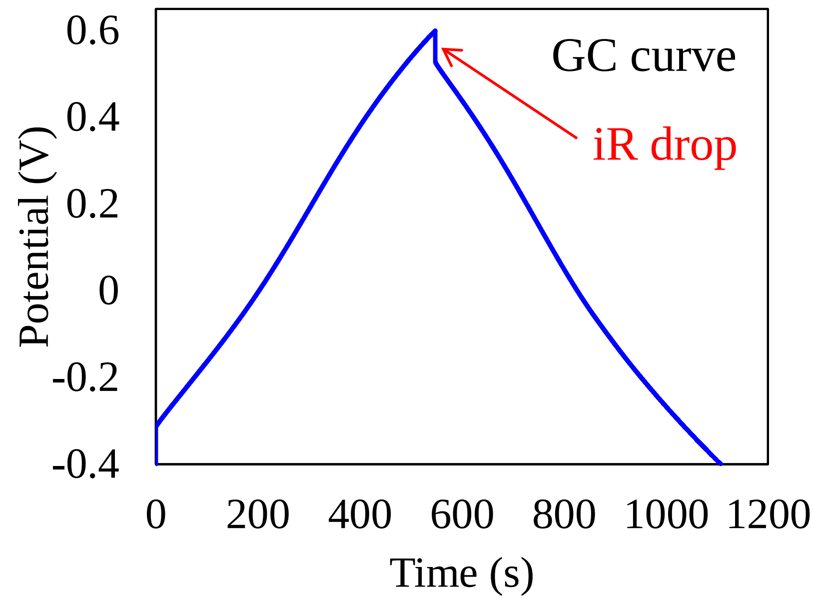
Voltammetric analyzer

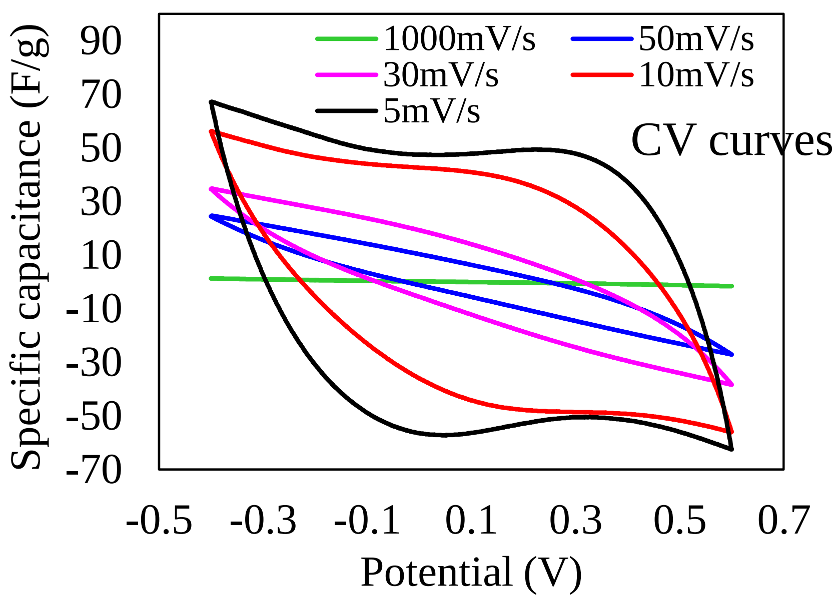


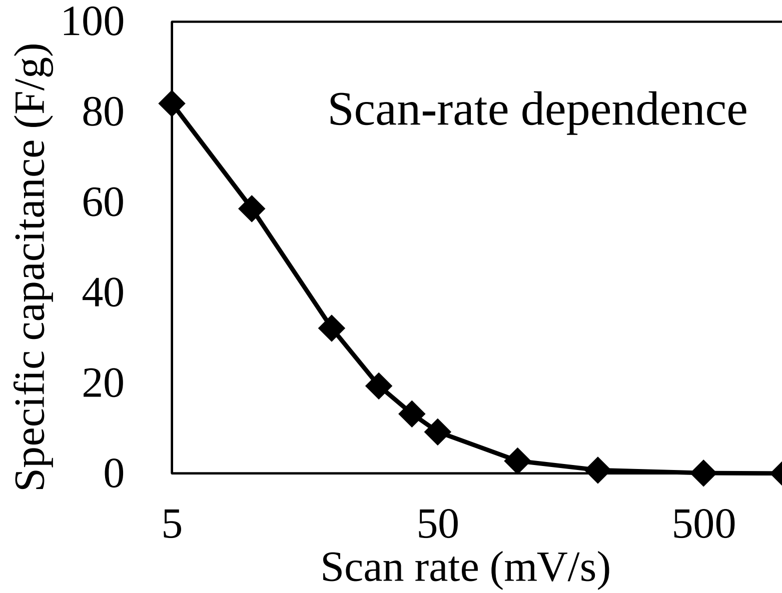


電雙層電容器之電容行為





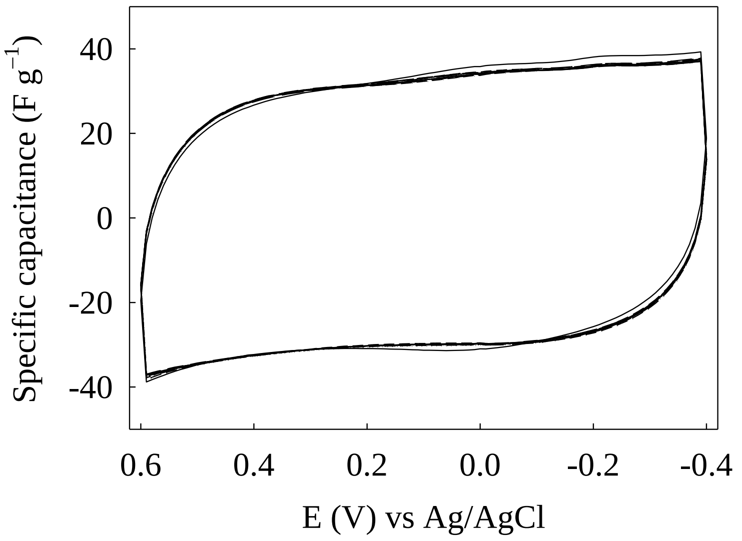


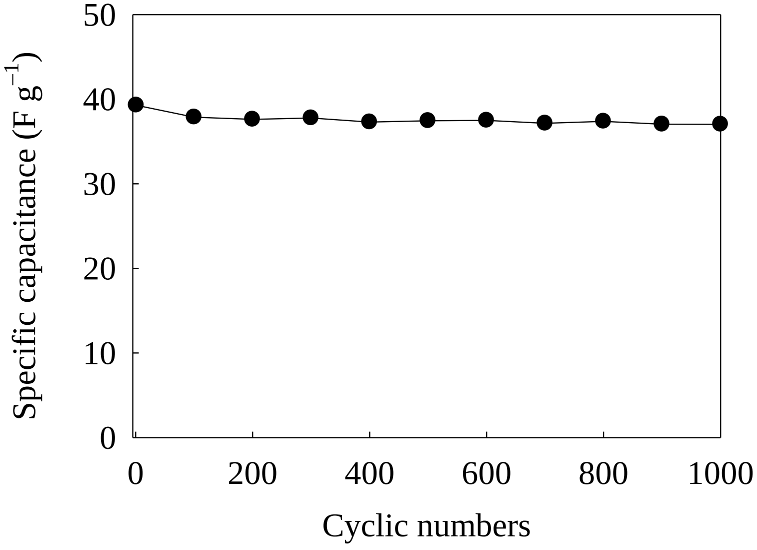


Activated carbon electrode 1 M NaCl solution.

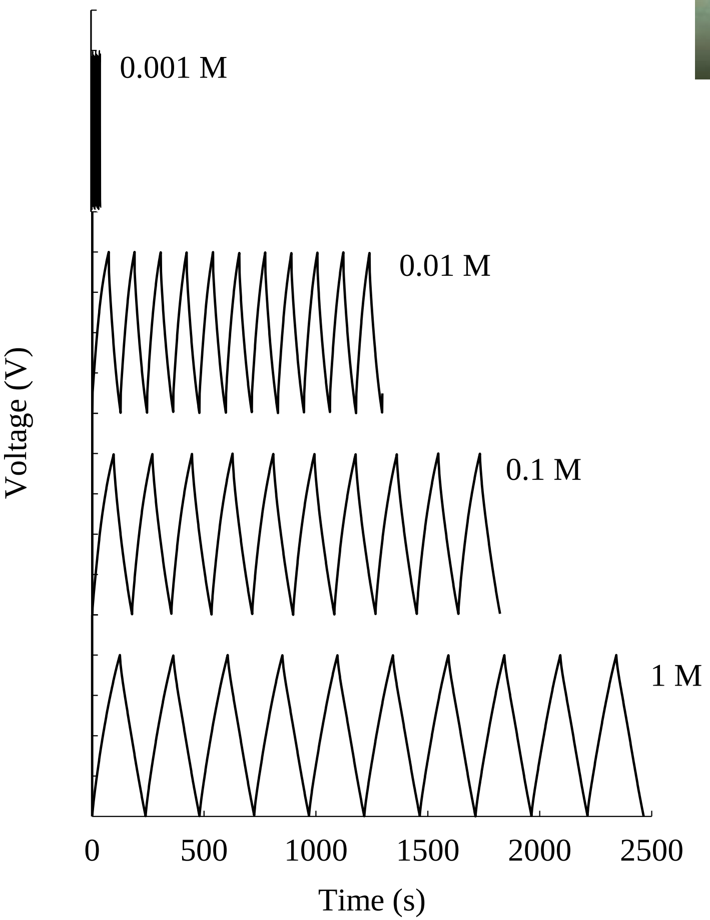
電化學穩定性

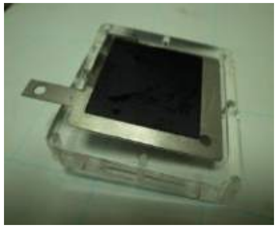
- Specific capacitance





- Galvanostatic charge/discharge

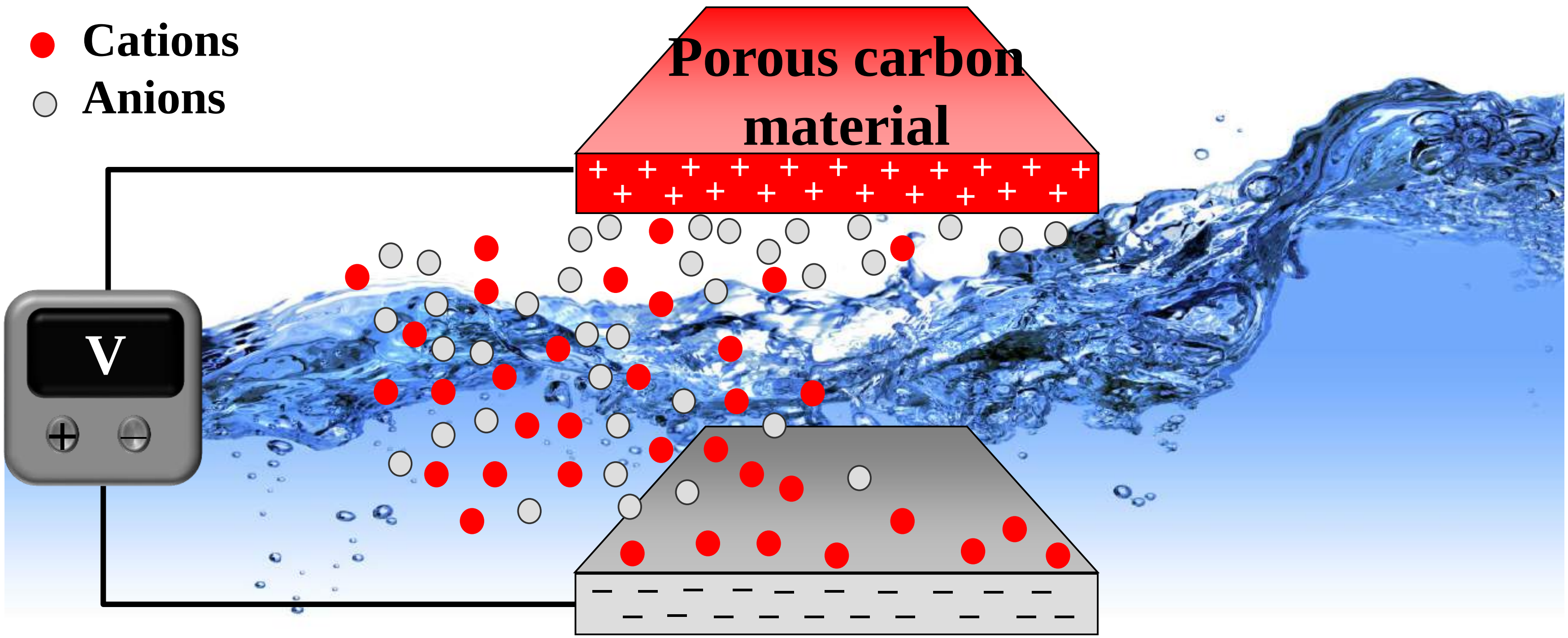




MWCNT-PVA composite electrode in 1 M NaCl

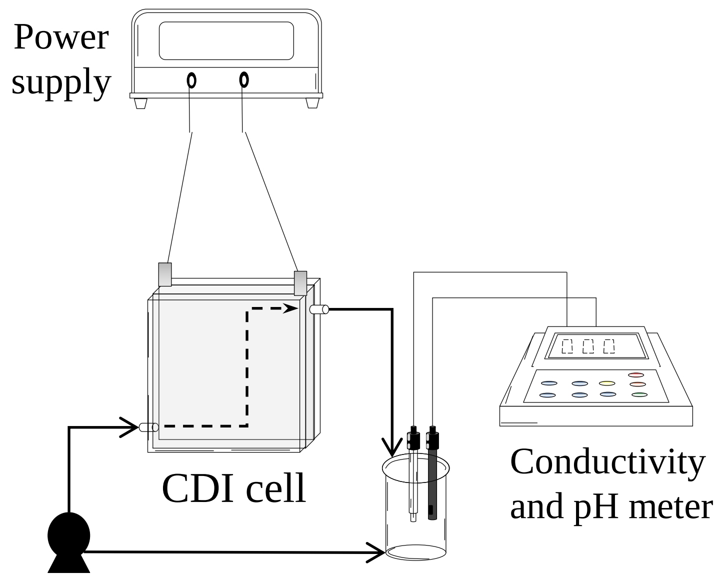
(Hou et al., Sep. Purif. Tech., 2014)

電容脫鹽之電吸附行為

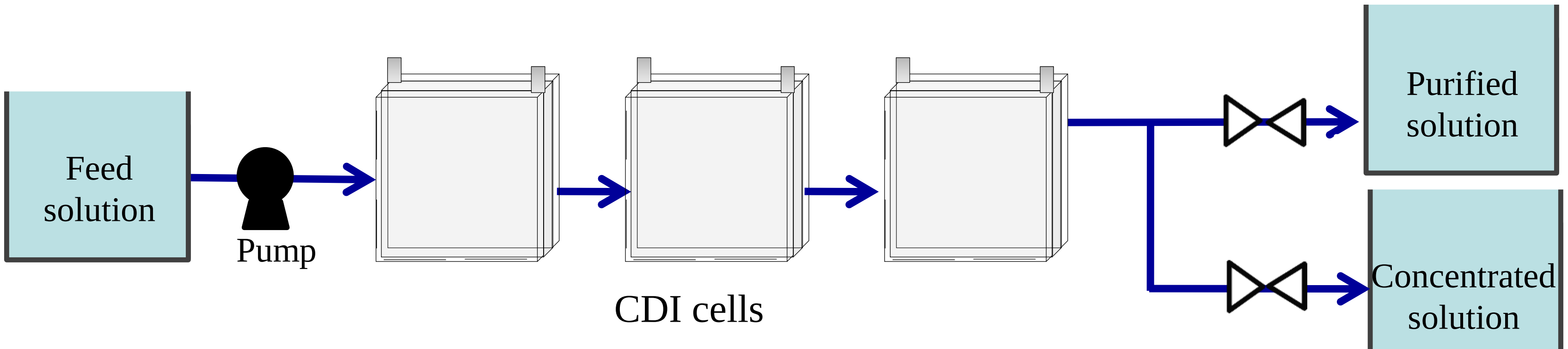


電容脫鹽之實驗

- Electrosorption performance
  - Batch mode experiment

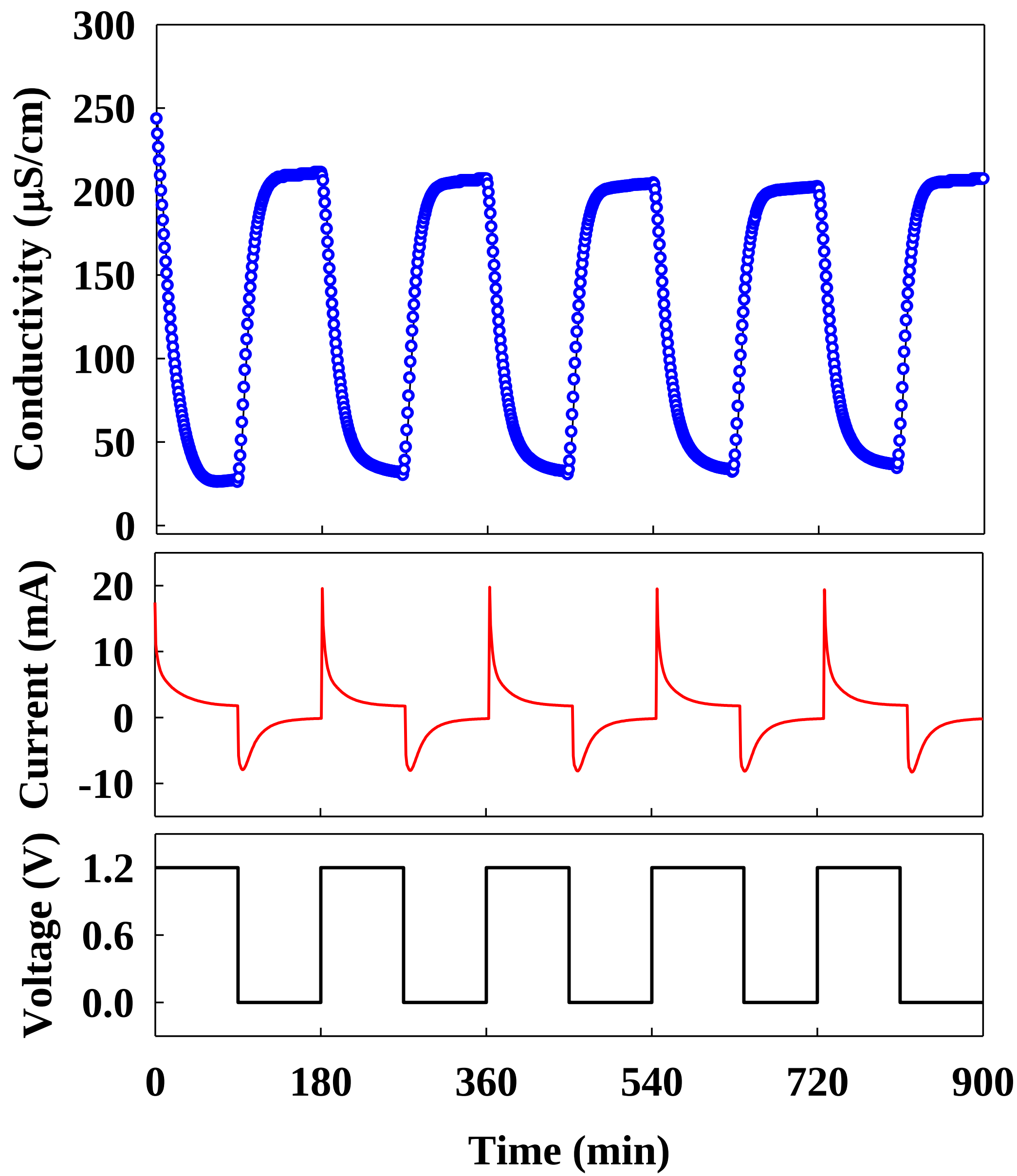


  - Continuous-flow (single-pass) mode experiment



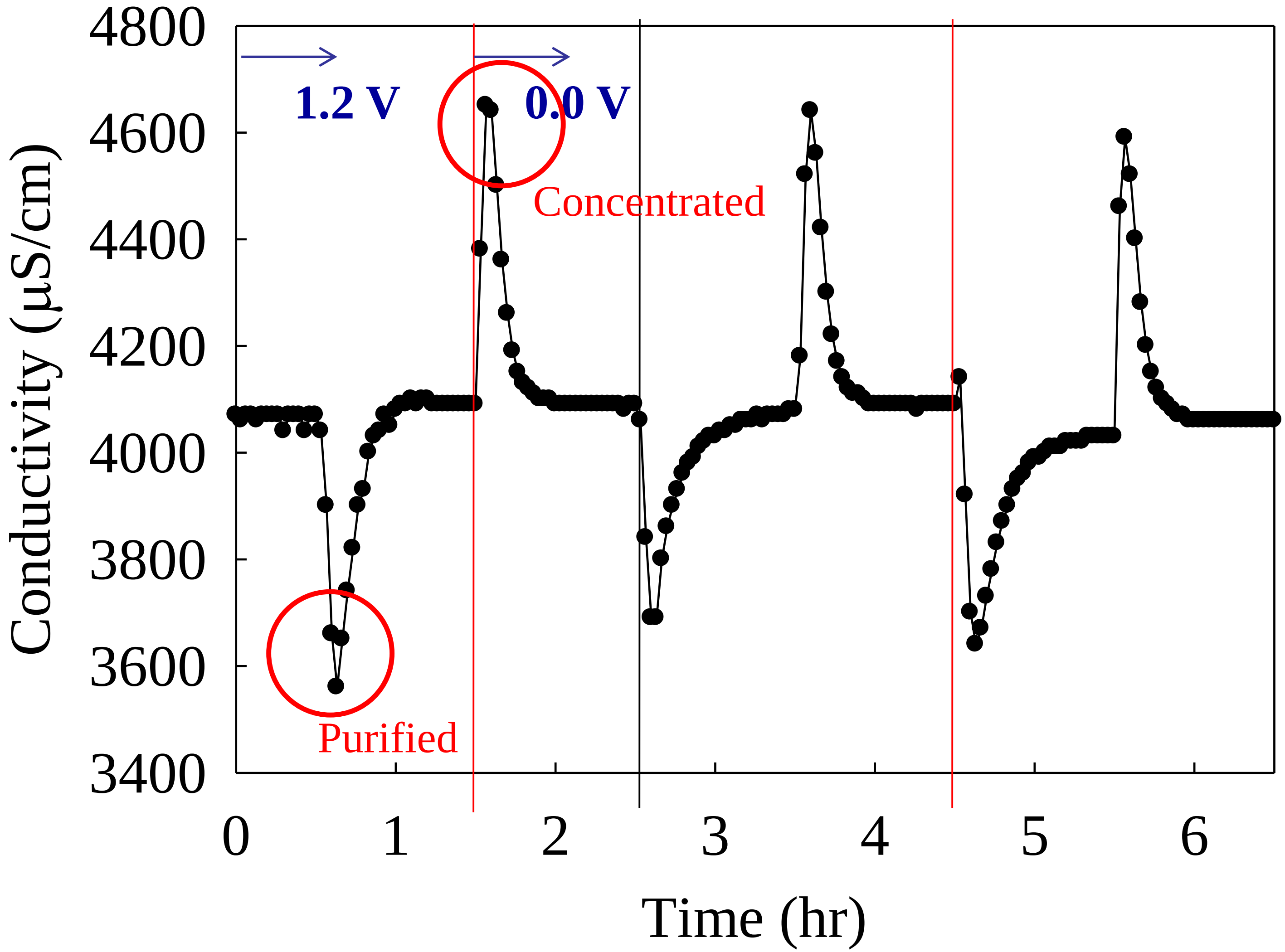
電容脫鹽之電吸附/脫附(充電/放電)曲線

- Batch mode experiment



Regeneration of the activated carbon electrode in a batch experiment . The solution was 50 mL, 0.002 M NaCl solution with a flow rate of 10 mL/min. The applied voltage was 1.2 V

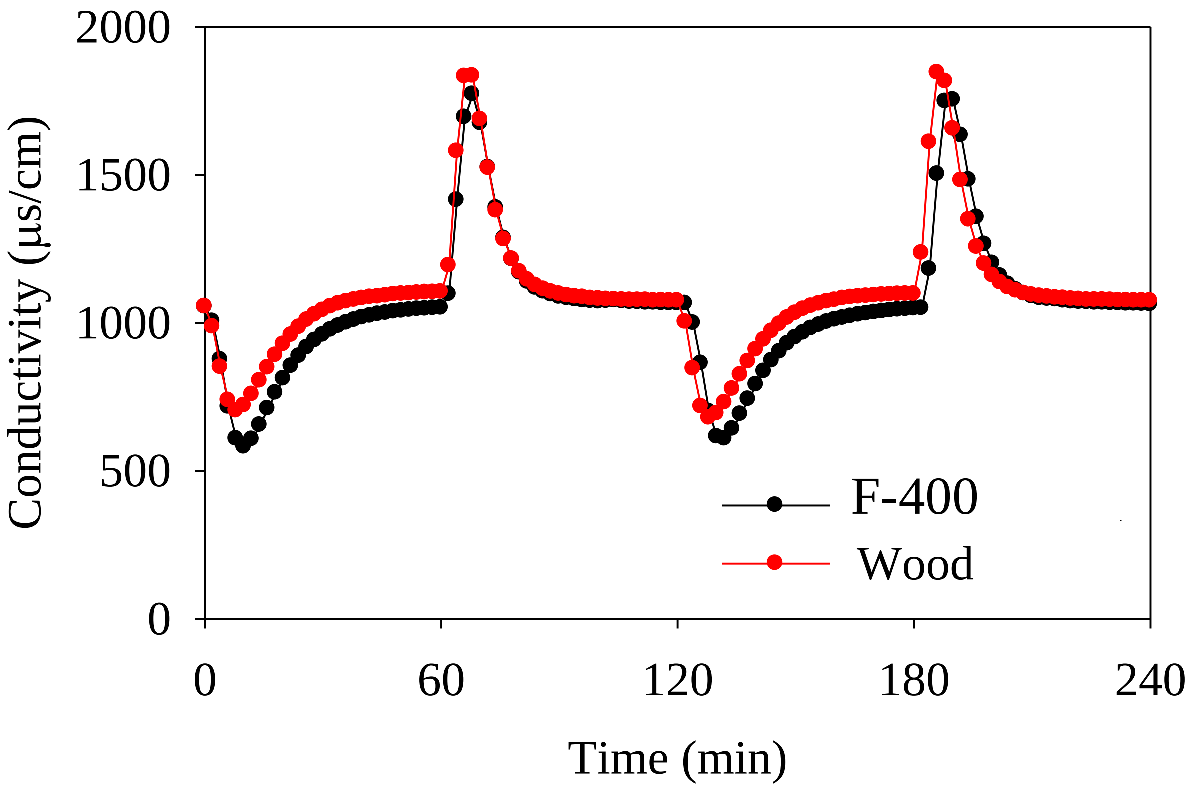
連續式電容脫鹽之曲線



Conductivity variation of 2000 ppm NaCl for multiple electrosorption-desorption cycles in CDI.

比表面積對於脫鹽之影響

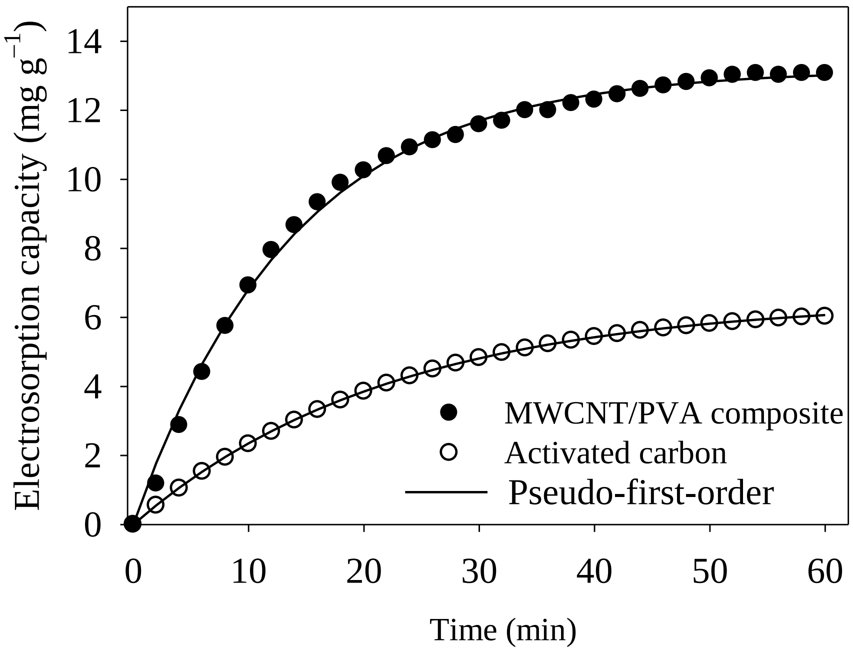
- Deionization of 500 ppm NaCl solution by activated carbon electrodes at 1.2 V and 5 mL/min in a continuous CDI system



- ✓ Carbon electrodes associated with higher specific surface area result in larger capacities for removal of NaCl from aqueous solutions.
- ✓ Generally, activated carbons operated in CDI have relatively low ion-accessible surface areas (< 10% of BET surface area)

奈米碳管複合材料之脫鹽效能

- Desalination experiments in bath mode CDI



Desalination of 1 mM NaCl solution using MWCNT and activated carbon electrodes at 1.2 V.

The presence of mesopores, facilitating ion transport, could be beneficial to ion electrosorption in CDI.

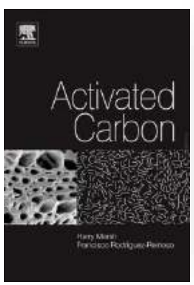
Carbon	MWCNT/ PVA	Activated carbon
BET surface area (m^2 g^{-1})	208	964
Micropore fraction (%)	11	53
Electrosorption capacity (mg g^{-1})	13.07	6.03
Surface utilization of BET surface area (%)	26.04	2.58
Rate constant (min^{-1}), fitted by first-order kinetic model	0.073	0.045
Energy consumption (kWh m^{-3})	0.038	0.155

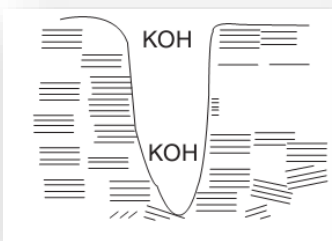
(Hou et al., Sep. Purif. Tech., 2014)

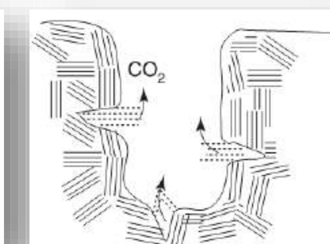
活性碳之可控制孔洞分佈技術

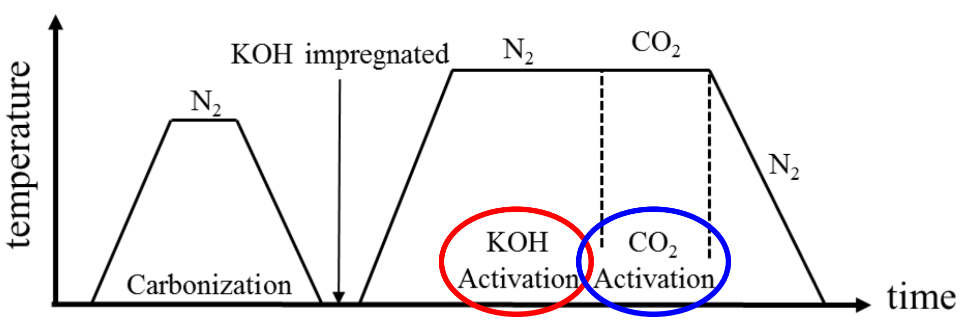
Two stage activated method

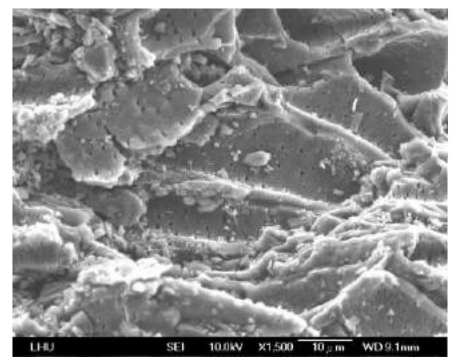
- KOH chemical activation
  - Activated with potassium hydroxide (KOH) under inert gas to form micropores accompanied with high surface area.
- CO_2 physical activation
  - Gasified by carbon dioxide (CO_2) to develop mesoporsity.



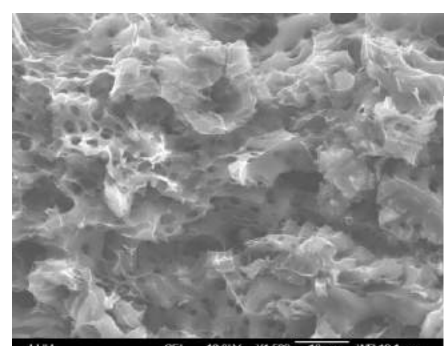








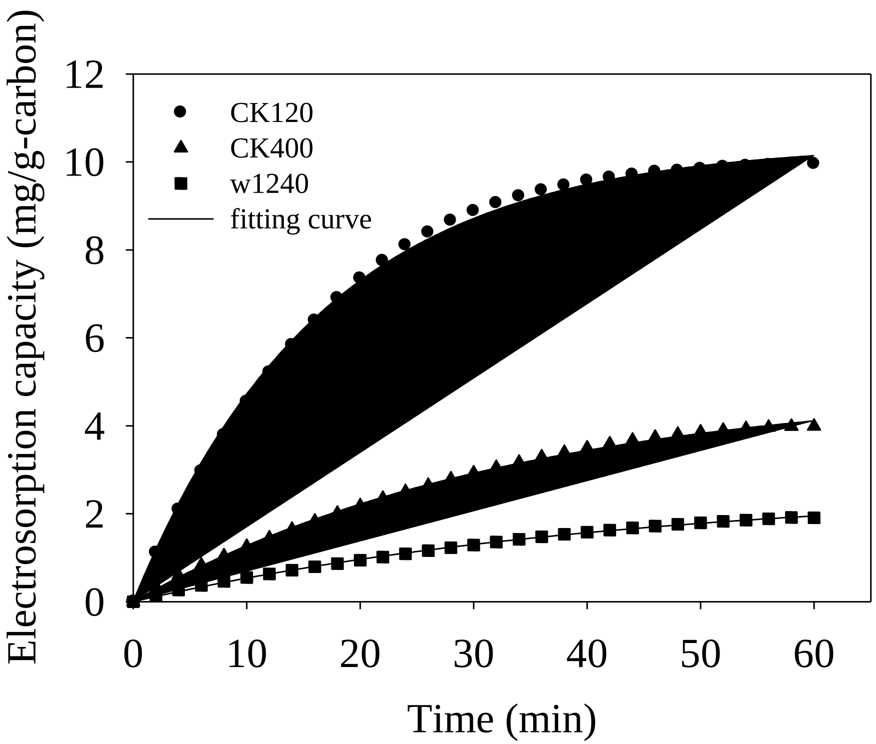
Commercial activated carbon



Activated carbon with controlled mesoporosity

高比表面積、高中孔洞活性碳之脫鹽效能

- Desalination experiments in bath mode CDI



Desalination of 0.5 mM NaCl solution using activated carbon electrodes at 1.0 V.

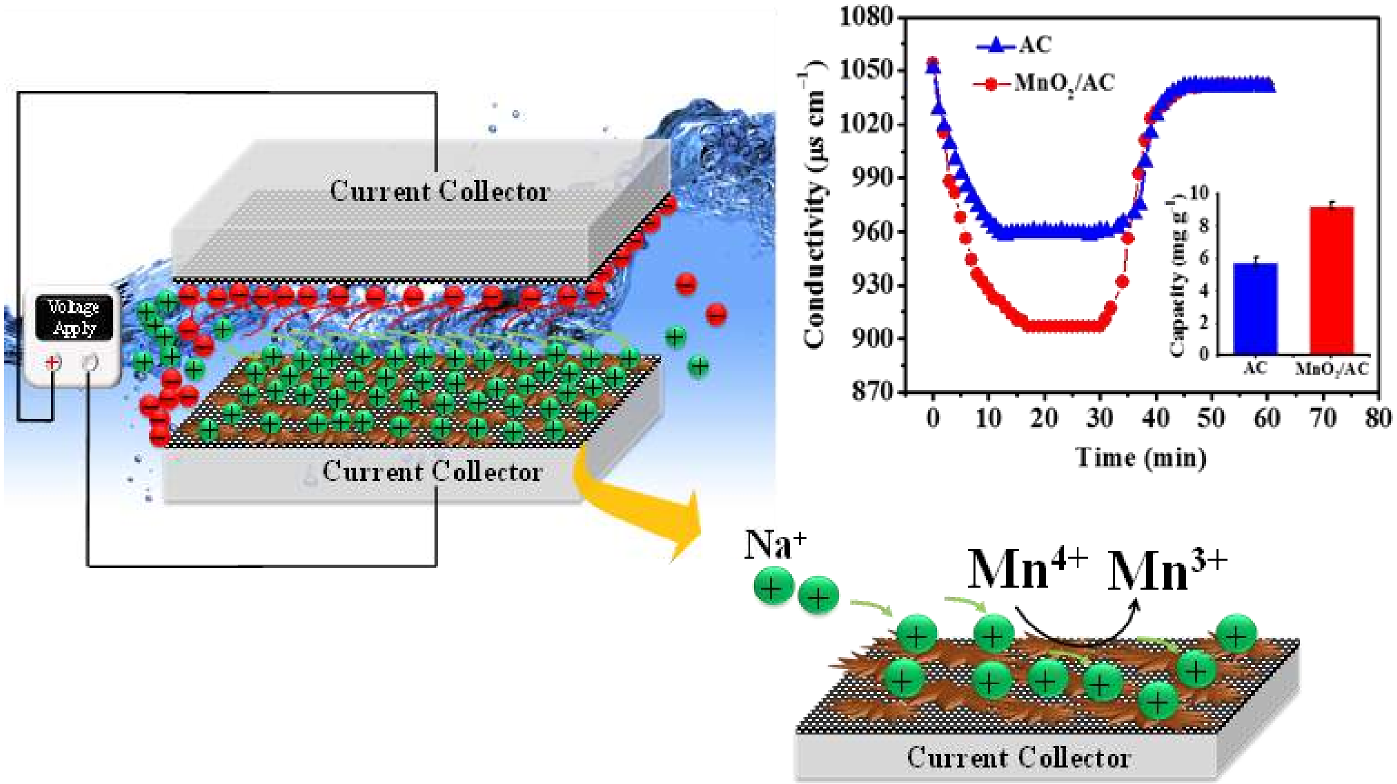
Carbon	w1240	CK400	CK120
BET surface area ($m^2\ g^{-1}$)	903	2162	2105
Mesopore fraction (%)	18.2	19.0	70.7
Electrosorption capacity (mg g^{-1})	2.60	4.93	10.42
Surface utilization of BET surface area (%)	0.87	0.78	1.91
Rate constant (min^{-1}), fitted by first-order kinetic model	0.023	0.030	0.060

Mesopore to micropore ratio is a key factor to determine the CDI performance.

Yeh et al., *Desalination*, 2015

過渡金屬/多孔活性碳複合材料

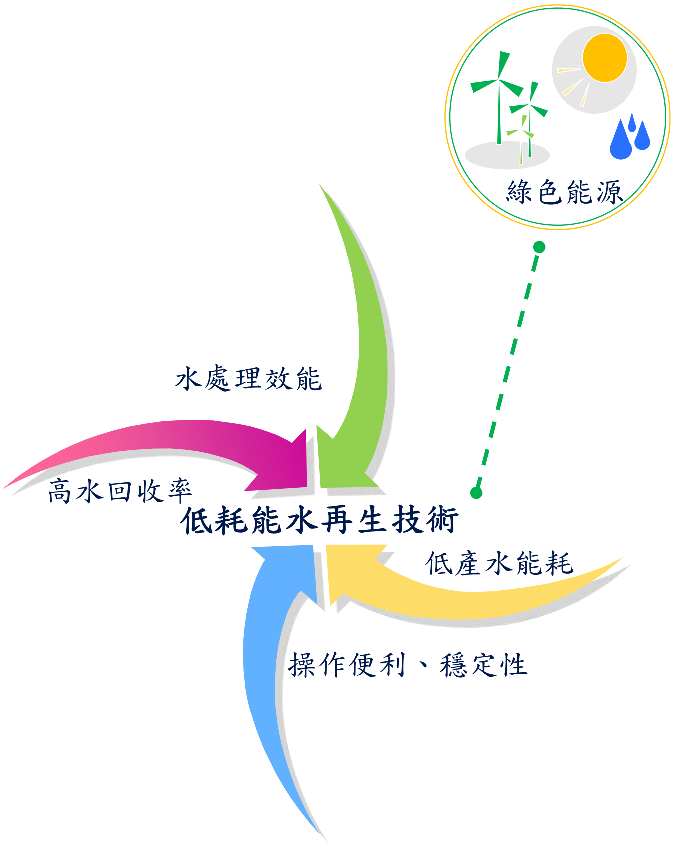
- Manganese dioxide (MnO_2)/activated carbon composite as high-performance CDI electrode



Liu et al., *ACS Sustainable Chem. Eng*, 2016

電容去離子技術之應用潛力

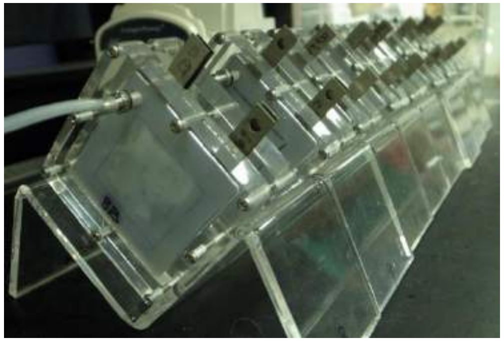
- CDI模組系統具有廣泛的適應性與良好的實用性
  - 半鹽水淡化
  - 家庭/工業再生水脫鹽
  - 飲用水淨化(如水軟化)
  - 微量污染物的去除
  - 地下水中重金屬的去除(如鎘、鉻、砷等)
  - 有價物質的選擇性回收

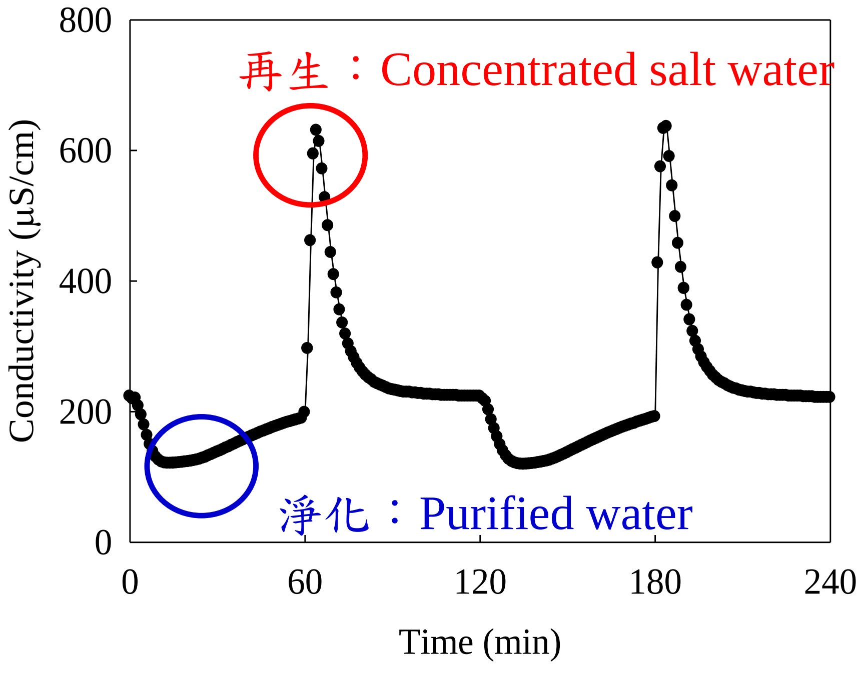


脫鹽、低能耗、可能源回收

Continuous flow model of CDI

– Reducing conductivity of water





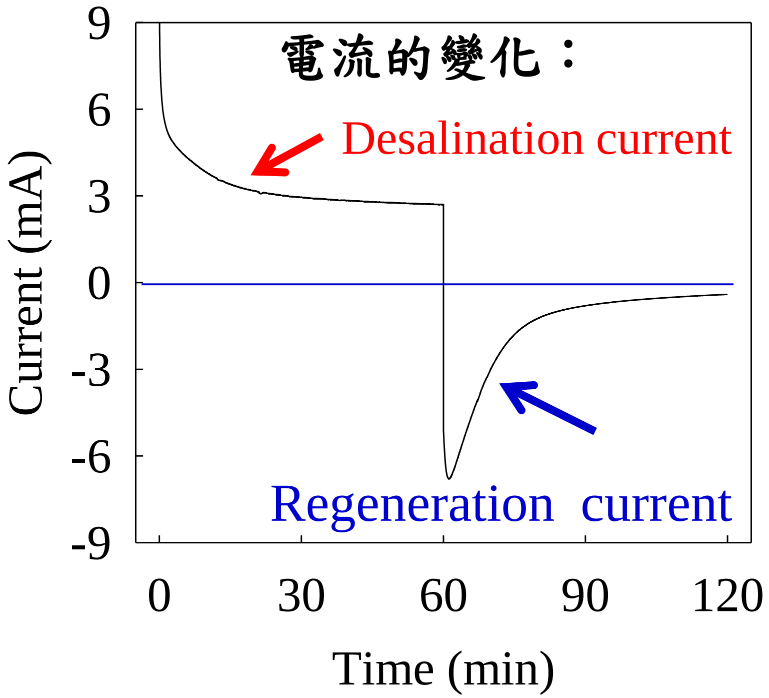
Energy recovery by reverse CDI process

– Desalination:

energy consumption

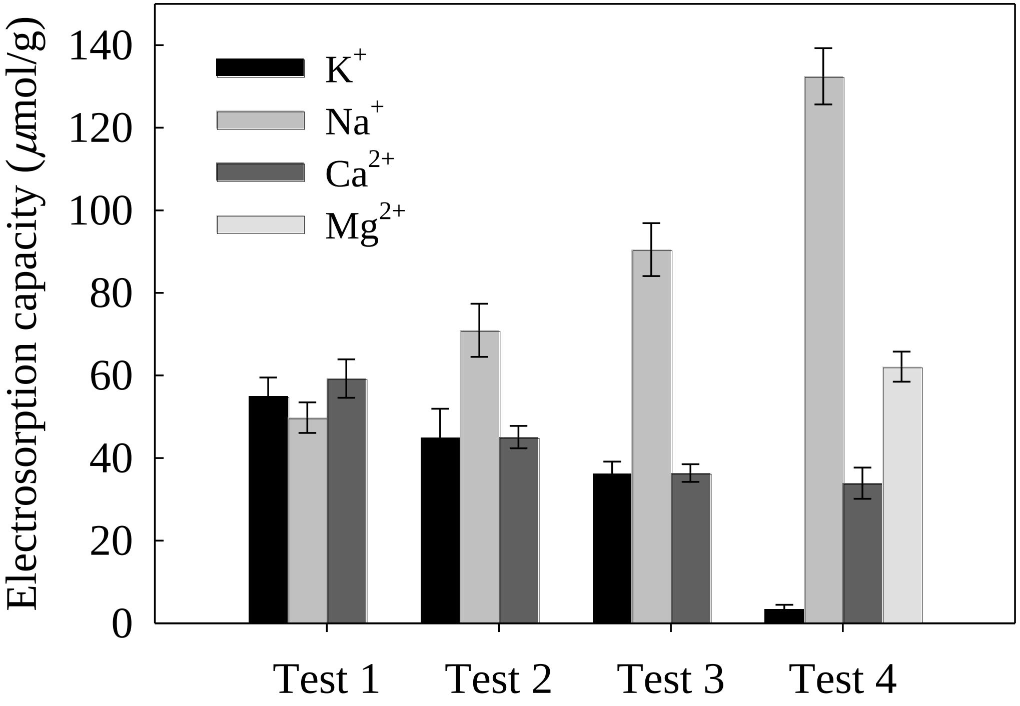
– Regeneration:

energy recovery (>40%)



電吸附選擇性：硬水軟化

- Study the ion selectivity during the electrosorption process
  – Hydrated size
  – Ionic charge
  – Feed solution



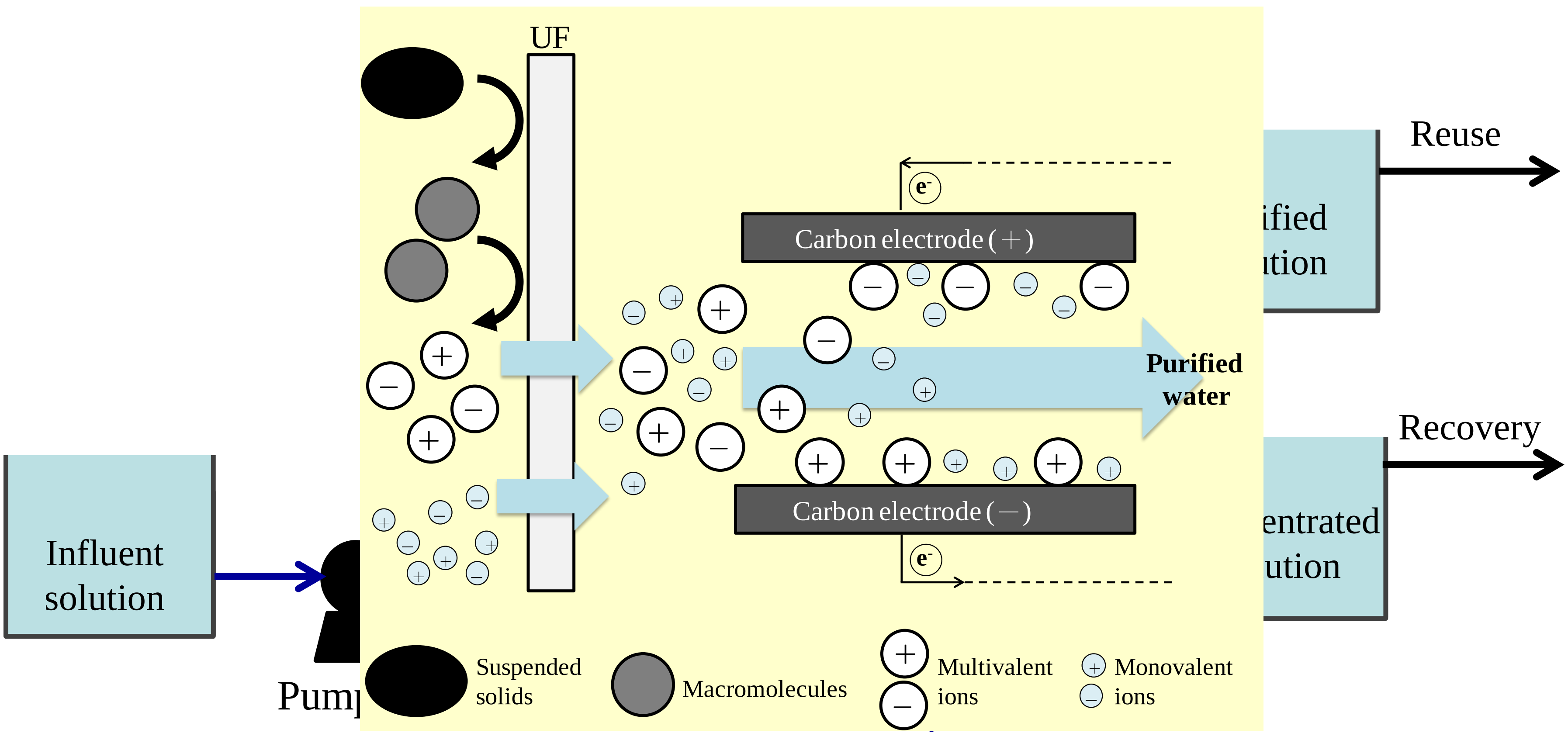
Ion	Test 1 (mM)	Test 2 (mM)	Test 3 (mM)	Test 4 (mM)
K^+	2	2	2	0.26
Na^+	2	4	6	10.57
Ca^{2+}	2	2	2	1.45
Mg^{2+}	0	0	0	2.41

✓ Preferential electrosorption : electrosorption capacity follows the order of $Ca^{2+} > Mg^{2+} > K^{+} > Na^{+}$

Hou and Huang, *Desalination*, 2013

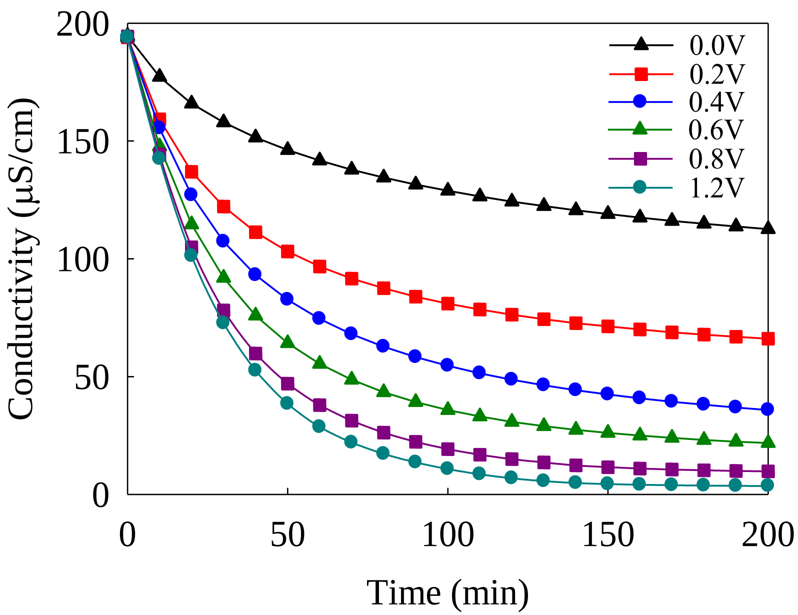
水回收/再生利用

- Proposed processes for water reuse and recover of heavy metals from waste water
  - Ultrafiltration: suspended solids
  - Capacitive deionization: ionic species

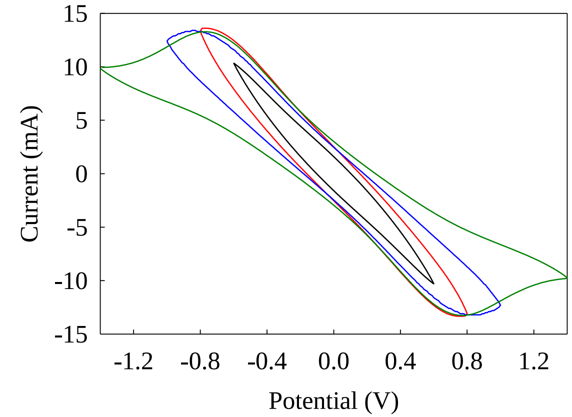


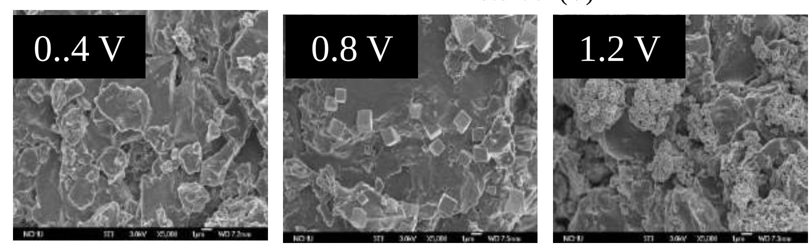
廢水中重金屬之移除

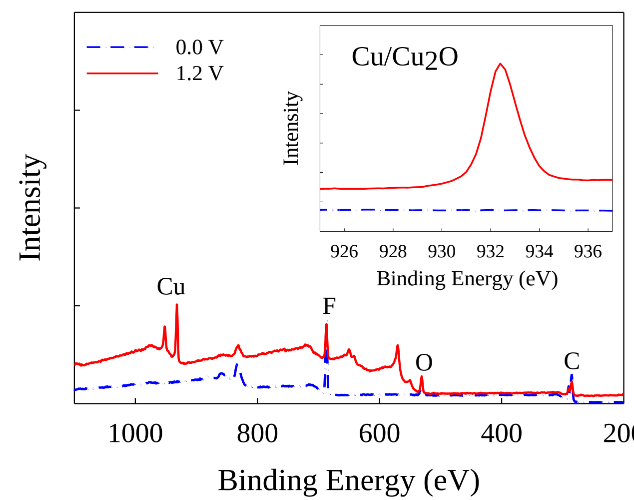
- Electro-enhanced removal of copper ions from aqueous solutions by CDI
  - –Electrodeposition (> 0.8 V)
  - –Electrosorption (< 0.8 V)



Removal of 50 ppm $CuNO_3$ solution at different applied voltages using activated carbon electrodes



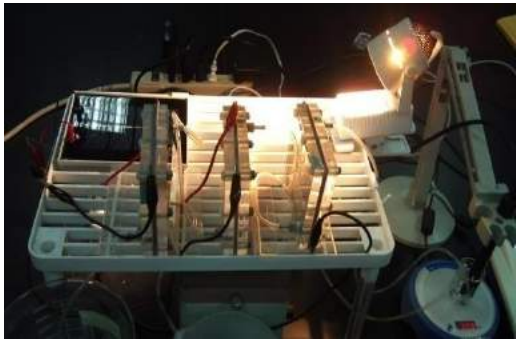


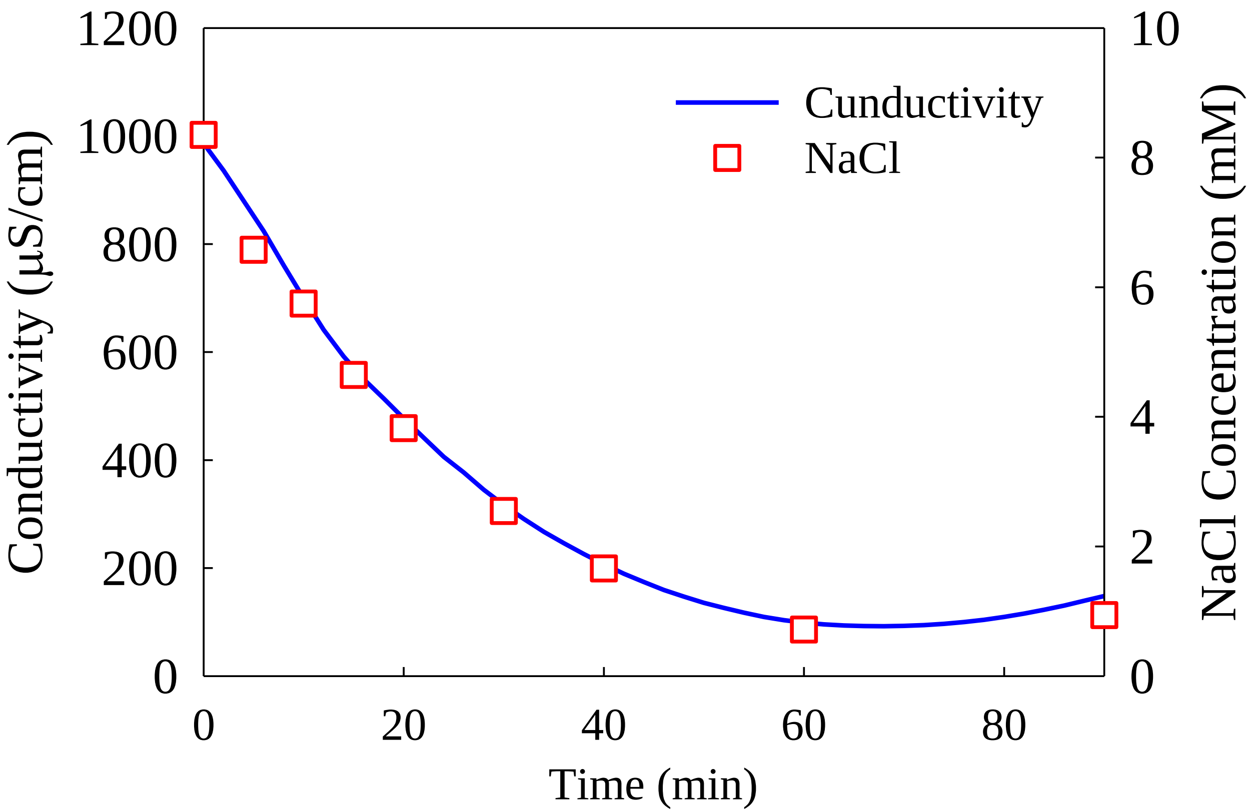


Huang et al., *J. Hazardous Materials*, 2014

綠色能源技術媒合潛力

- Capacitive deionization incorporates with renewable energy such as solar, wind, small-scale energy

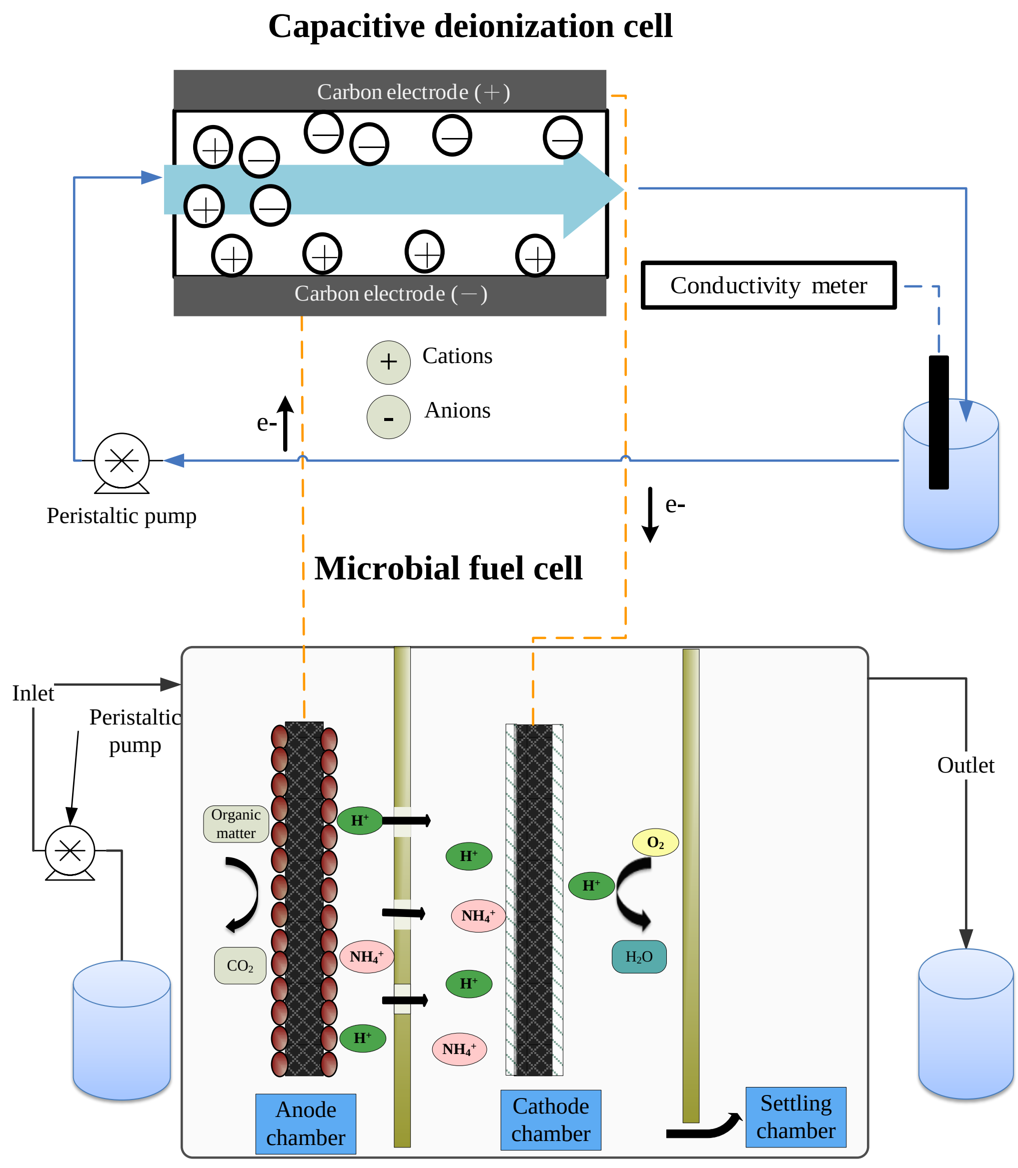




結合生物電化學系統：產電-脫鹽技術

- Microbial fuel cell
  - Electricity generation
  - Wastewater treatment
- Capacitive deionization
  - Energy saving
  - Desalination

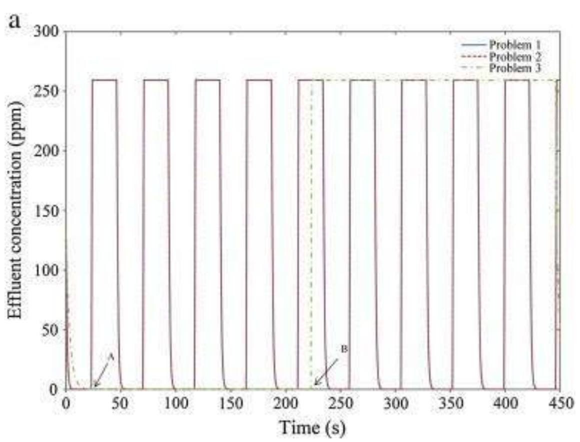
Sustainable water treatment process



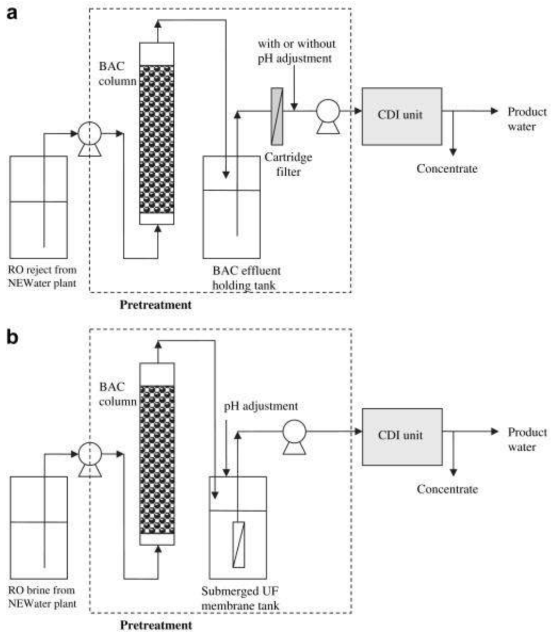
Feng et al., Chemosphere, 2013

系統性整合RO與CDI技術

- Combined RO for seawater desalination (Jande et al., 2013; Minhas et al., 2014)
- Integrated pretreatment with CDI for RO reject recovery from water reclamation plant (Lee et al., 2009)



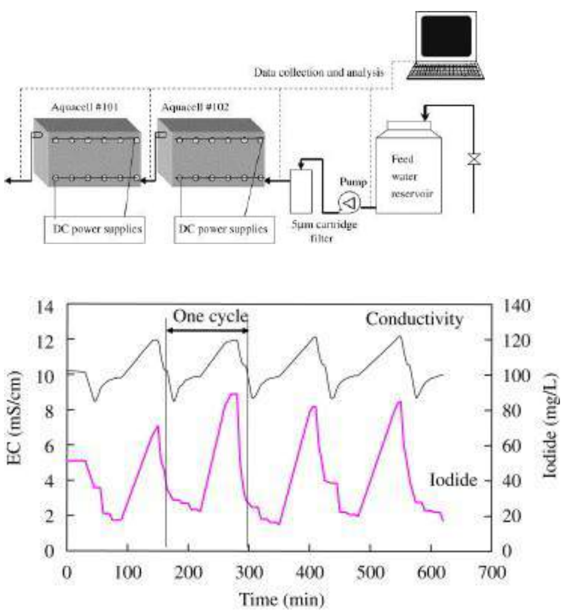
Ultrapure water from seawater using integrated RO-CDI system



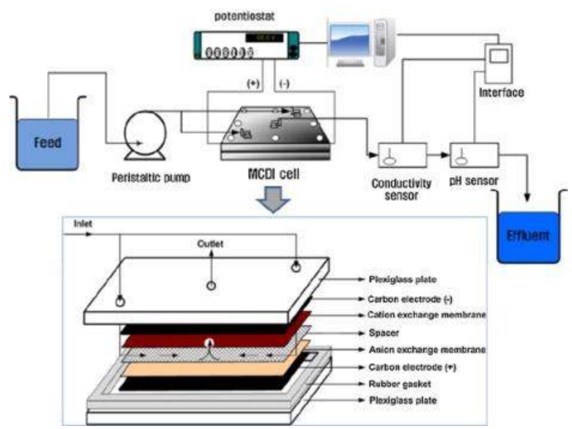
Pretreatments using biological activated carbon (BAC) and BAC–ultrafiltration (UF)

電容脫鹽在水處理的應用

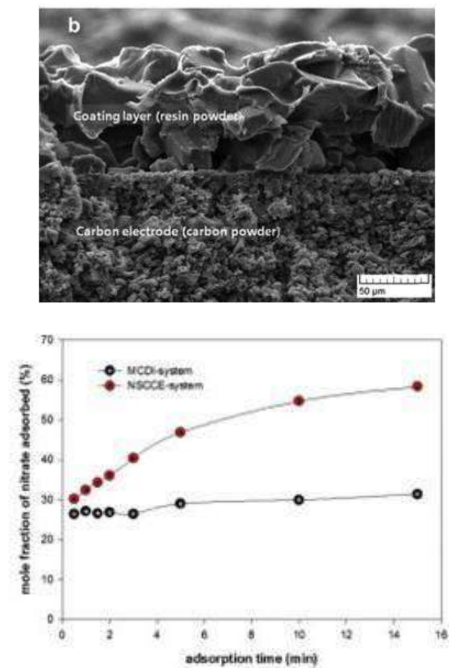
- Treatment of brackish water (Xu et al., 2008)
- Water softening (Seo et al., 2009)
- Producing ultrapure water (Lee and Choi, 2012)
- Selective removal of boron (Avraham et al., 2011) and nitrate ion (Kim and Choi, 2013)



Treating brackish water and recovering iodide from water.



Production of ultrapure water (10 mg/L NaCl influent)

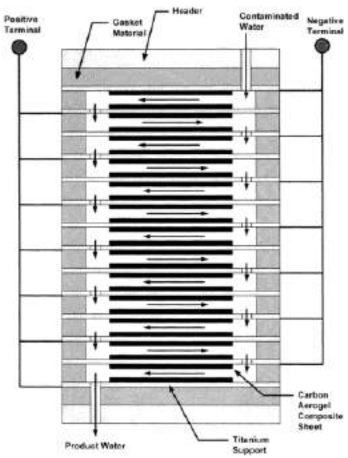


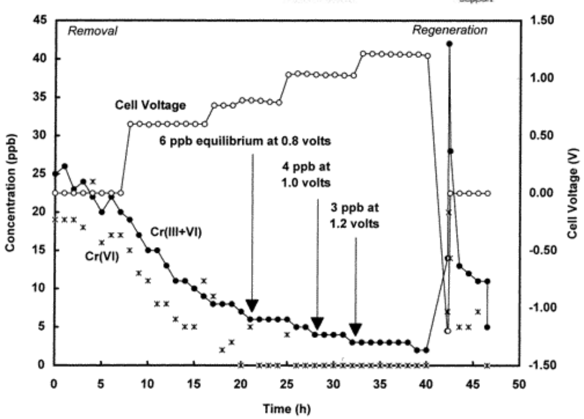
Nitrate-selective electrode for the selective removal of nitrate

地下水脫鹽與整治

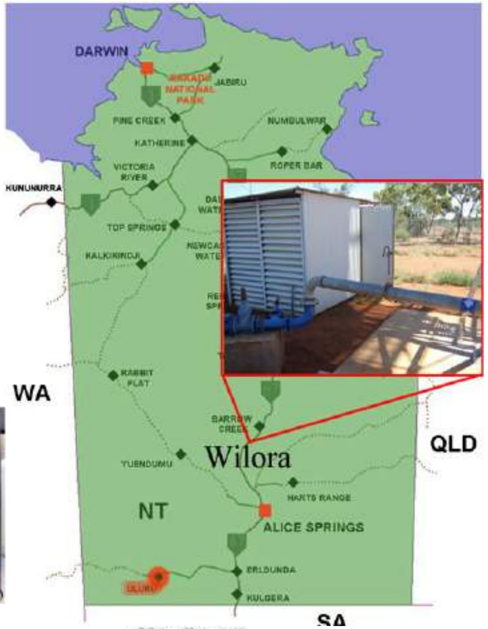
- Groundwater remediation (Framer et al., 1997)
- Desalination in a remote location (Mossad et al., 2013)
- Arsenic Removal from Groundwater (Fan et al., 2016)

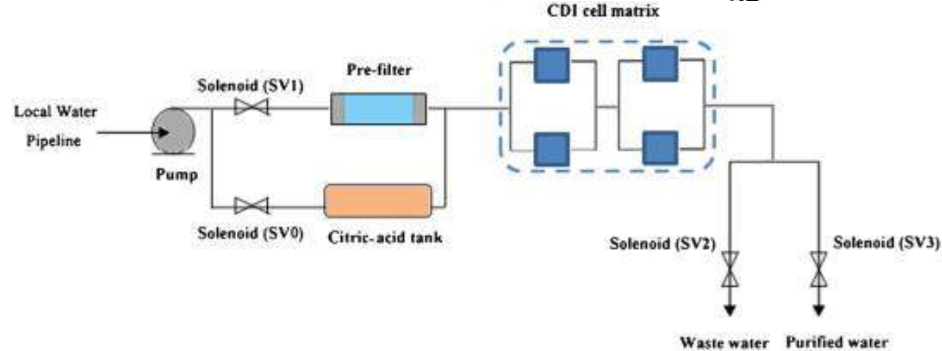
Electrosorption of Cr(VI) on carbon aerogel electrodes as a means of remediating ground water





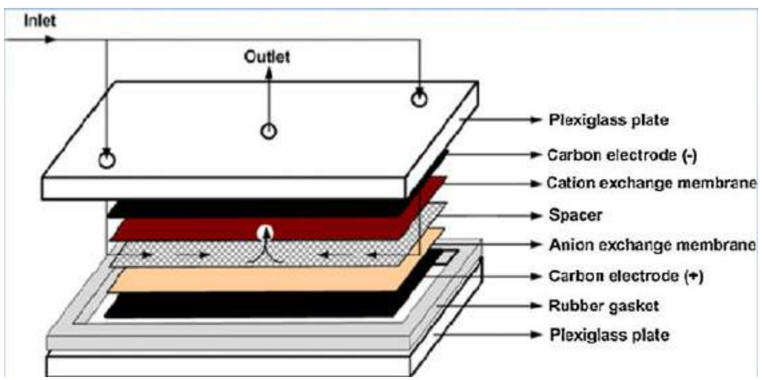
Using CDI for inland brackish groundwater desalination in a remote location

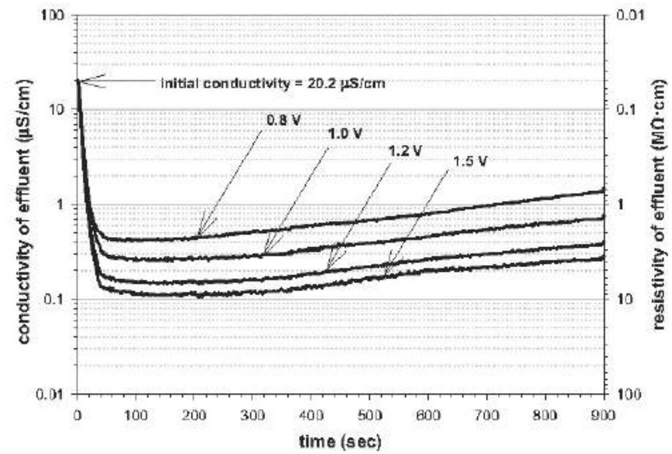


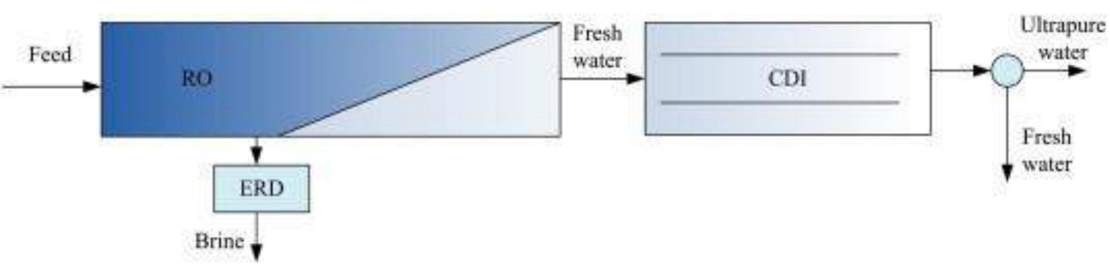


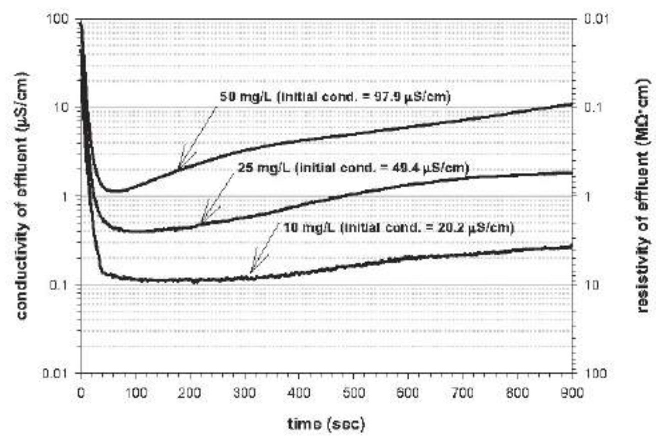
超純水的製造

- Membrane capacitive deionization (Lee and Choi, 2012)
- Combined RO and CDI (Jande et al., 2013)









Puree (Korea)

- Needed less energy for the desalination process because high pressure pumps are not required.
- Possible to make use of solar/wind power to power desalination units.
- More efficient for applications (withstand much higher temperatures than membranes)
- Far more efficient for the energy recovery than the membrane tech as the CDI modules act as EDLCs.

ECOMITE-U

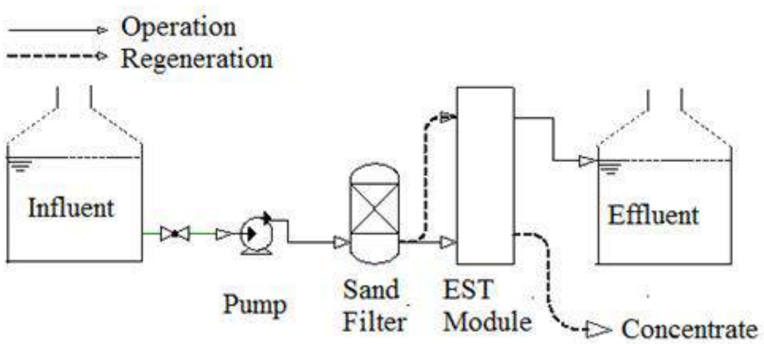
ECOMITE-M

ECOMITE-S SERIES

Model	TYPE	FLOW RATE(LPM)	SIZE(mm)	TDS REMOVAL	TEST CONDITION
Ecomite-U	Unit	0.03	160x160x40	> 85%	TDS 200ppm
Ecomite-M	Module	0.2~2	190x160x95	> 80%	TDS 1,000ppm
Ecomite-S	Unit/Module	0.03~2	565x650x8150	> 80%	TDS 2,000ppm

EST Water & Technologies (China)

- Large scale CDI desalination modules
  - Municipal wastewater reuse (60,000 m^3/day)
  - Coal mine Municipal wastewater reuse (5000 m^3/day)
  - Low energy consumption ~ 1.0 kWh/m^3



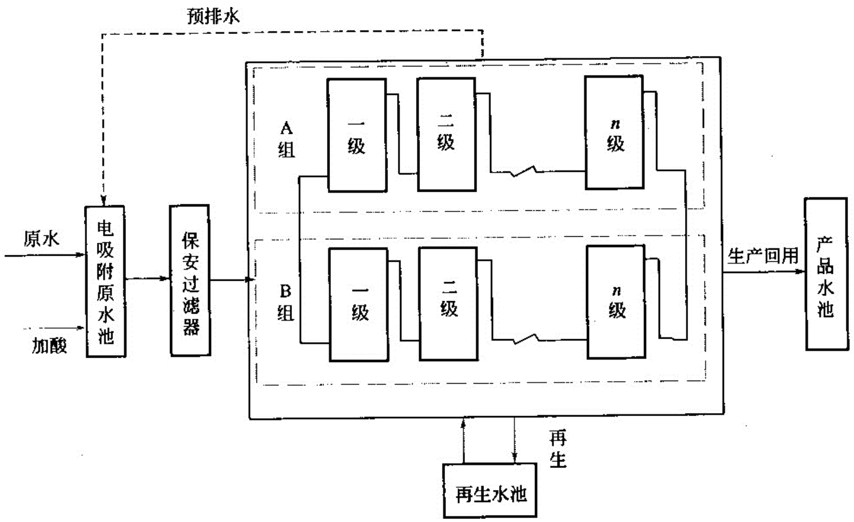
- Low energy consumption
- No chemicals added
- Convenient operation
- Long lasting service

EST (爱思特)

- 電吸附水處理技術特點：運行成本低、耐受性強、適應性強、水利用率高、無二次污染
  - 内蒙某电力集团循环排污水回用项目
  - 河北某化肥园区循环排污水回用工程
  - 山东某矿业集团矿井水利用工程
  - 山西某化工集团废水回用提质工程
  - 上海某钢铁集团冷轧废水零排放工程
  - 浙江宁波某再生水厂水质提升工程
    (循环水补水、120000m^3/d、产水率75%、氯离子去除率：85%、水电耗：0.75kWh/m^3)
  - 宁波明耀火电厂深度除盐工程
  - 中石化山东某炼油废水回用工程

爱思特：電吸附脫鹽的實例

電吸附模組的串聯

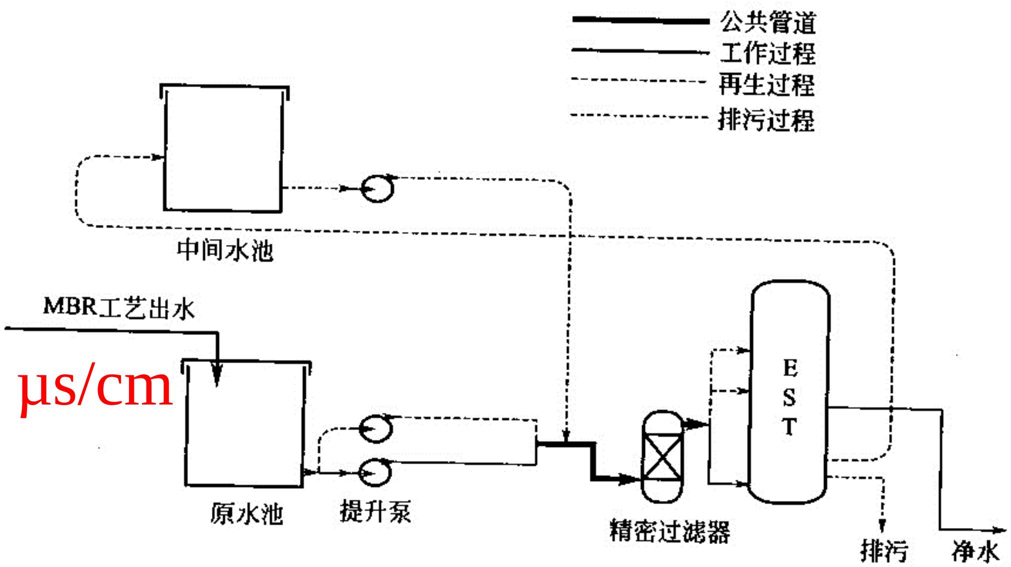


水的除鹽方法與工程應用，化學工業出版社2009

MBR出流水再經過電吸附系統除鹽：

除鹽率：50 %

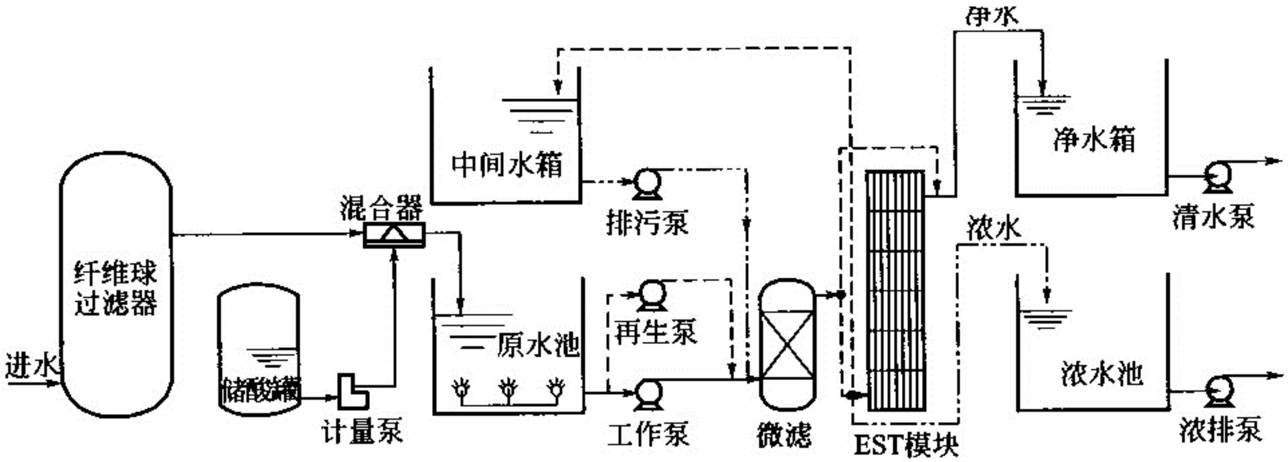
產水率: 75 %



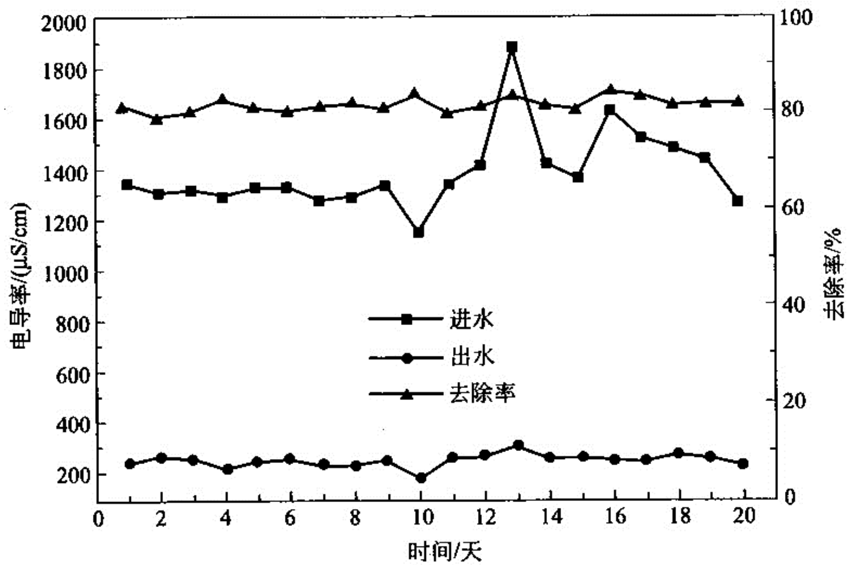
3000 μs/cm

1500 μs/cm

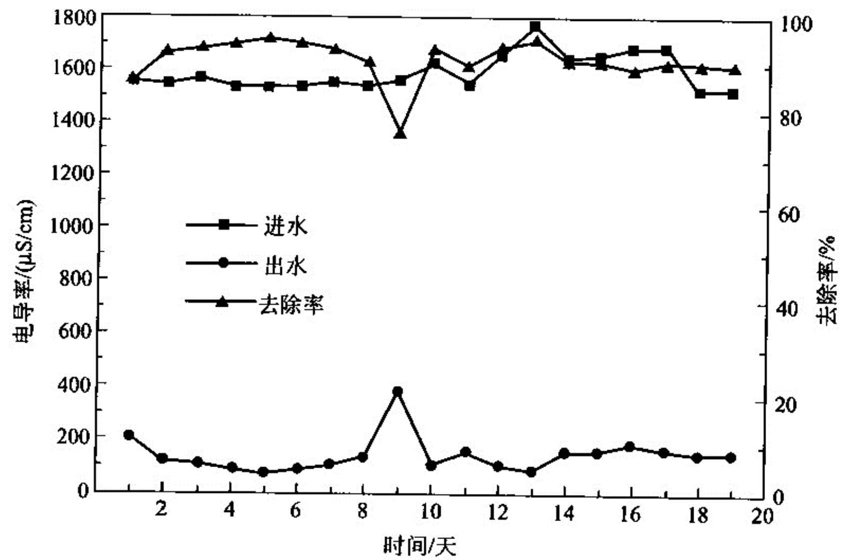
爱思特：電吸附脫鹽的實例



汙水處理站出流水的脫鹽處理



造紙廢水的脫鹽處理



Voltea (The Netherlands)

- Voltea CapDI system (MCDI)
  - Cooling tower
  - Wastewater reuse
  - Domestic water softening
  - Desalination of brackish water

- Energy efficient
- Chemical Free
- High water recovery (80-90%)
- Scalable
- Sustainable

Aqua EWP (USA)

- Electronic Water Purifier
  - Commercial systems: US$ 2500 ~ 12000
  - One module: 1000~3000 ppm, 1~3.6 CMD

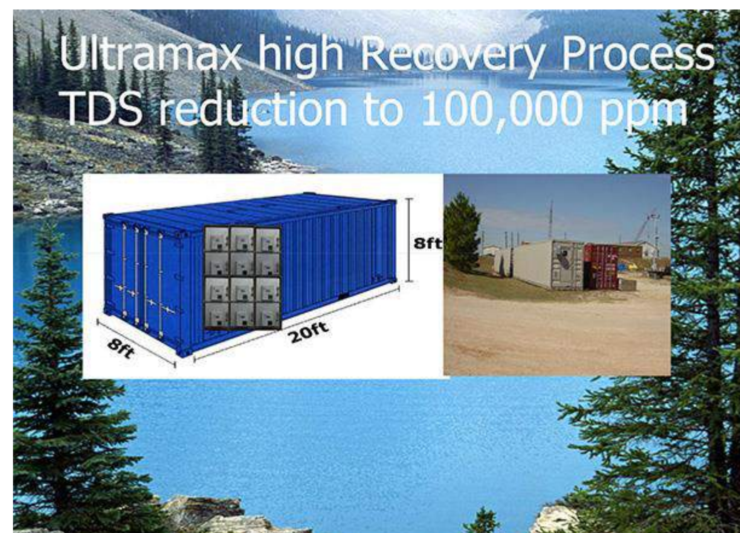
US $2500

US $5000

US $7500

US $12500

  - Feed salinity to 35,000 ppm, 95% purification, 75% recovery
  - Energy storage
  - Pollutants Removed



Test Reports of EWP

General Specifications

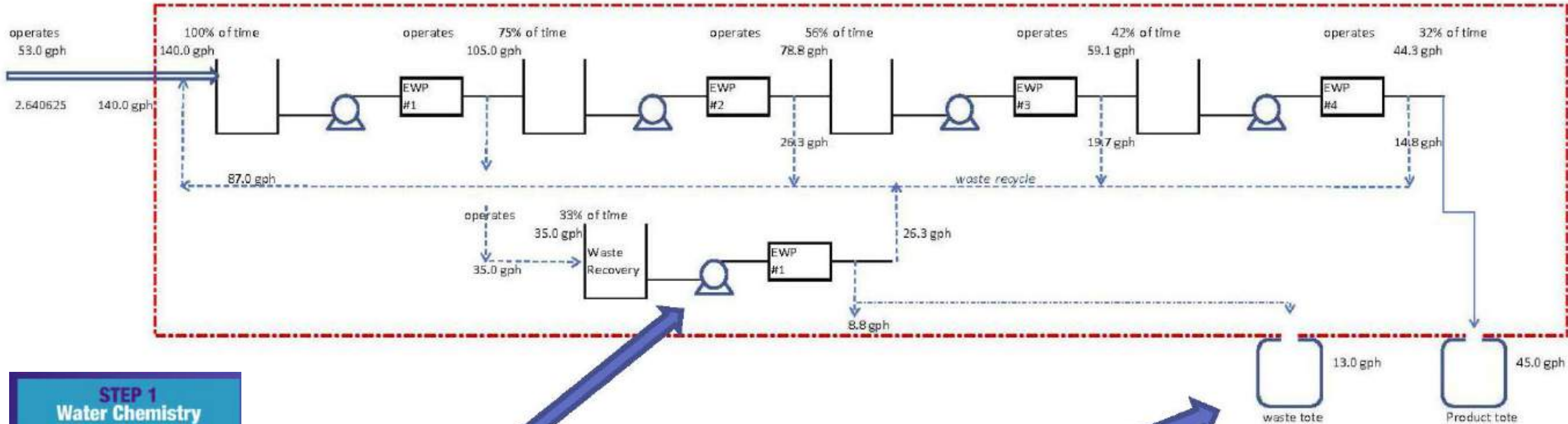
Flow Size:	WH-1 : 500 to 1,000 GPD
Limits: TDS	WH-1. 1,000 ppm
Recovery:	80%
Current:	2 amps max @110 VAC,
Size: unit	**16"d x 12"w x 18" h**

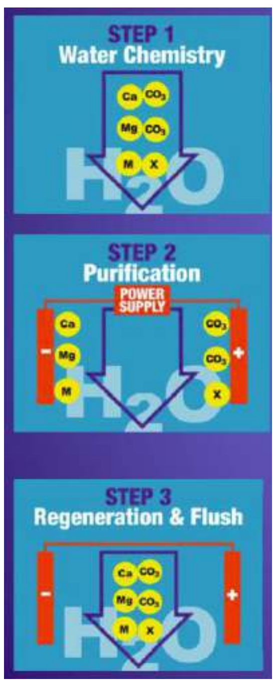
Results

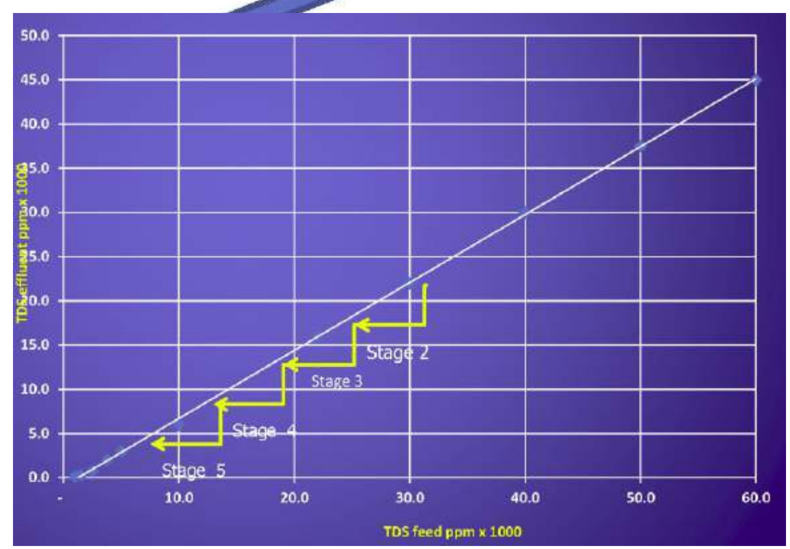
Parameter analyzed / **Water source**	**RAW**	**FINISHED**	**WASTE**
Calcium (Ca) ppm	3	0	5
Sodium (Na) ppm	203	40	484
Potassium (K) ppm	2	0	5
Boron (B) ppm	0.32	0.24	0.45
Carbonate (CO3) ppm	9	0	22
Bicarbonate (HCO3) ppm	393	88	919
Sulfate (SO4) ppm	25	5	62
Chloride (Cl-) ppm	63	13	148
Nitrate-N (NO3-N) ppm	0.019	0	0.032
Phosphorus (P) ppm	0.32	0.08	0.066
pH	8.08	7.26	8.01
Conductivity umhos/cm	806	170	1764
Hardness (CaC03)	11	0	17
Alkalinity (CaC03)	337	72	789
Total Dissolved Salts (TDS)	700	149	1648
SAR	26.2	8.1	51

Zero Liquid Discharge Process

97% Recovery? How?







結論與建議

- 電容去離子技術為新穎的脫鹽技術，具有低能耗、操作簡易、高產水率、較無積垢問題、與環境友善性等優點。
- 多孔電極材料的比表面積、孔洞分佈、電容特性在電吸附脫鹽過程中，扮演重要的角色。
- 電容去離子技術具有廣泛的適應性與良好的實用性，可以應用在水淡化、硬水軟化、水再生利用(脫鹽)、重金屬去除、以及有價物質的選擇性回收等。
- 技術發展尚缺乏模組驗證，朝向模組系統開發，與商業化階段發展。

謝謝聆聽!

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環境電化學與分離技術實驗室