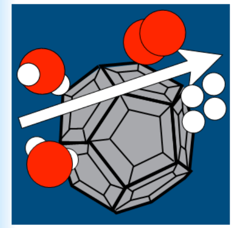
國立臺灣大學工學院 水科技與低碳永續創新研發中心

工業用水技術研究及發展

駱尚廉

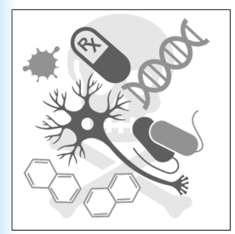
國立臺灣大學環境工程學研究所

Water Innovation, Low-Carbon and Environmental Sustainability Research Center



先進材料

新穎水科技



新興污染物

水資源管理

永續水資源與教育之跨領域研究

水科技整合範疇：研發規劃及學研企劃

水科技創新教育與研發中心

中心願景與使命：

國際主要的水科技整合範疇諮詢中心

國際主要的水處理方法中心

國際主要的水資源保護中心

中心指標性技術

1. 先進材料
- 環境奈米技術
- 新穎奈米孔洞碳材的合成與製備
- 先端功能性的奈米孔徑材料

2. 新穎水科技
- 膜分離技術
- 電容去離子電控選擇性分離技術
- 臭氧及高級氧化處理程序
- 環境生物技術

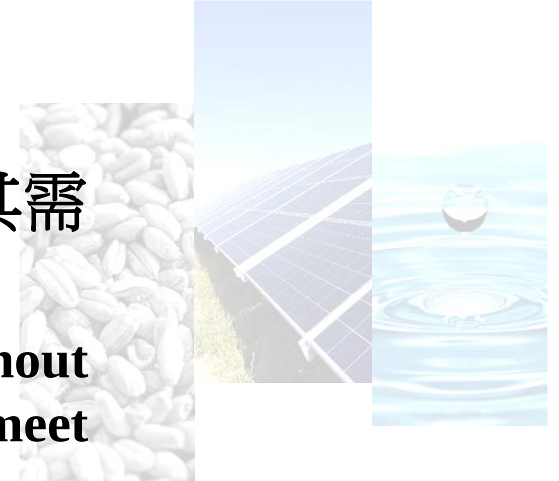
3. 新興污染物
- 環境有機污染物微量分析方法
- 持久性有機污染物之光觸媒降解
- 新興污染物工程處理技術

4. 水資源管理
- 環境資訊管理與決策分析
- 環境規劃與管理
- 環境衝擊分析
- 生命週期評估與管理

全球國際合作
- 建立國際合作計畫
- 舉辦或協辦國際研討會
- 建立國際研究合作平台

教育與人才培養
- 提供完整的環境水科技相關之知識教育平台
- 國內外之間產業學術鏈的合作交流

永續發展 Sustainable Development



滿足當代的需求，而不損害後代子孫滿足其需求的能力

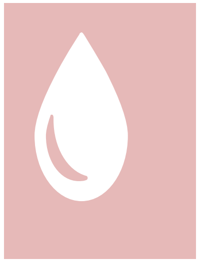
Development that meets the needs of the present without compromising the ability of future generations to meet their own needs.

糧食、能源、水(Food-Energy-Water, FEW)的永續性扮演重要角色

- 大多數的人類活動與糧食、能源、水相關
- 在2030 年時，人類需要更多的水(30%)、能源(45%)和食物(50%)
- 任何一個面向的充足提供(或匱乏)對人類生存有巨大的影響

糧食提供人類生命延續及飽足

能源提供經濟發展基礎動力



水滿足民生需求及工業/農業發展

聯合國永續發展目標(Sustainable Development Goal, SDGs)

目標二：消除飢餓，實現糧食安全，改善營養獲得及提升永續農業

目標六：確保人人享有水及衛生設施的可取得性及永續性

目標七：確保人人可獲得可負擔、可靠、永續且現代化能源

糧食-能源-水鏈結(Food-Energy-Water Nexus, FEW Nexus)

2011

斯德哥爾摩環境研究所《水、能源和糧食安全的關係：對綠色經濟的解決方案(**The Water, Energy and Food Security Nexus: Solutions for the Green Economy)**》

- 將糧食、能源和水間三者鏈結的途徑闡述為：透過提高效率、減少權衡、建立協同效應及改善治理

2011

世界經濟論壇《水安全：水-糧食-能源-氣候鏈結(**Water Security: The Water-Food-Energy-Climate Nexus)**》

- 借鑑政府、學者、非政府組織及企業的觀點，分析管理未來用水需求挑戰及解決方案

2012

國際能源署《世界能源展望(**World Energy Outlook 2012)**》

- 專章探討水與能源間的聯繫，報告中討論全球水資源在能源生產下不同地域的需求

2013

世界銀行《飢渴能源(**thirsty energy)**》

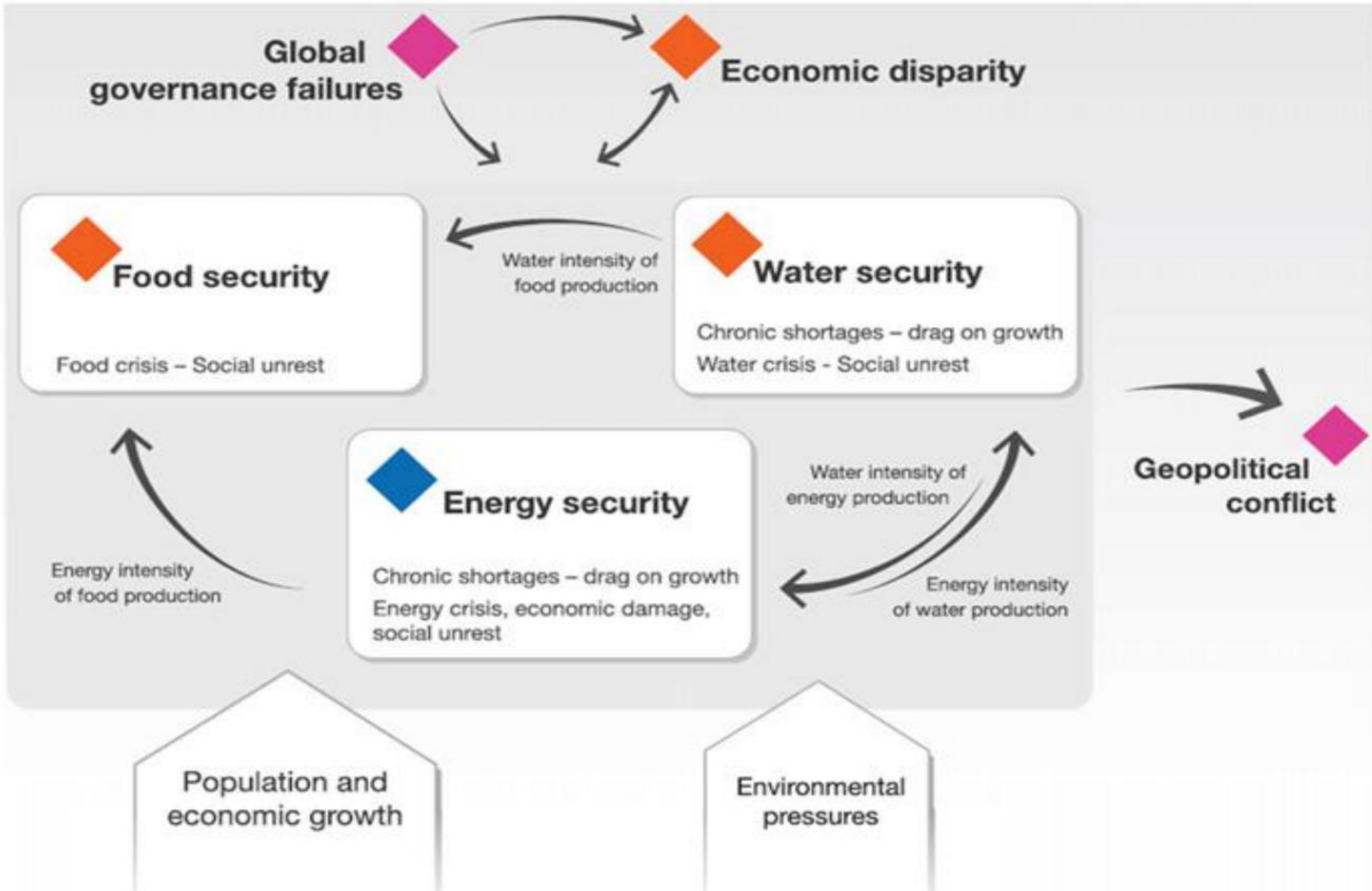
- 提供成員國重視水與能源間的課題及挑戰

2014

聯合國《世界水資源發展報告(**World Water Development Report ,WWDR)**》

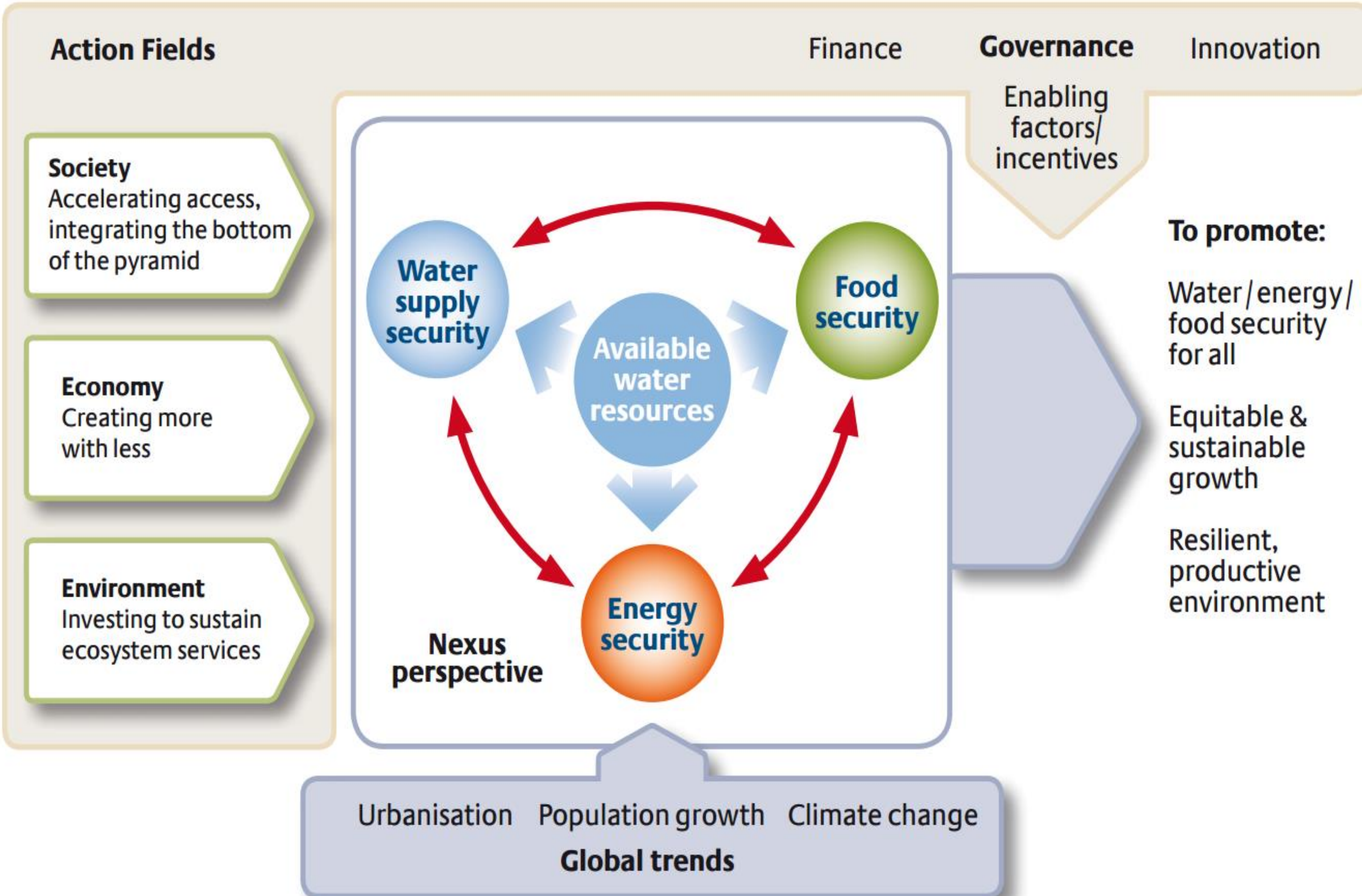
- 對水及能源關係，就數據及文獻進行分析，討論範圍並延伸至糧食與農業問題；報告中指出公共政策應與能源、水及相關領域鏈結，並鼓勵制定層級架構來兼顧水資源與能源在永續上的要求，包括法律及體制框架、可靠的數據及統計分析、技術的創新研究等

糧食-能源-水鏈結(Food-Energy-Water Nexus, FEW Nexus)



Source: WEF Nexus security (WEF, 2011)

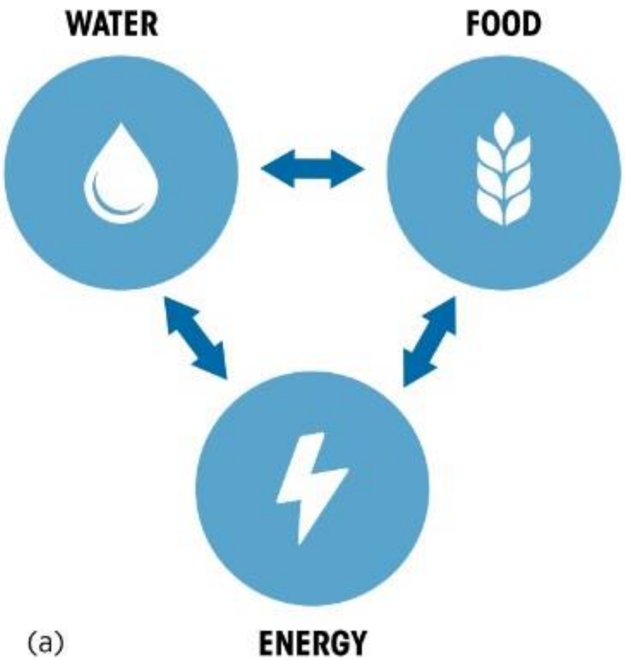
糧食-能源-水鏈結(Food-Energy-Water Nexus, FEW Nexus)



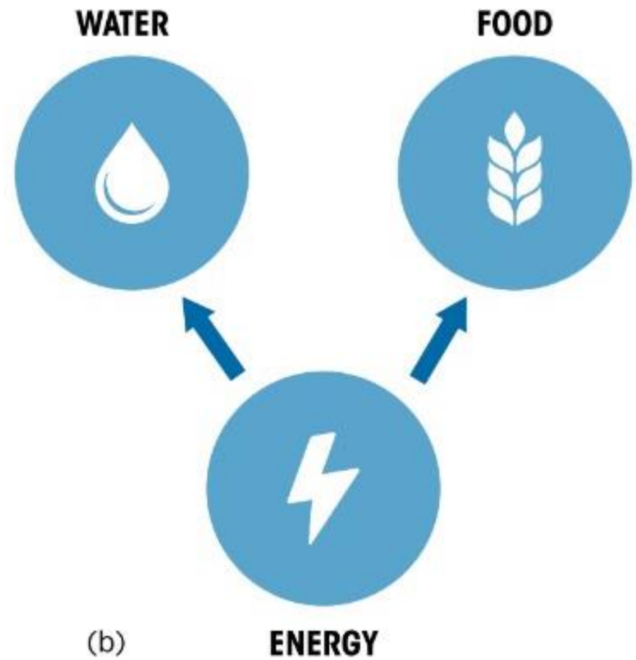
Source: BONN 2011 NEXUS conference: the water, energy and food security nexus

糧食-能源-水鏈結(Food-Energy-Water Nexus, FEW Nexus)

糧食、能源、水鏈結途徑



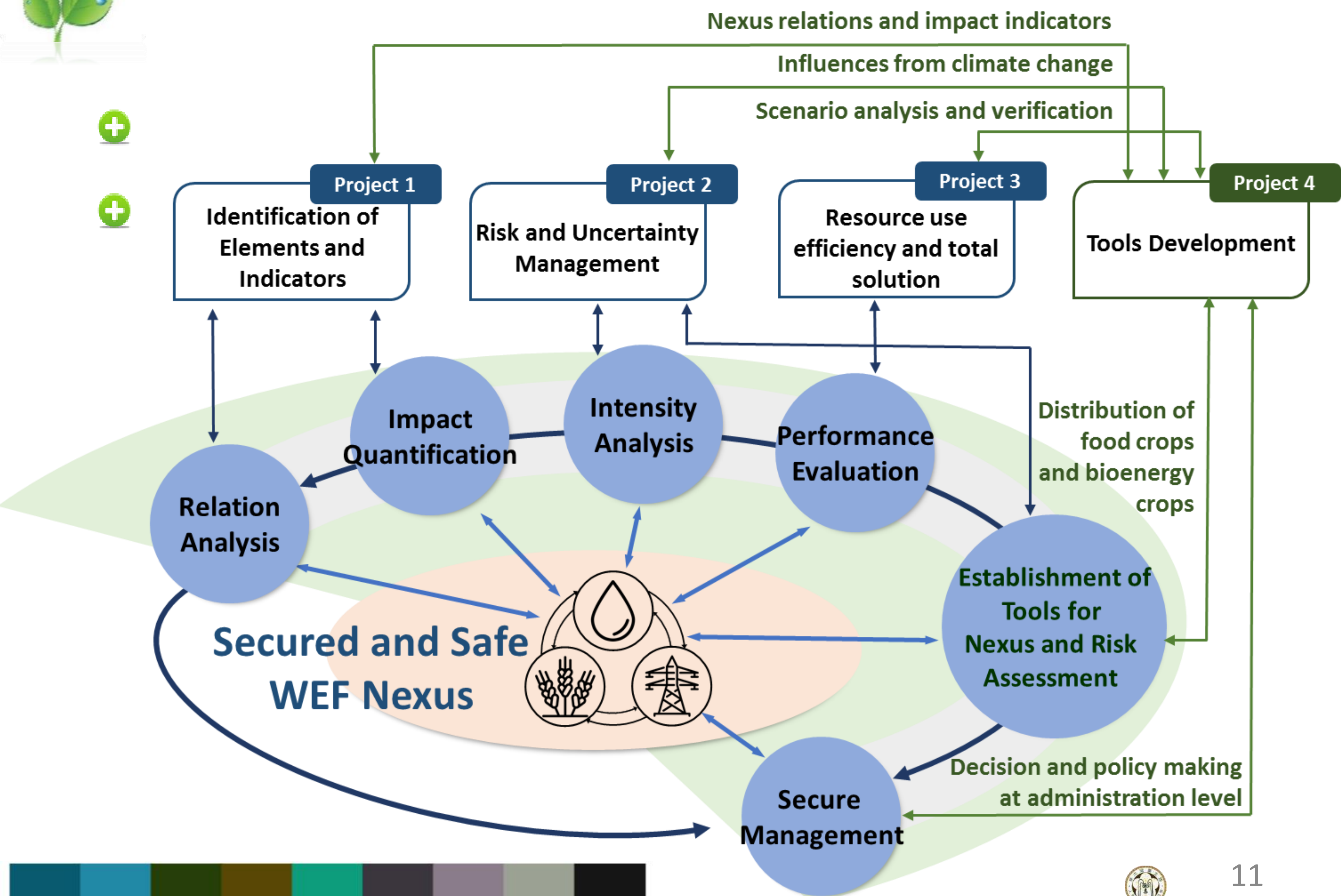
(a) 整合型



(b) 單一切入點型

IRENA (2015)

The goal of bridging FEW Nexus is to optimize Food, Energy and Water security.


Nexus relations and impact indicators
Influences from climate change
Scenario analysis and verification
Project 1
Identification of Elements and Indicators
Project 2
Risk and Uncertainty Management
Project 3
Resource use efficiency and total solution
Project 4
Tools Development
Impact Quantification
Intensity Analysis
Performance Evaluation
Distribution of food crops and bioenergy crops
Relation Analysis
Establishment of Tools for Nexus and Risk Assessment
Secured and Safe WEF Nexus
Decision and policy making at administration level
Secure Management

CRUNCH (Climate Resilient Urban Nexus CHoices: Operationalising the Food-Water-Energy Nexus)

2018.01	2018.04	2019.04	2020.04

Year 1
2018.04 Southern-on-Sea, UK
2018.09 Gdansk, Poland

Year 3
2020.04 Miami, US
2020. Taipei, Taiwan

Funded by the Belmont Forum
- CRUNCH- Climate Resilient Urban Nexus Choices: Operationalizing the Food-Water-Energy Nexus

Year 2
2019.05 Eindhoven, Netherlands
2019.10 Uppsala, Sweden

CRUNCH 1st Meeting in UK

CRUNCH 2nd Meeting in Poland

CRUNCH 3rd Meeting in Netherlands

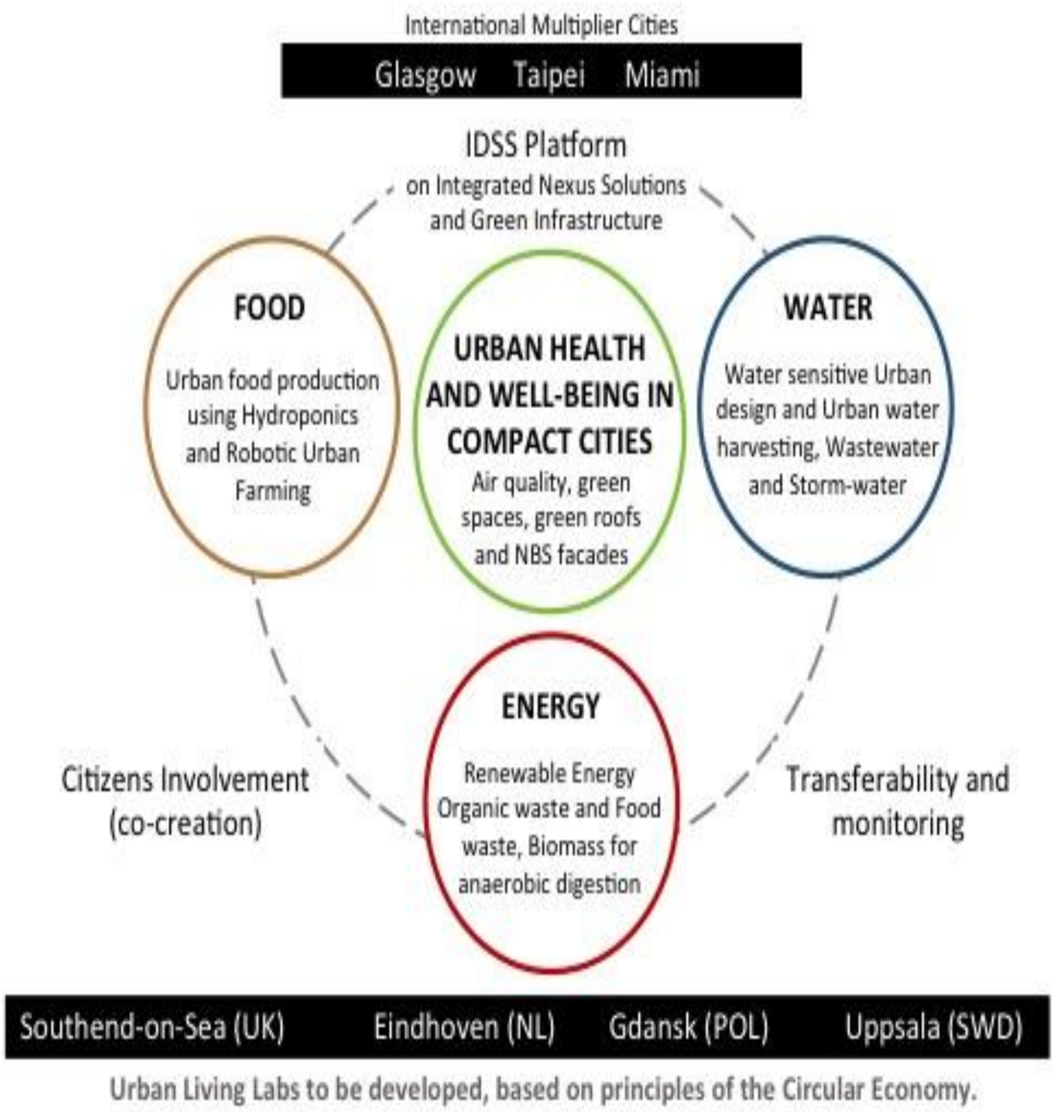
CRUNCH 4th Meeting in Sweden

Oct. 16-17, 2019

CRUNCH
The Food-Water-Energy Nexus

FEW跨國研究團隊

Climate Resilient Urban Nexus CHoices (CRUNCH)– Operationalising the Food-Water-Energy Nexus



1 計畫目標
如何透過FEW鏈結強化都市韌性

2 都市生活實驗室 (Urban Living Labs, ULLs)
Southend-on-sea (英國)
Gdansk (波蘭)
Miami (美國)
Eindhoven (荷蘭)
Uppsala (瑞典)
Taipei (臺灣)

3 建立整合決策支援系統 作為改善都市發展決策分析工具
Integrated Decision Support System tool, IDSS

Futekeng Environmental Rehabilitation Park
Taipei Urban Living Lab

It was the first sanitary landfill facility in Taipei established in 1985

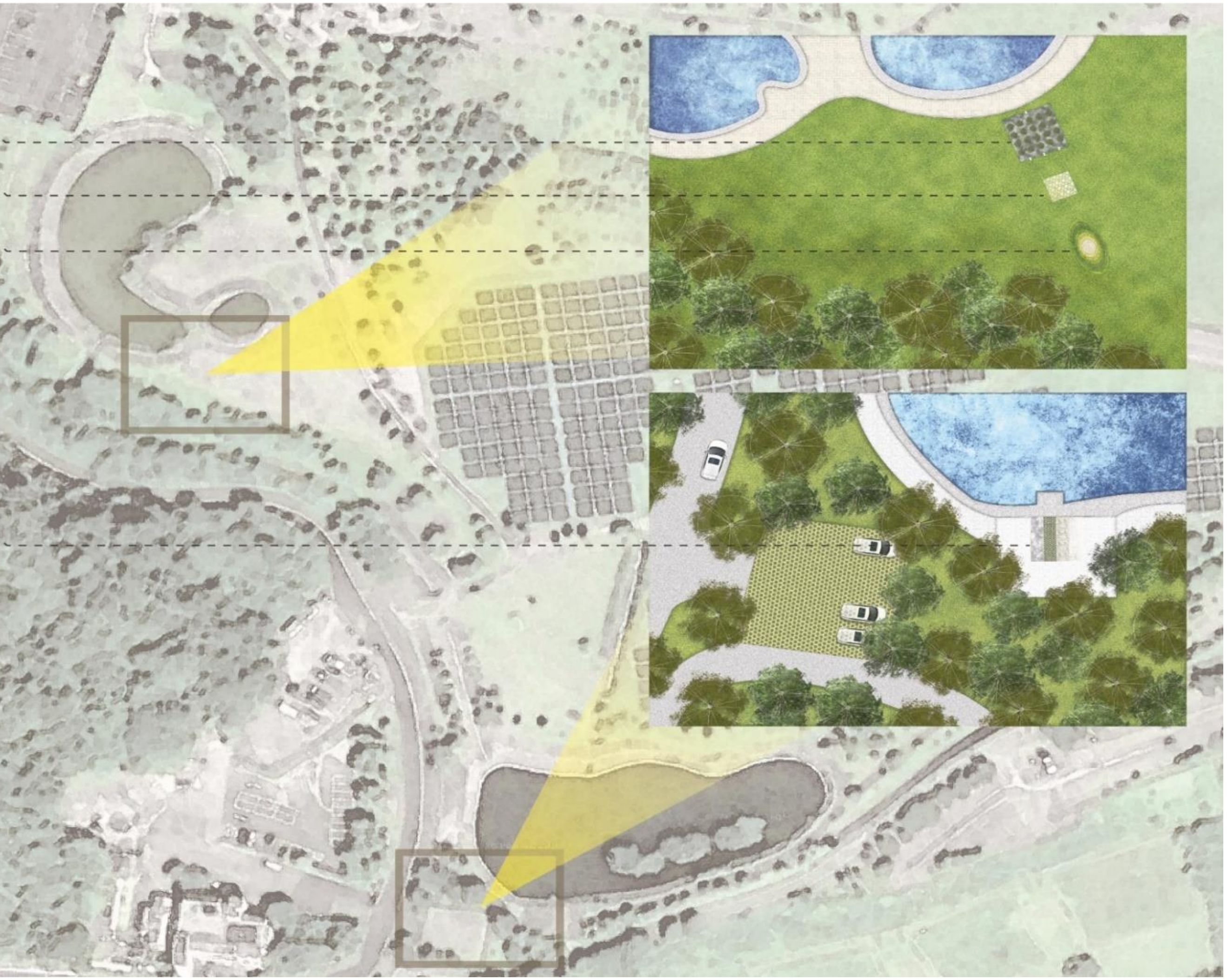
Constructing a sustainable water resources and green energy technology pilot zone

No extra energy

No extra water

Low impact to landscape

- Exploring natural-based solution



Plant microbial fuel cell

Bio-filtration basin

Rain garden

Permeable pavement

Constructing a sustainable water resources and green energy technology pilot zone

A workshop in July

Facilitating connections with stakeholders

Main tasks

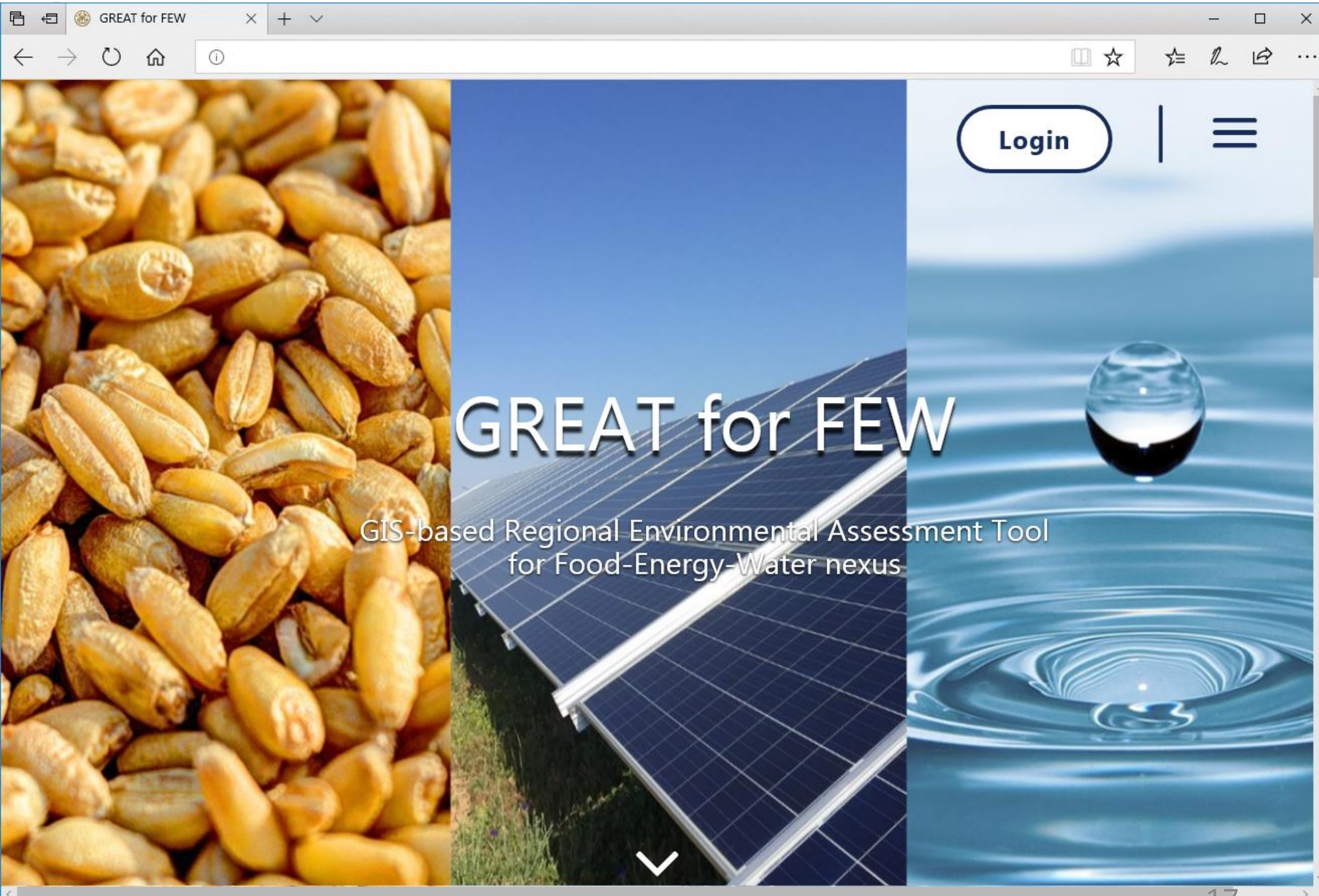
- Providing interaction platforms for scientists and societal stakeholders for mutual learning and research co-design and co-production.

Participants

- Scientists
- Government
- The public
- Stakeholders

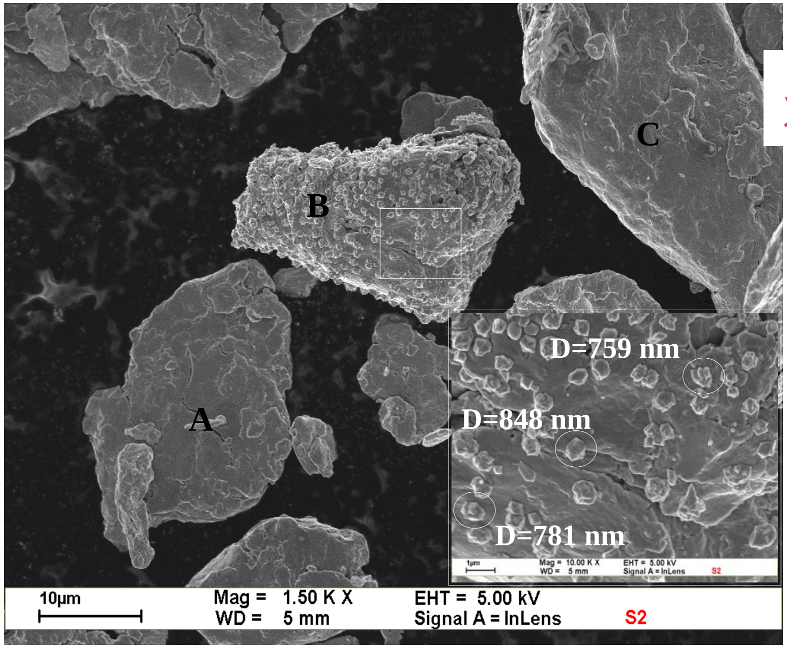
Department of Environmental Protection Taipei City Government

臺北市政府環境保護局


GREAT for FEW
Login
GREAT for FEW
GIS-based Regional Environmental Assessment Tool
for Food-Energy-Water nexus

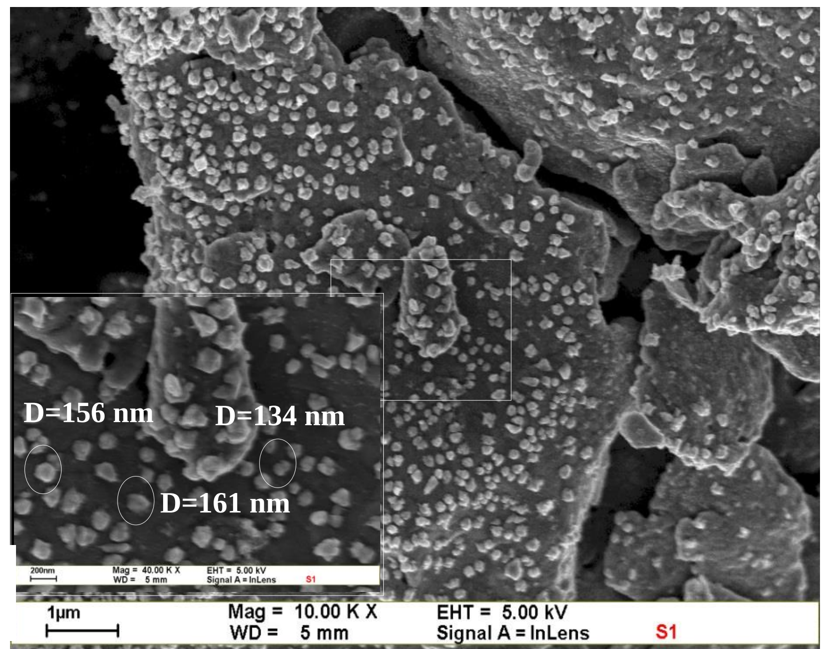
以還原性雙金屬還原硝酸鹽與可見光光催化氨氮之系統

- 零價鐵(Fe^0)披覆少量貴金屬如鈀(Pd)、鉑(Pt)、銅(Cu)等貴金屬於Fe^0表面可大幅提升反應活性。
- 主要機制是兩金屬間的電位差快速驅動Fe^0釋出電子至貴金屬表面，並將吸附在表面的氫離子還原為高還原能力的H，進一步降解污染物或是再結合為氫氣釋出。



未進行前處理之Fe^0

經前處理之Fe^0



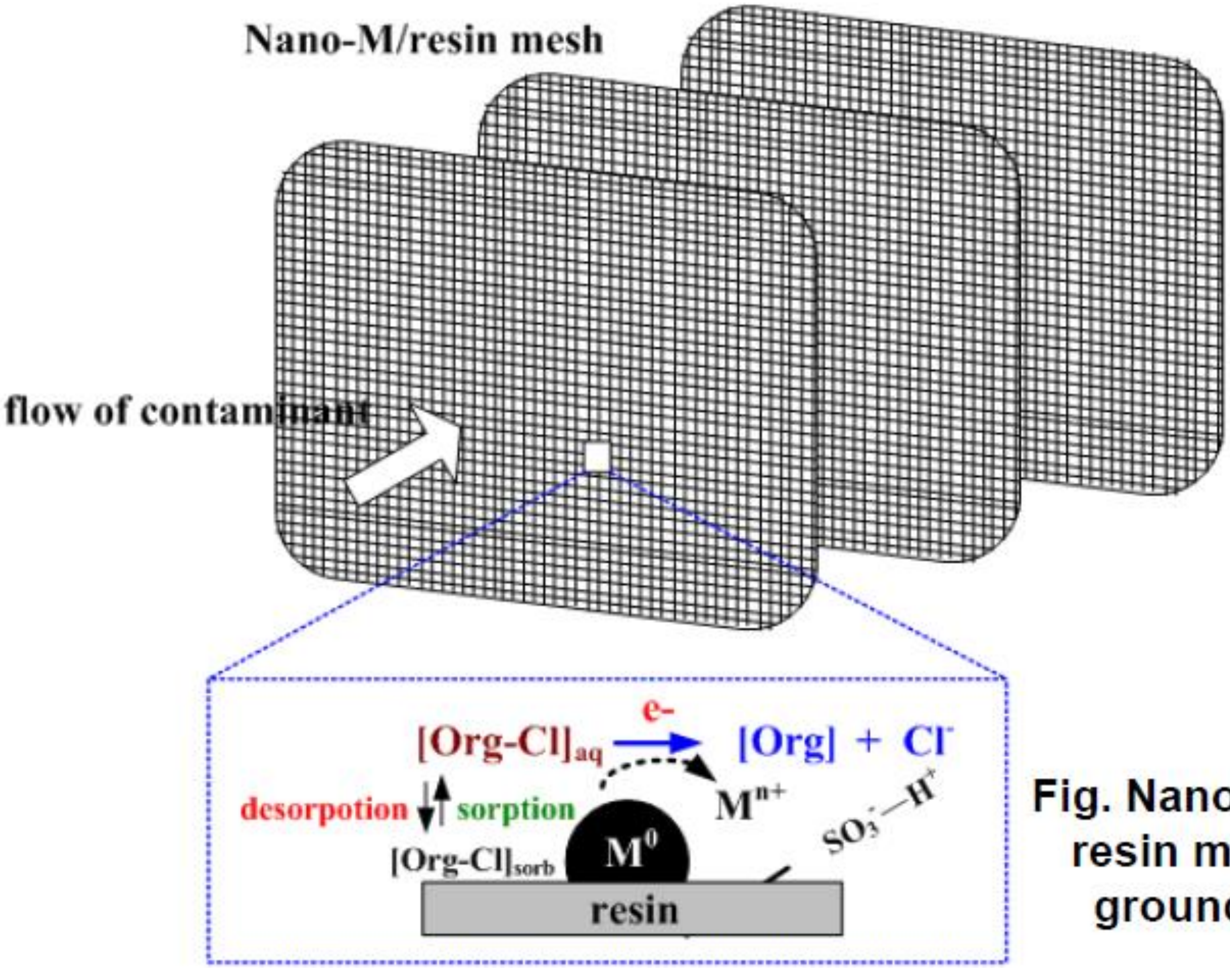


Fig. Nanoscale zerovalent metal coate resin mesh application in an above-ground reactor and the reactions.

銅金屬奈米顆粒附載於離子交換樹脂上及其反應

選擇性光催化氧化水中氨氮反應

光觸媒激發出之氫氧自由基 (OH・)具有強大之氧化力，但無法選擇性地將NH_3-N (-Ⅲ) 轉換成N_2 (0)，我們探究利用具有光催化能力與離子交換能力的微波型氧化鈦奈米管($Na_xH_{2-x}Ti_3O_7$,TNTs)，其對於水中氨氮降解具有成效。於製備氧化鈦奈米管過程中所輸入之微波能主導了鈦管結構內之鈉含量及其結晶程度，而此兩項結構參數亦與光催化水中氨氮之氧化效率有直接之相關性。就鈦管晶體結構而言，純鈦管結構對於氨氮降解並無明顯之助益，而當摻雜金紅石相(rutile)晶型時，氧化效率可大幅提昇。

(1) Irradiation of TNTs

$$\mathrm{TNTs} + h\nu \longrightarrow e^- + h^+$$

(2) Surface Trapping on TNTs

$$>\mathrm{Ti^{IV}OH} + h^+ \xrightarrow{H_2O} >\mathrm{Ti^{IV}OH}\bullet$$

$$>\mathrm{Ti^{IV}OH} + e^- \longrightarrow >\mathrm{Ti^{III}OH^-}$$

(3) Surface Trapping on PtO2

$$>\mathrm{Ti^{IV}/Pt} + e^- \longrightarrow >\mathrm{Ti^{IV}Pt^-} \quad (a)$$

$$\mathrm{PtO_2} + 4e^- \longrightarrow \mathrm{Pt} + 4\mathrm{O}^- \quad (b)$$

(4)Platinium surfaces

$$>\mathrm{Ti^{IV}Pt^-} + \mathrm{NH_3} \longrightarrow >\mathrm{Ti^{IV}Pt\dot{H}} + \mathrm{\dot{N}H_2}$$

$$>\mathrm{Ti^{IV}Pt\dot{H}} + \mathrm{NH_3} \longrightarrow >\mathrm{Ti^{IV}PtH_2} + \mathrm{\dot{N}H_2}$$

$$2\,\mathrm{\dot{N}H_2} \longrightarrow \mathrm{H_2N\text{-}NH_2}$$

$$3\,\mathrm{N_2H_4} \longrightarrow \boxed{\mathrm{N_2}} + 4\,\mathrm{NH_3}$$

(5) Titanate surfaces

$$>\mathrm{Ti^{IV}OH}\bullet + \mathrm{NH_3} \xrightarrow{H_2O} >\mathrm{Ti^{IV}OH_2} + \mathrm{\dot{N}H_2}$$

$$>\mathrm{Ti^{IV}OH}\bullet + \mathrm{\dot{N}H_2} \xrightarrow{H_2O} >\mathrm{Ti^{IV}OH_2} + \mathrm{NH_2OH}$$

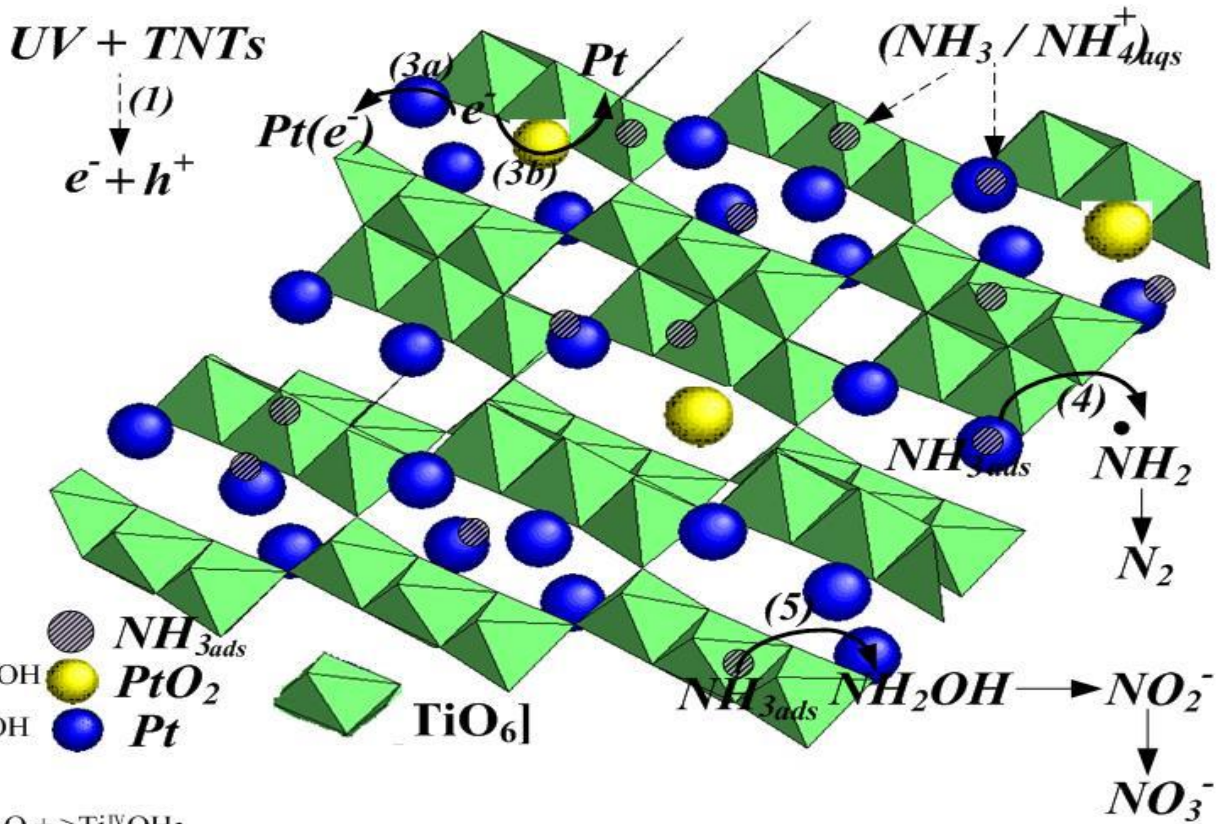
$$>\mathrm{Ti^{IV}OH}\bullet + \mathrm{NH_2OH} \xrightarrow{H_2O} >\mathrm{Ti^{IV}OH_2} + \mathrm{\dot{N}HOH}$$

$$\mathrm{\dot{N}HOH} + \mathrm{O_2} \longrightarrow \bullet\mathrm{O_2NHOH}$$

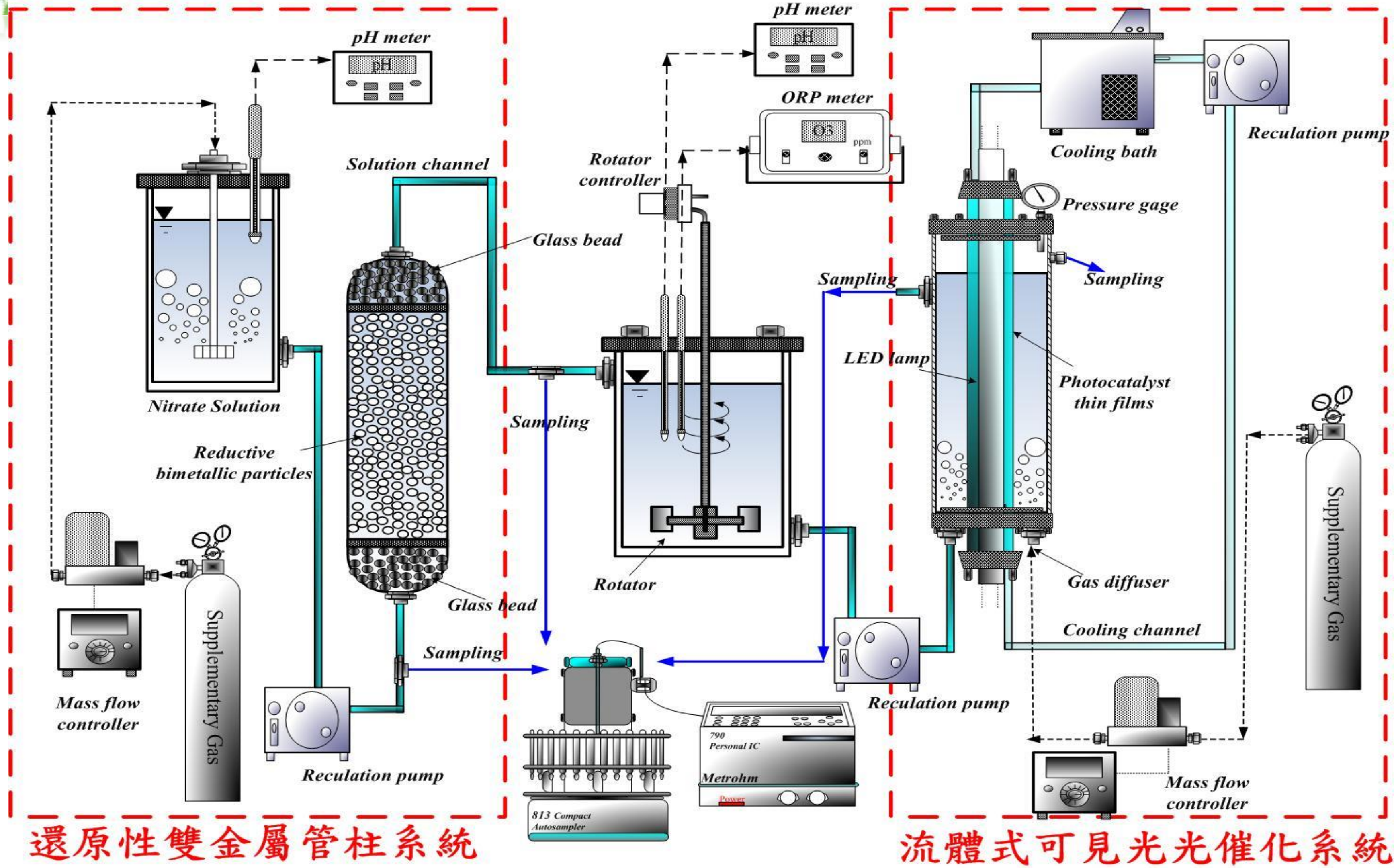
$$>\mathrm{Ti^{III}OH^-} + \bullet\mathrm{O_2NHOH} \longrightarrow \boxed{\mathrm{NO_2^-}} + \mathrm{H_2O} + >\mathrm{Ti^{IV}OH}\bullet$$

$$>\mathrm{Ti^{IV}OH}\bullet + \mathrm{NO_2^-} \xrightarrow{H_2O} >\mathrm{Ti^{IV}OH_2} + \mathrm{HONO_2}$$

$$\mathrm{HONO_2} \longrightarrow \boxed{\mathrm{NO_3^-}} + \mathrm{H^+}$$



奈米鈦管表面光催化氧化NH_3/NH_4^+示意圖

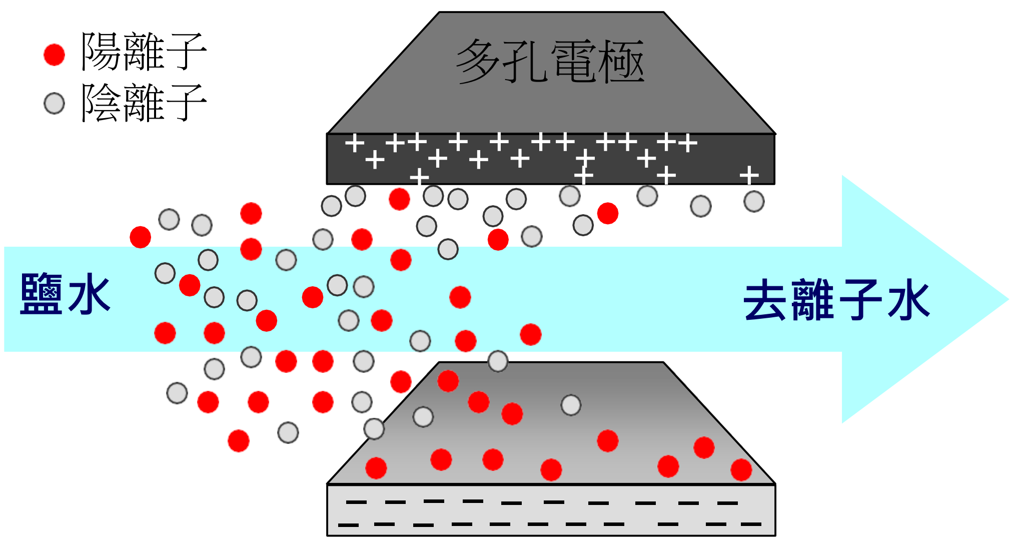


還原性雙金屬還原硝酸鹽與可見光光催化氨氮系統設計圖

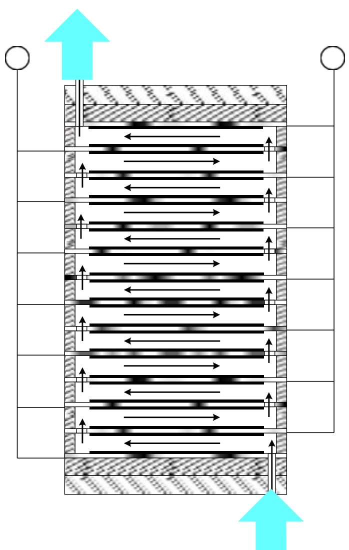
電容去離子技術 (Capacitive Deionization, CDI)

技術原理

- 新型的低耗能脫鹽技術，以電荷分離與超級電容器工作原理，從水體中移除帶電荷離子。
- 基於奈米孔洞電極，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


電吸附的裝置示意圖

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

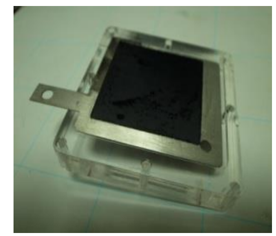
*Energy consumption (2000 mg/L salty water):
RO: 2.25 kWh/m3
EDR: 2.03 kWh/m3
CDI : 0.59 kWh/m3

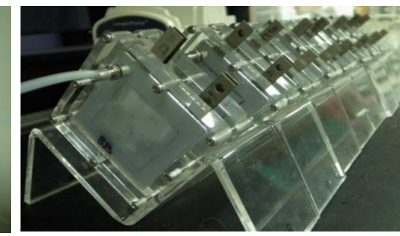
(Welgemoed and Schutte, 2005)

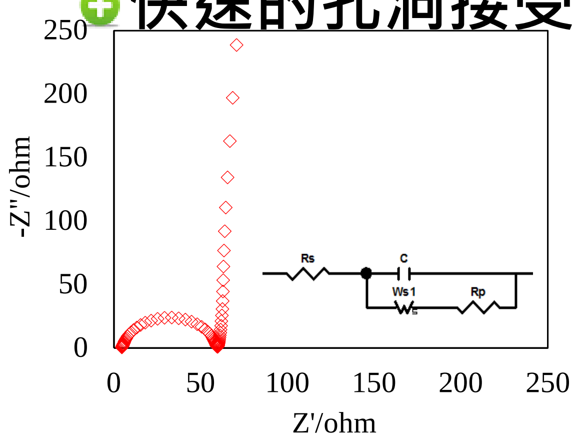
脫鹽技術	技術原理
逆滲透 (RO)	**外加壓力與反滲透膜** 高壓下運行 薄膜積垢與操作維護複雜
電透析 (ED)	**電驅動與陰陽離子交換膜** 薄膜極化與水解現象 消耗化學藥品
電容去離子 (CDI)	**電吸附與超級電容原理** 通道式結構 OECD(2009)評估最具有取代現有脫鹽技術之潛力 低耗能 < 1.0 kWh/m3

CDI電極材料的製備

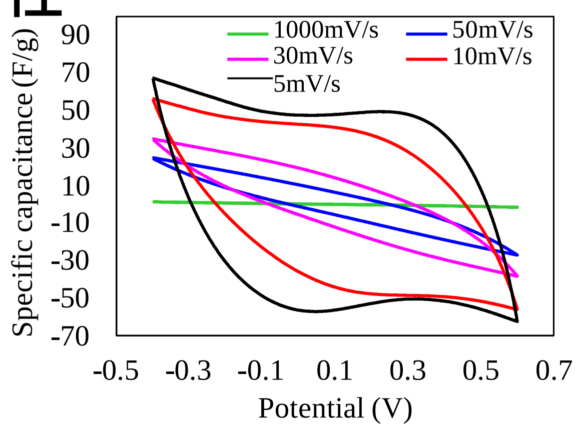
- 奈米孔洞碳材: 活性碳、活性碳纖維、碳氣凝膠、中孔碳材、奈米碳管、石墨烯等
  - 高比表面積
  - 好的電化學穩定性
  - 良好的導電性
  - 高的親水性
  - 快速的孔洞接受性



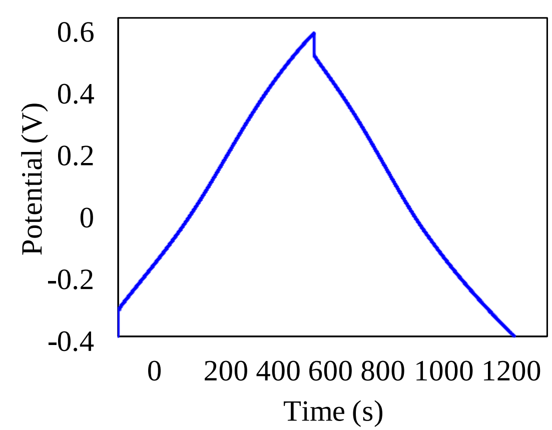




電阻抗分析



電容特性

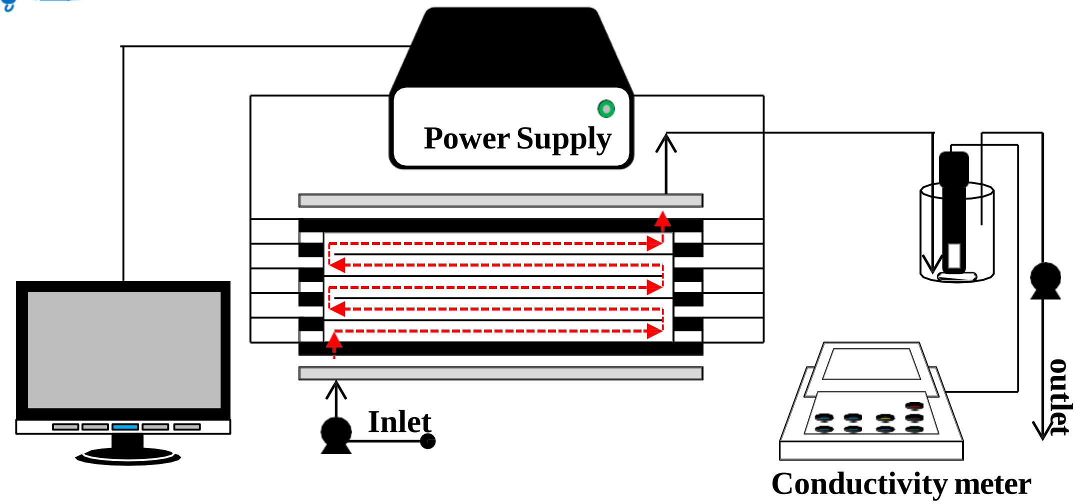


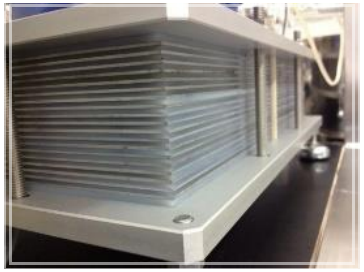
定電流充放電

電容去離子技術的發展

- 發展現況
  - 由基礎階段往模組驗證與商業化階段發展
  - 商業模組系統：EWP(美國)、Voltea (荷蘭)
  - 實場規模應用(5,000~60,000 m^3/day)：EST(大陸)
- CDI模組的設計

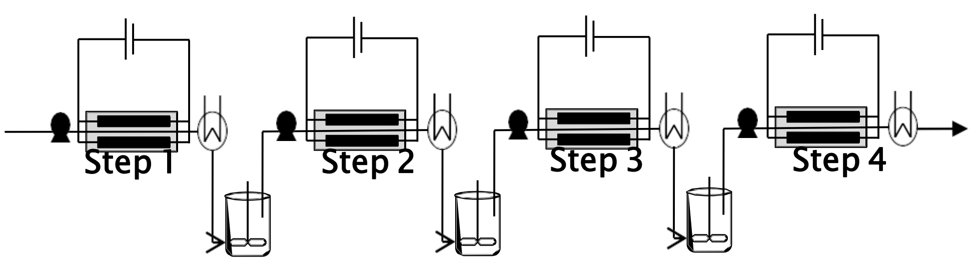
國立臺灣大學環境工程學研究所



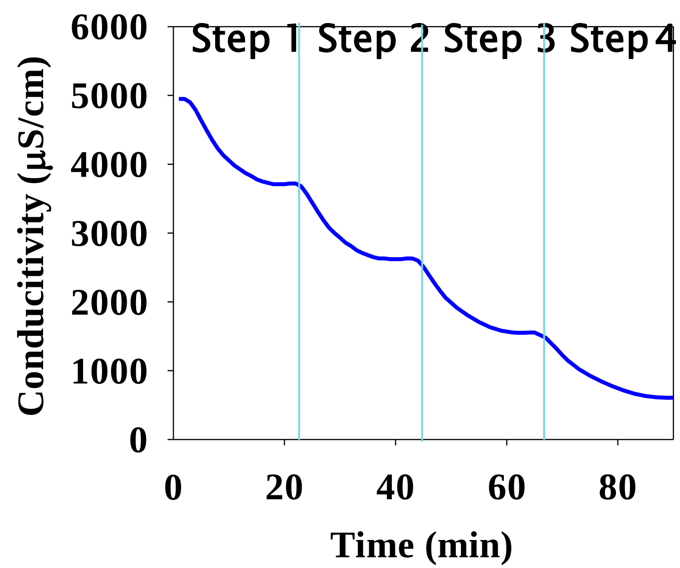


電容去離子技術的應用範圍

- 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



CDI模組的串聯操作



操作電壓：1.2 V 流速：25 mL/min
脫鹽效率：88％ 能耗：0.05

超聲波水處理強化技術

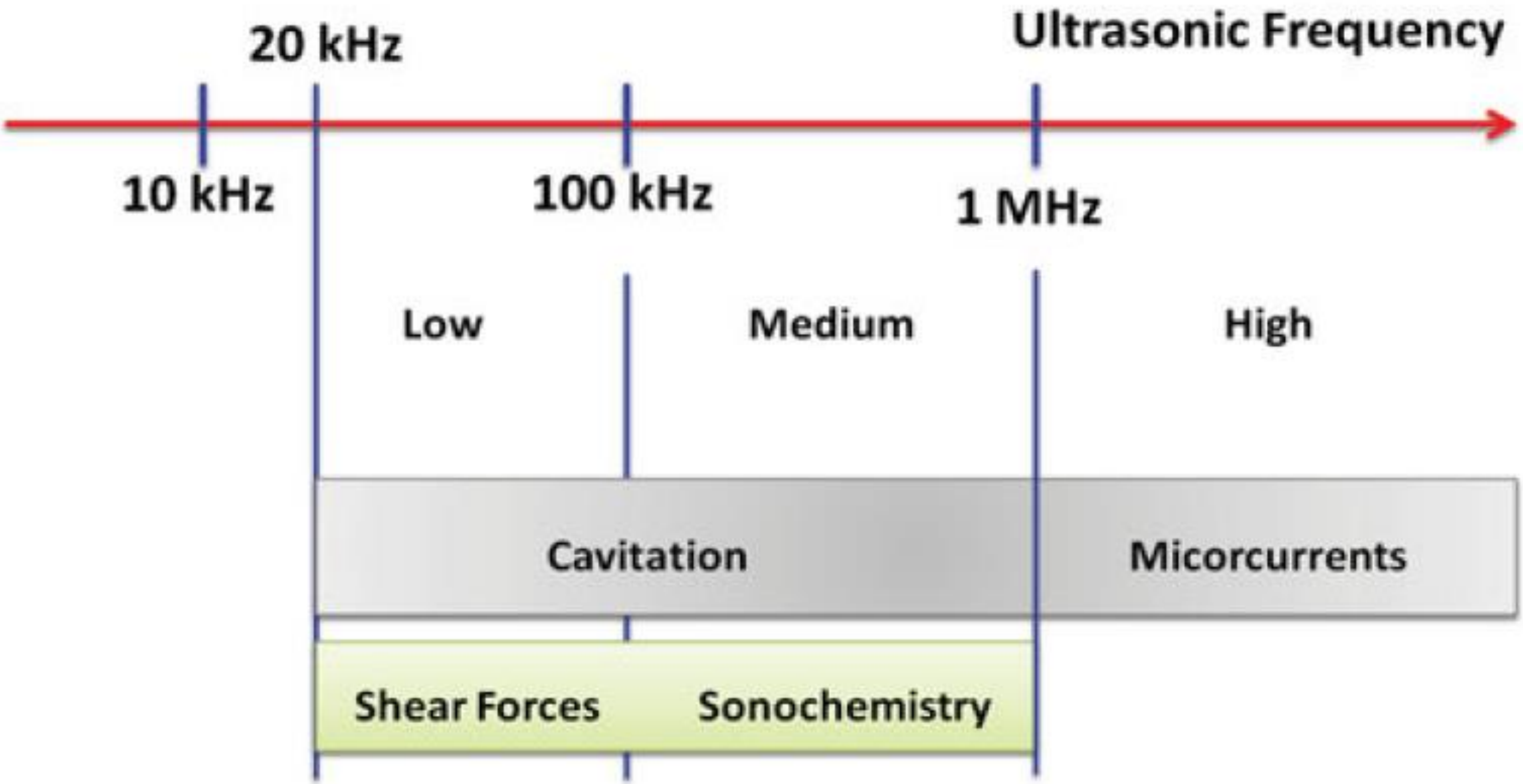


FIGURE 1. Classification of ultrasonic frequencies.

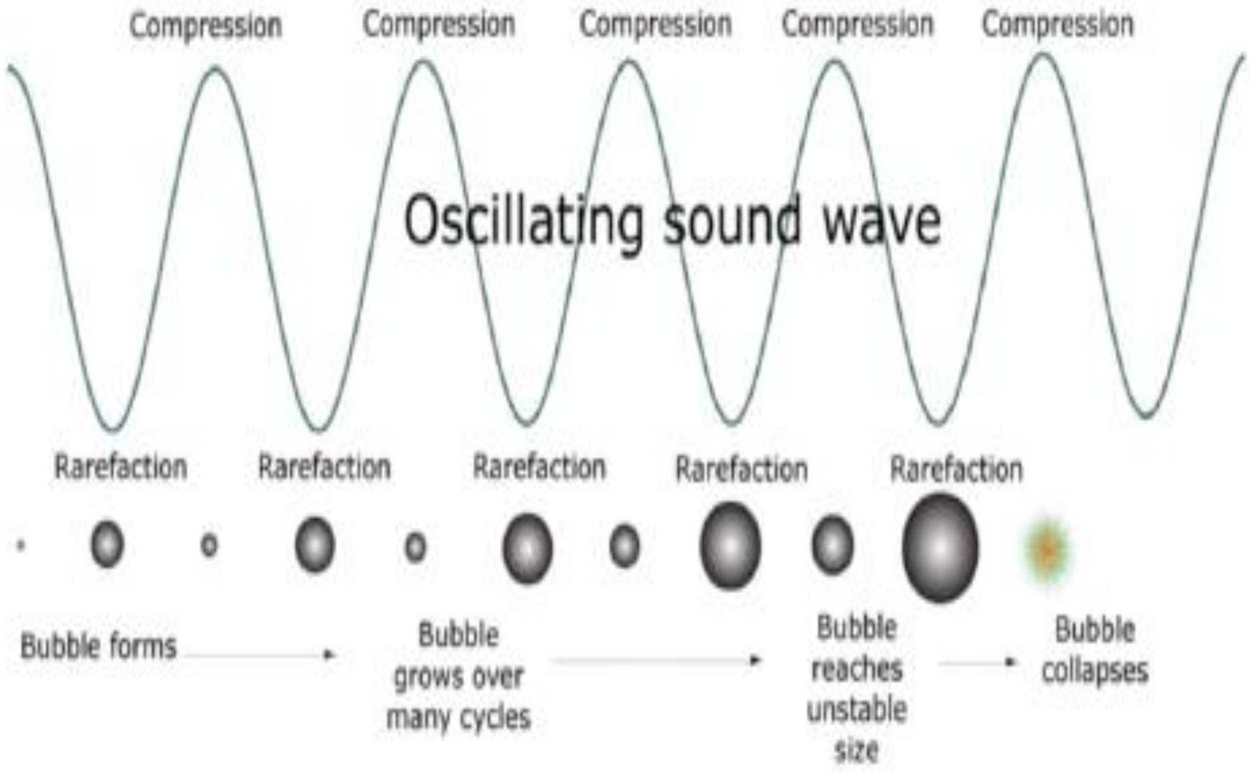
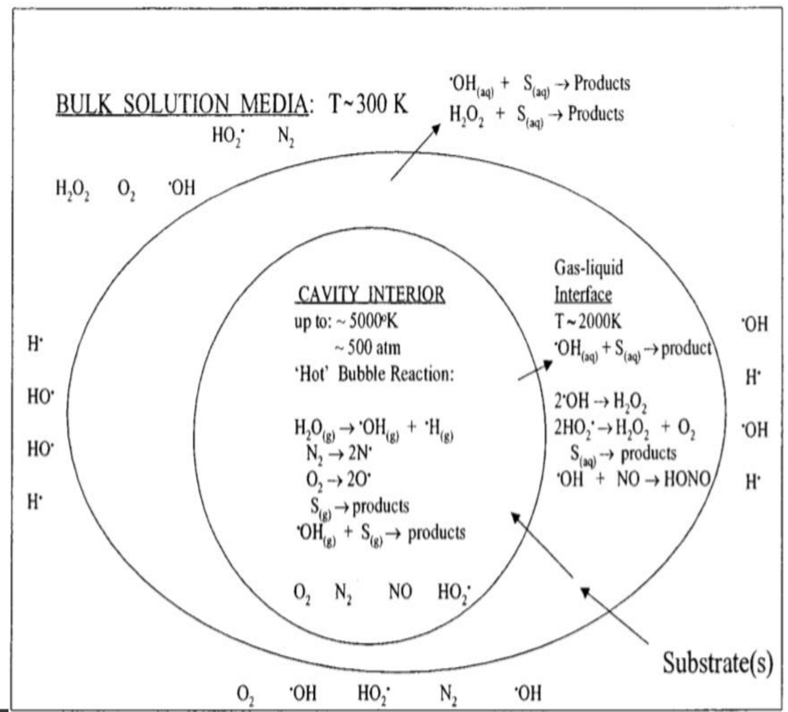


圖 2-5 微泡形成之過程

(Leong, 2011)

Ultrasonic wave

1. **Causing cavitation, generating energy to increase the temperature and pressure in the bubble up to 5,000°K and 500 atm, respectively.**
2. **Pyrolysis inside the bubble and hydroxyl radical-mediated reactions.**



1. 超聲波水處理強化技術

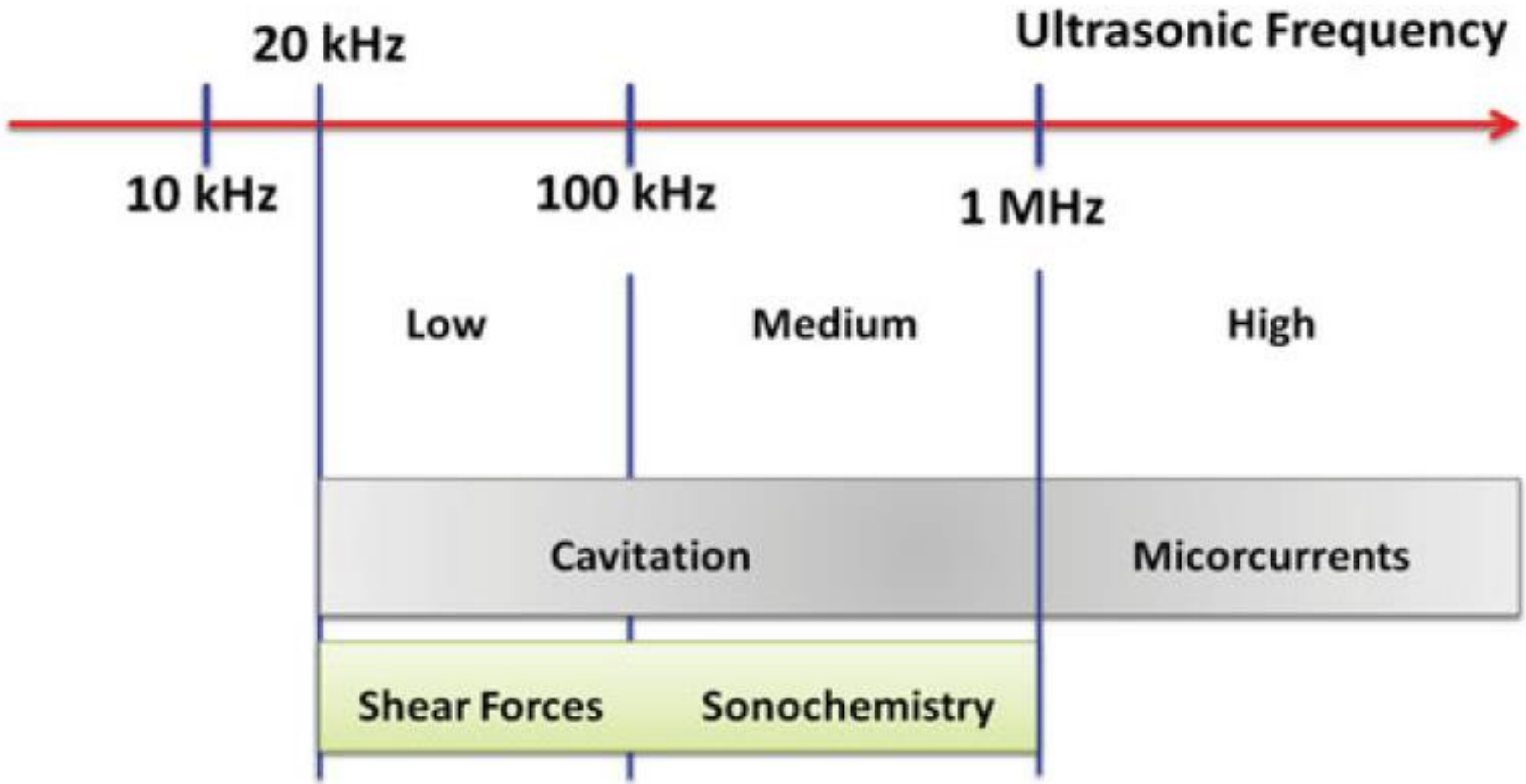


FIGURE 1. Classification of ultrasonic frequencies.

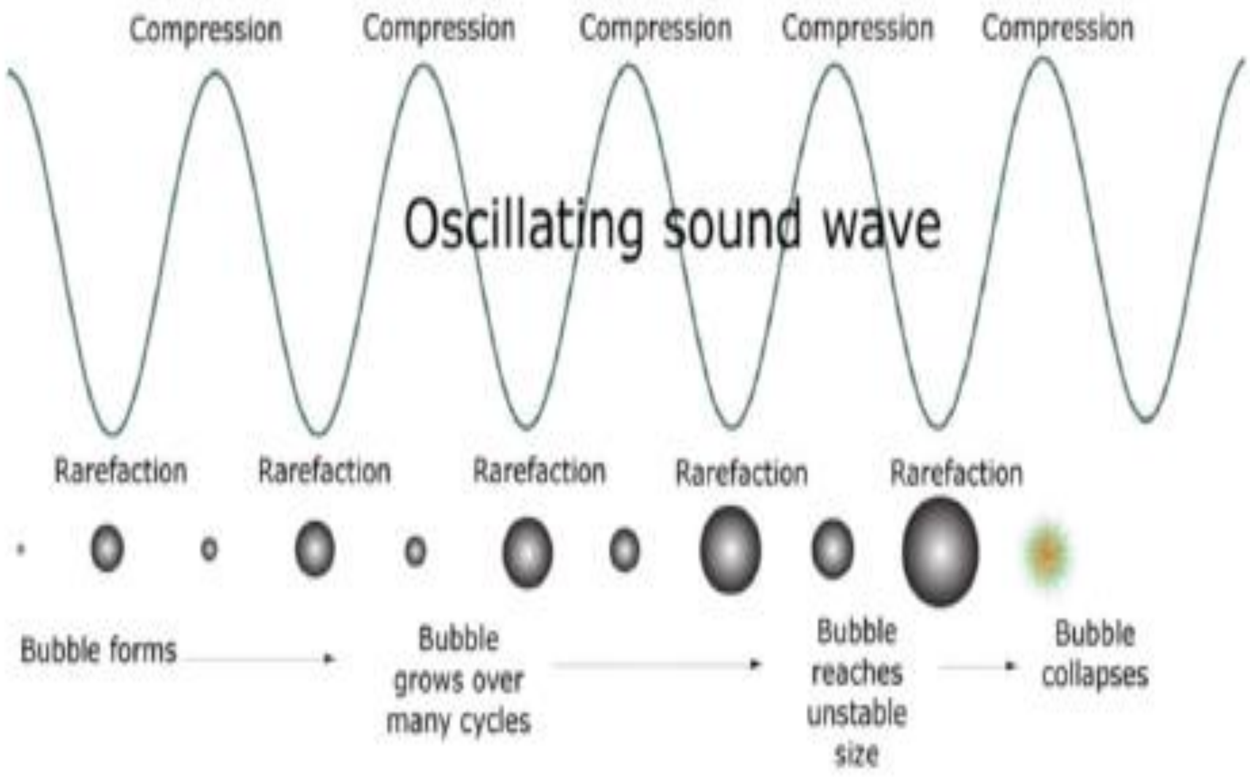


圖 2-5 微泡形成之過程

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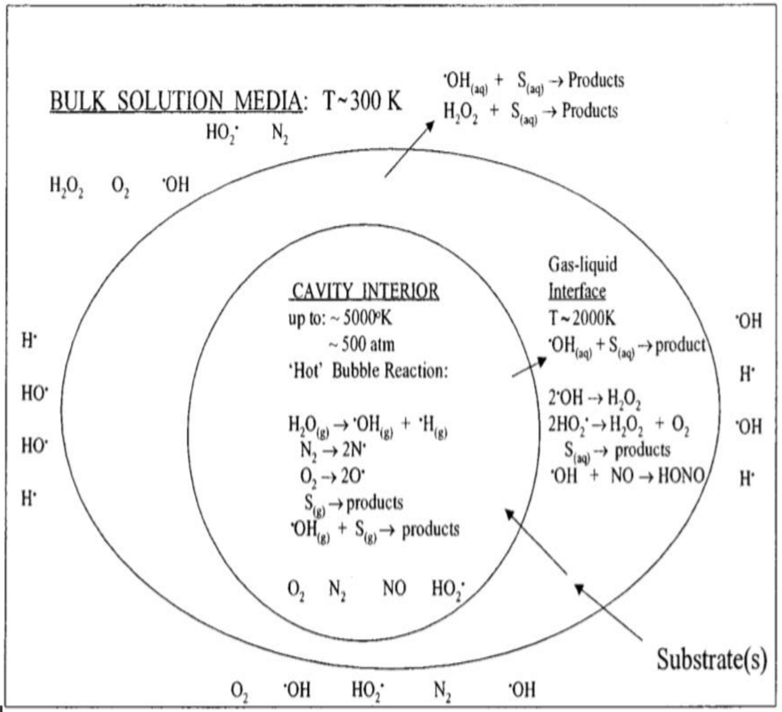
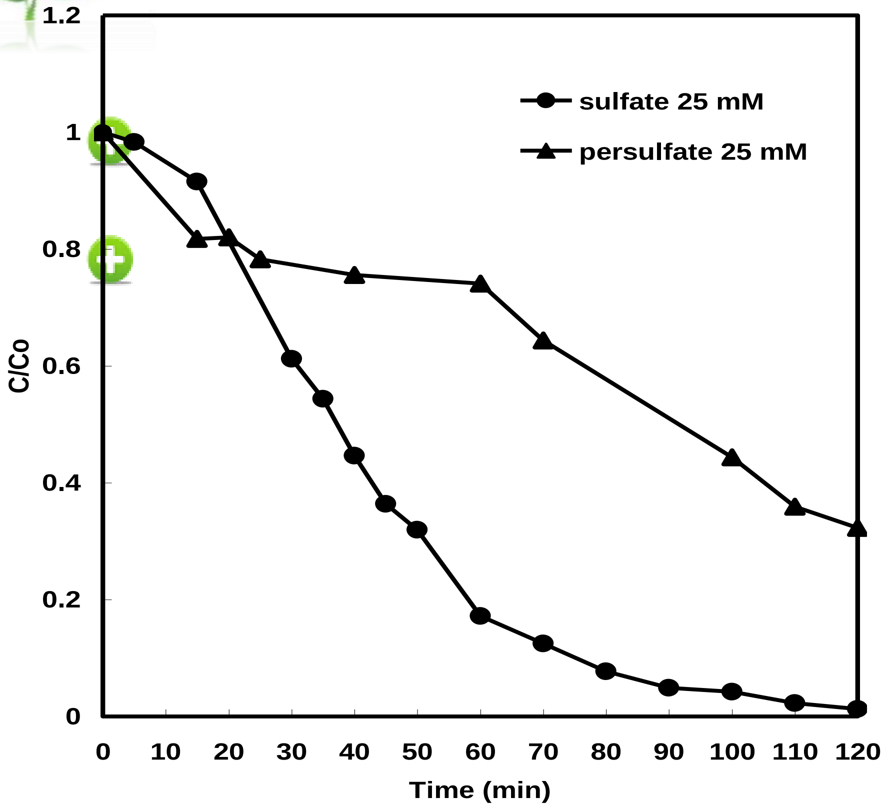
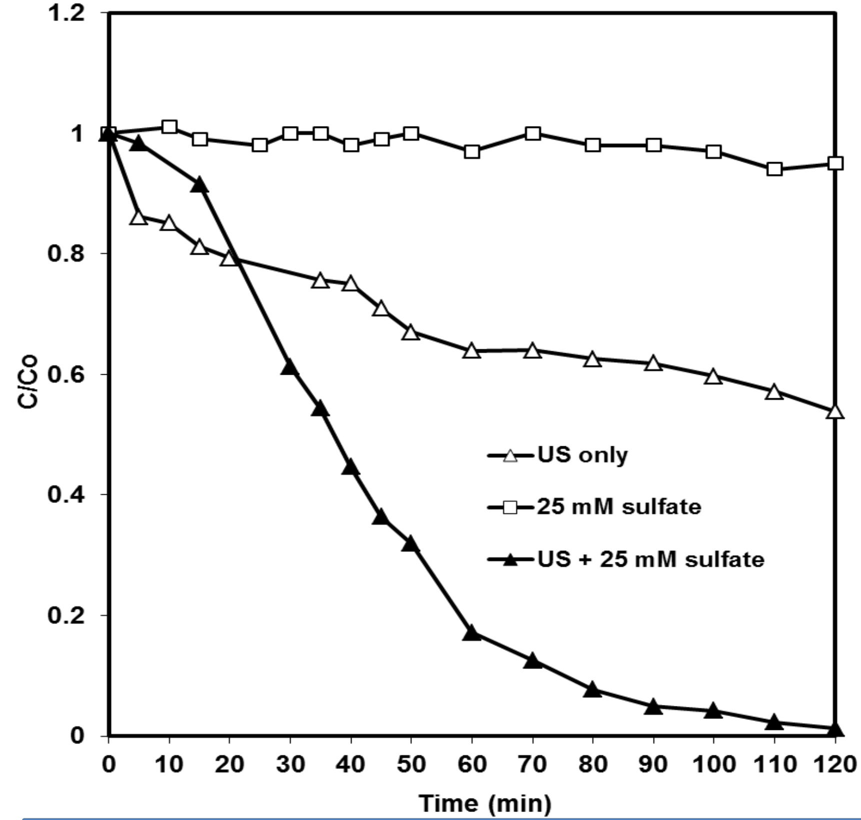


Degradation of PFOA

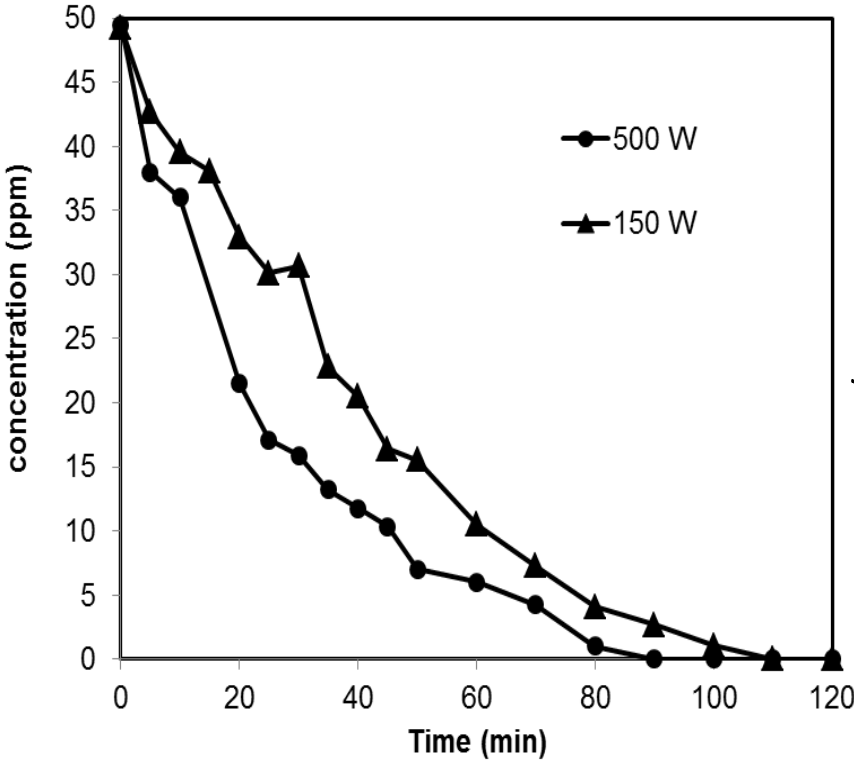


Effects of sulfate and persulfate addition on PFOA removal ($[PFOA]_0$ = 0.12 mM; $[sulfate]_0$ = 25 mM; $[persulfate]_0$ = 25 mM;initial pH = 4.3; T = 25 ˚C; power =150 W).

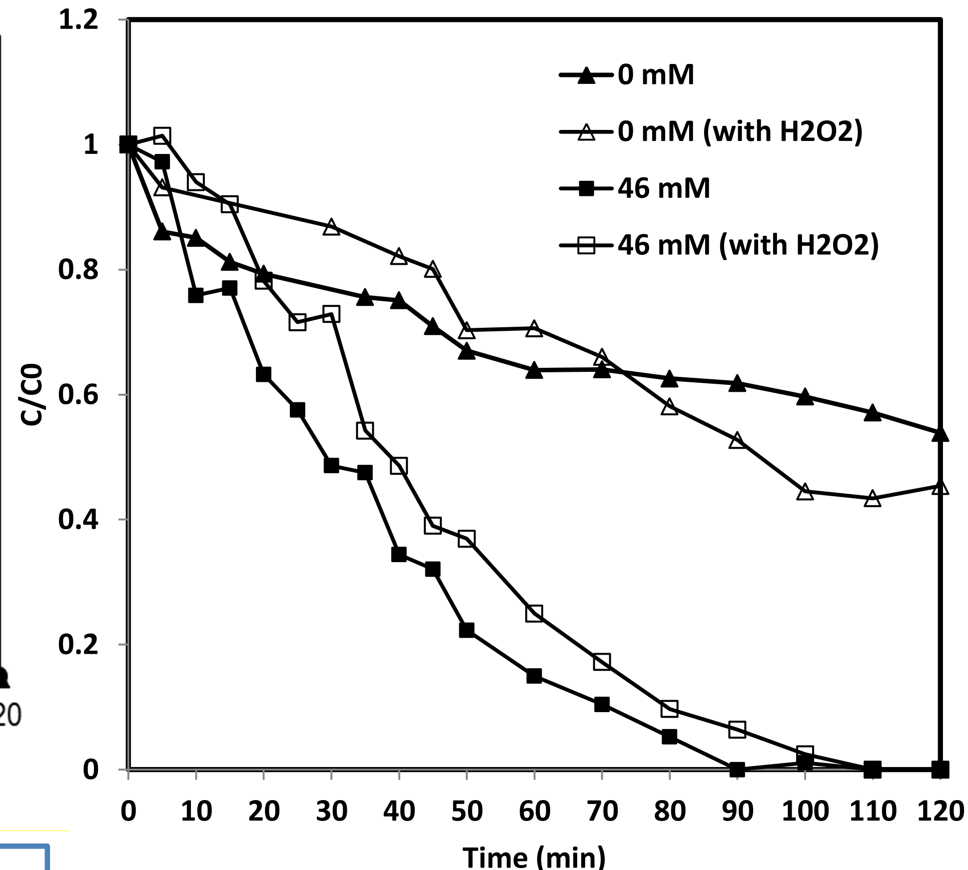


Effects of sulfate addition on PFOA removal ($[PFOA]_0$ = 0.12 mM; $[sulfate]_0$ = 0mM, 25 mM; initial pH = 4.3; T = 25 ˚C; power =150 W).

Degradation of PFOA (2)



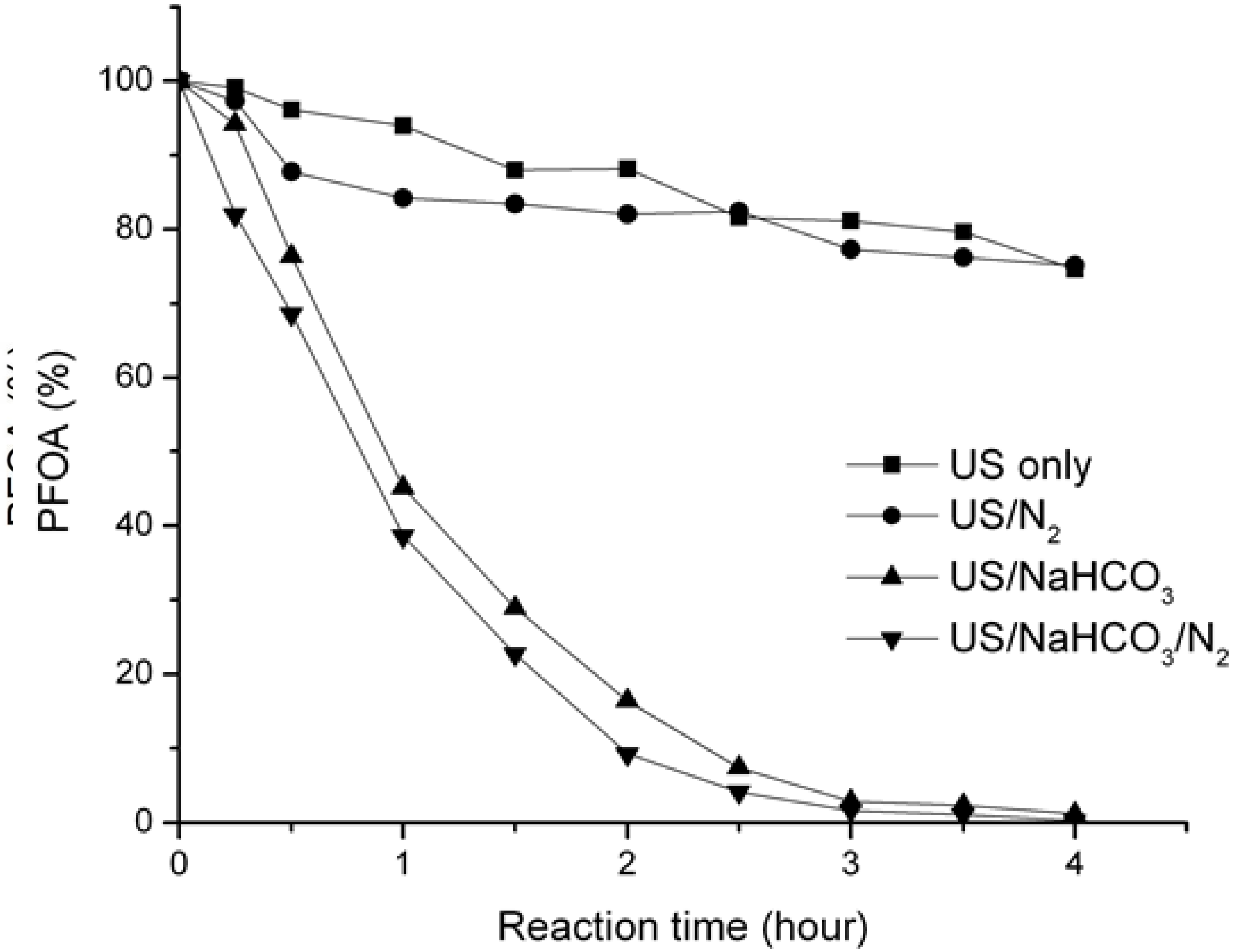
Effects of US power on PFOA removal ($[PFOA]_0$ = 0.12 mM; $[sulfate]_0$ = 46 mM; initial pH = 4.3; T = 25 ˚C; power =150 W)



Effects of sulfate and H_2O_2 addition on PFOA removal($[PFOA]_0$ = 0.12 mM; $[sulfate]_0$ = 46 mM; $[H_2O_2]_0$ = 0.22 mM; initial pH = 4.3; T = 25 ˚C; power =150 W).

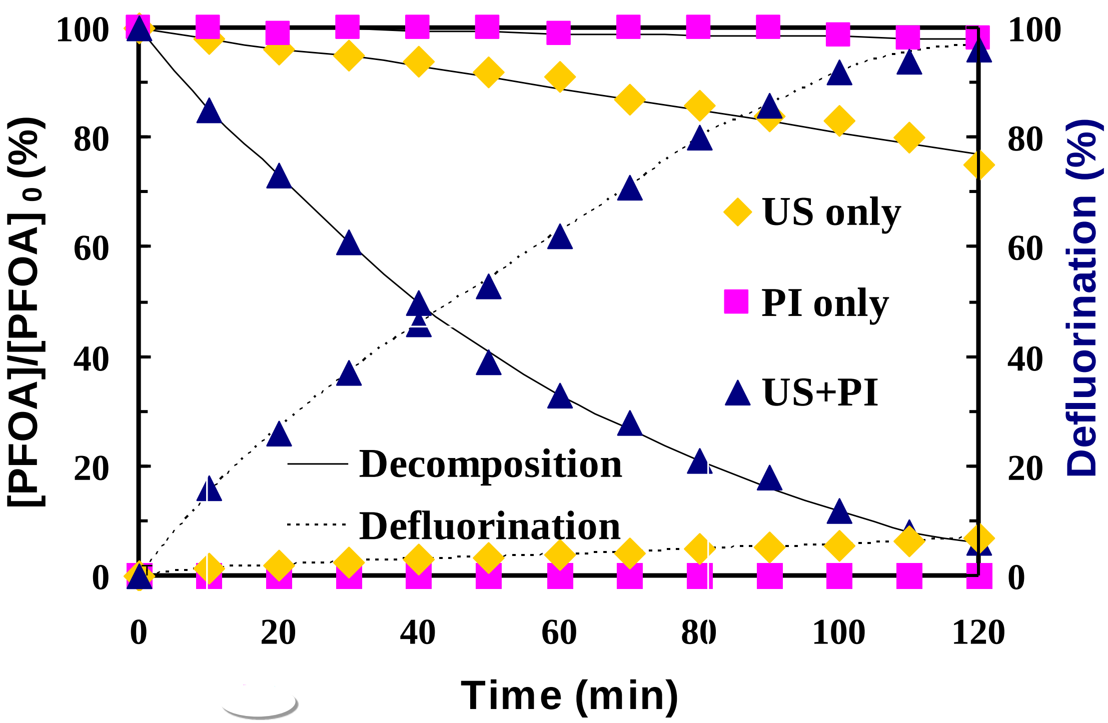
Results – sonodecomposition

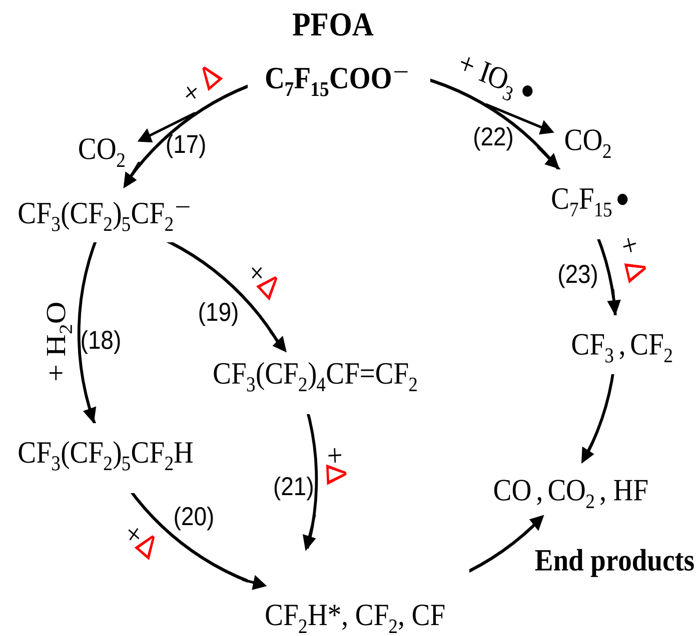
Decomposition and defluorination of PFOA



Sonochemical Degradation of PFOA Using Periodate.

■Lee. *et. al*, 2016

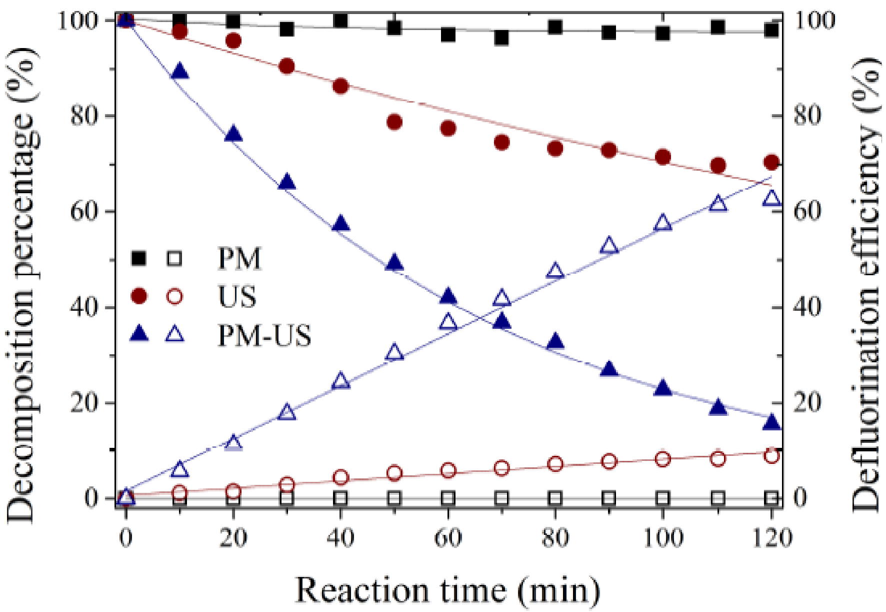


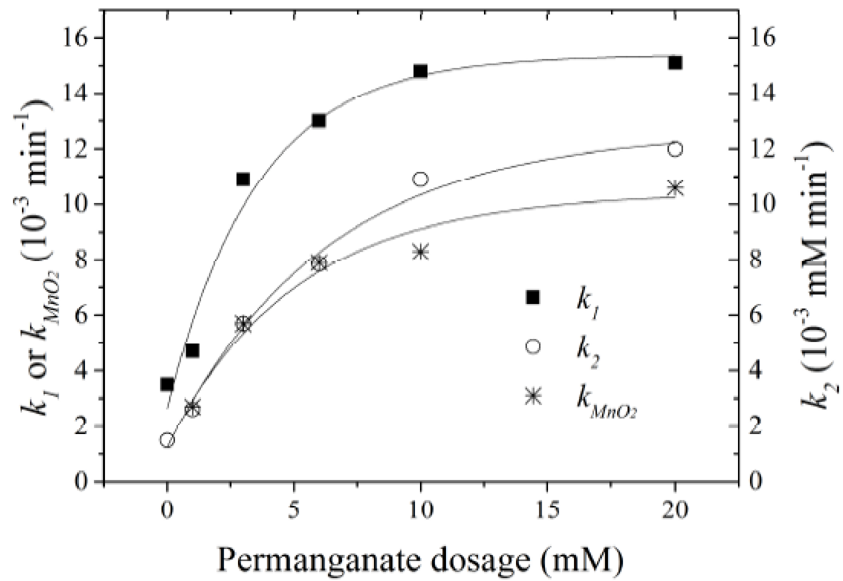


With an addition of 45 mM PI, 96.5% of PFOA was decomposed with a defluorination efficiency of 95.7% after 120 min of sonolysis.

Autocatalytic degradation of dissolved PFOA in a permanganate-ultrasonic system.

Hu. *et. al*, 2018





After a 120-min ultrasonication, a PM dosage of 6 mM increased the pseudo first-order rate constant ("k_1") for PFOA decomposition from 3.3 to 14.6×10^{-3} min^{-1} and increasedthe pseudo zeroth-orderrate constant ("k_2") for PFOA defluorination from 1.5 to 7.9×10^{-3} mM min^{-1}.

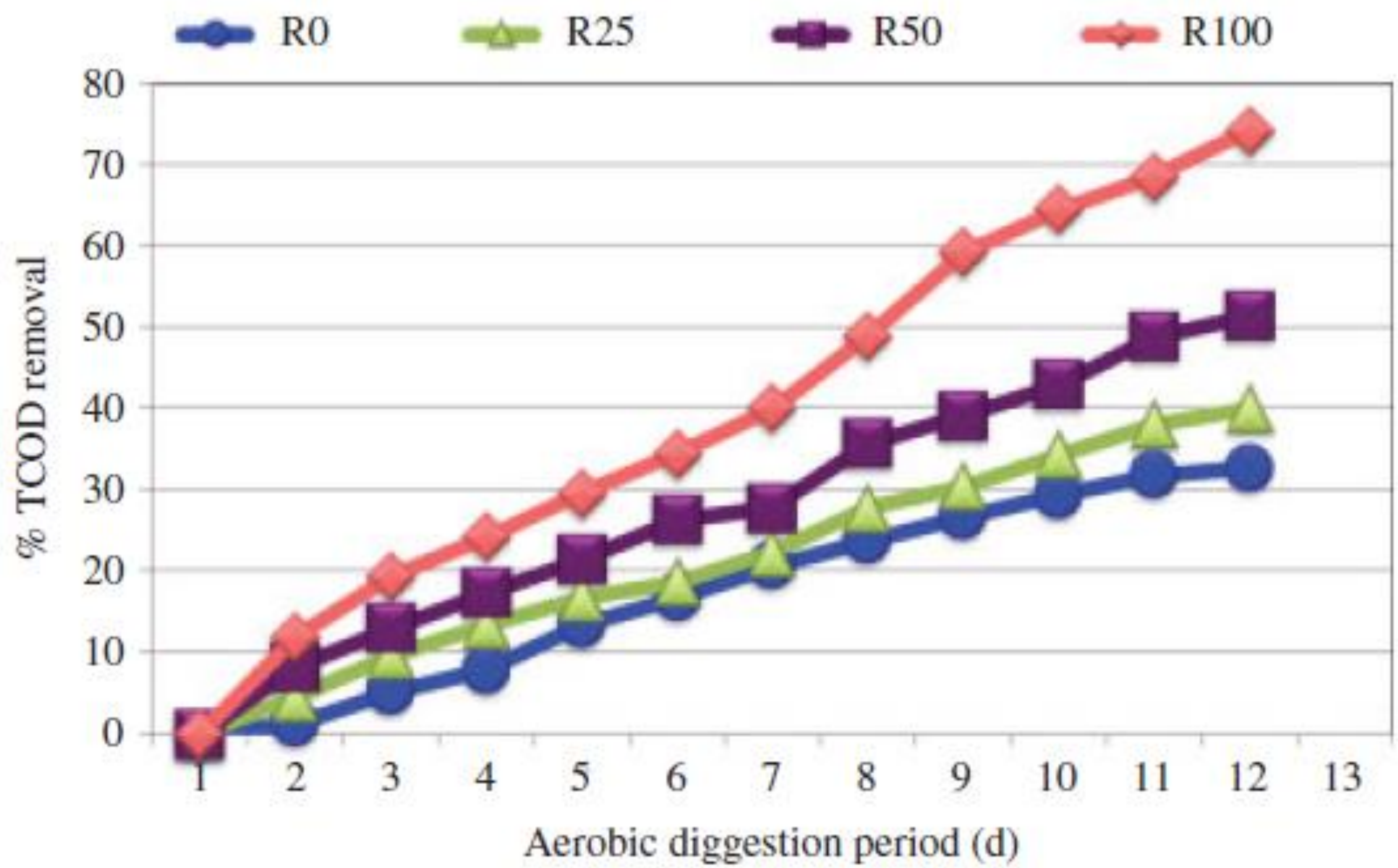


Figure 4. Effect of sono-biostimulation on TCOD reduction efficiency of aerobic digestion (optimized sonication density 0.2 W mL^{-1} and time 60 s; R_0 Control; R_{25} 25% sludge sonicated; R_{50} 50% sludge sonicated; R_{100} 100% sludge sonicated; sonication frequency every 8 h).

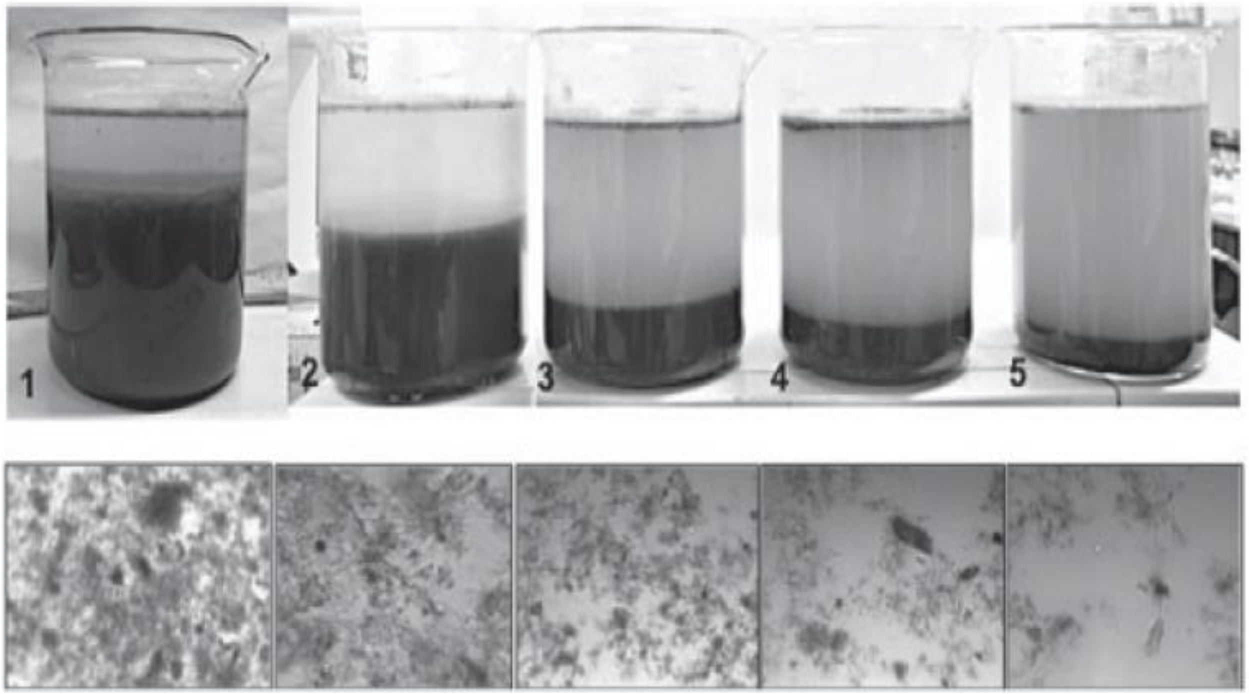


Figure 6. Sludge volume and morphology before and after 12 days of aerobic digestion: (1) raw AS; (2) control reactor sludge, R_0; (3) 25% sonicated reactor sludge, R_{25}; (4) 50% sonicated reactor sludge, R_0; (5) 100% sonicated reactor sludge R_{100}.

Methods

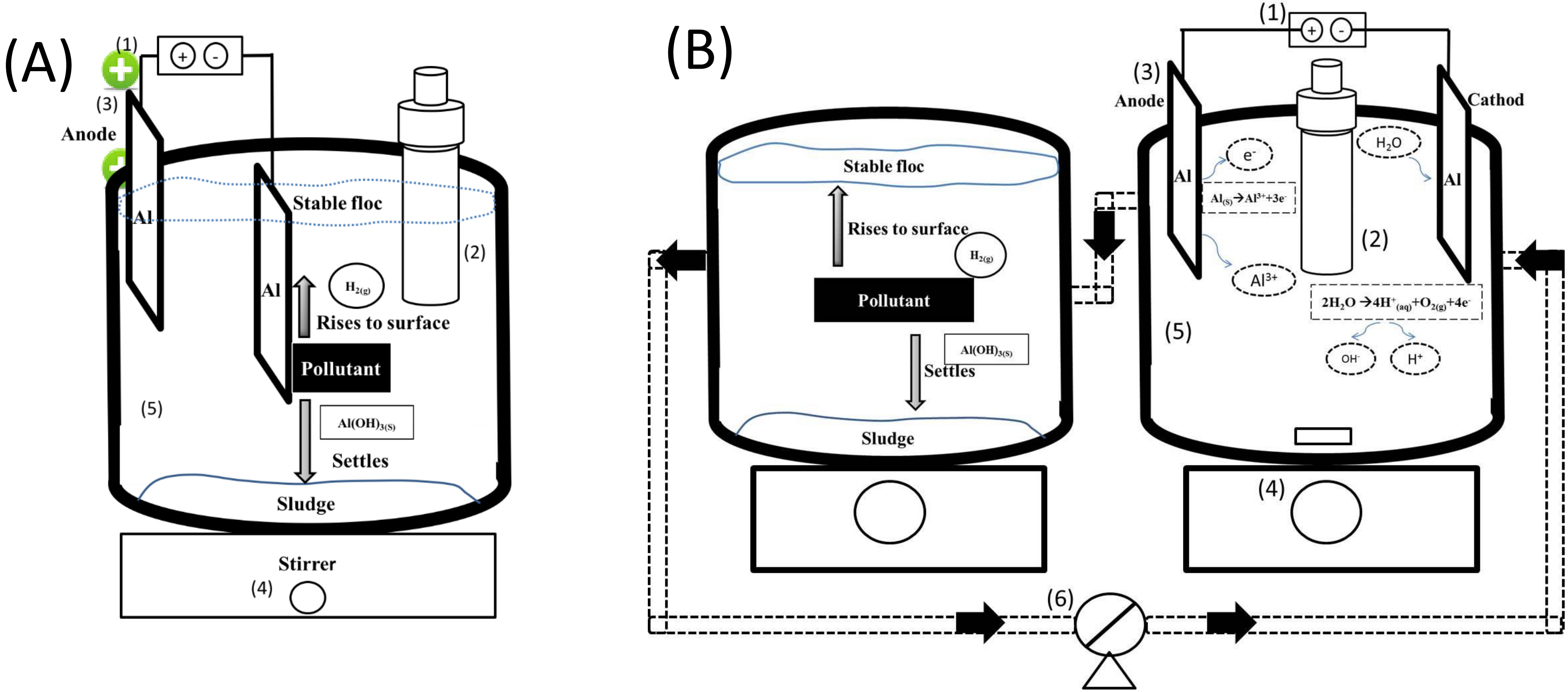


Fig. 4. Schematic diagram of the sono-EC process used in this study:
(A)Single (B) double
(1) DC power supply, (2) ultrasonic probe, (3) aluminum electrodes, (4) stirrer, (5) electrolyte solution

Results

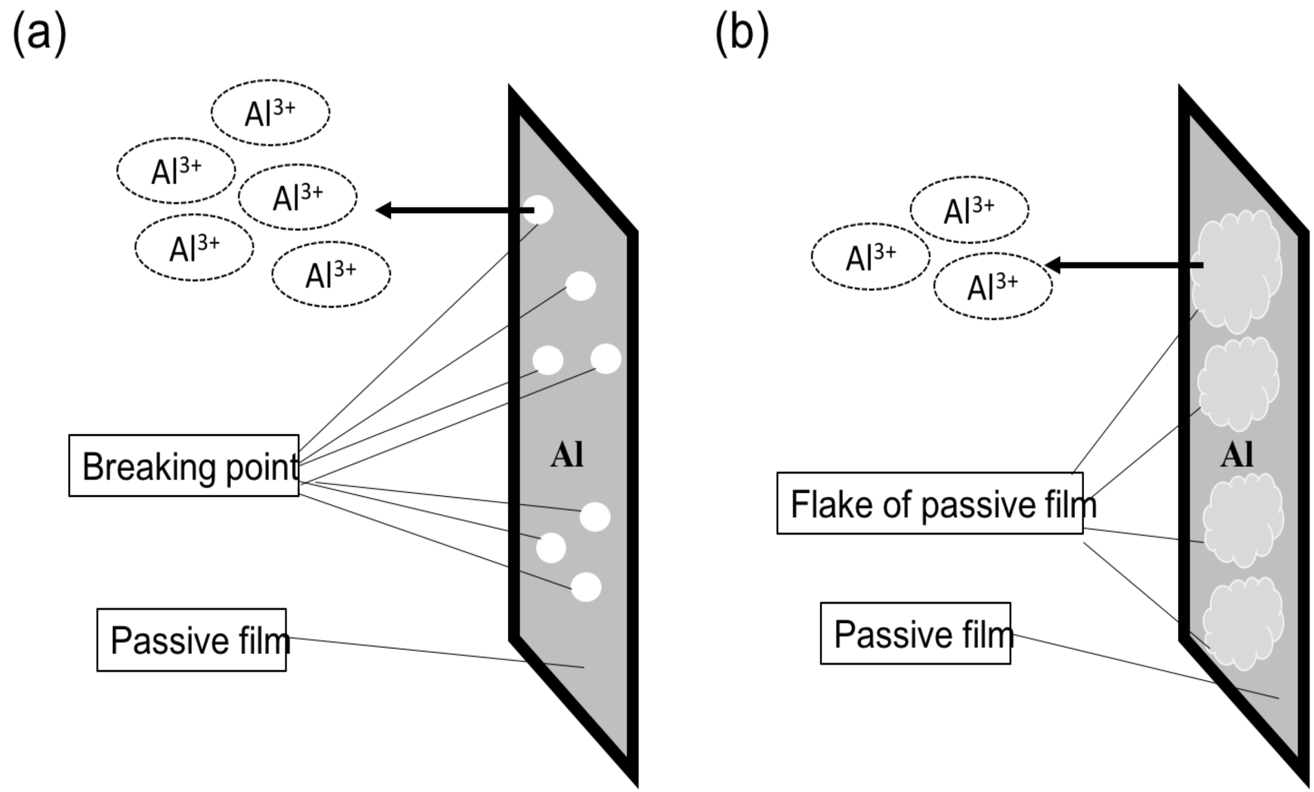


Fig. 15. Schematic diagram of aluminum anodes after different intensity of sono-EC process.
(1)low watt(under 150 W) (2) high watt (over 150)W

Results

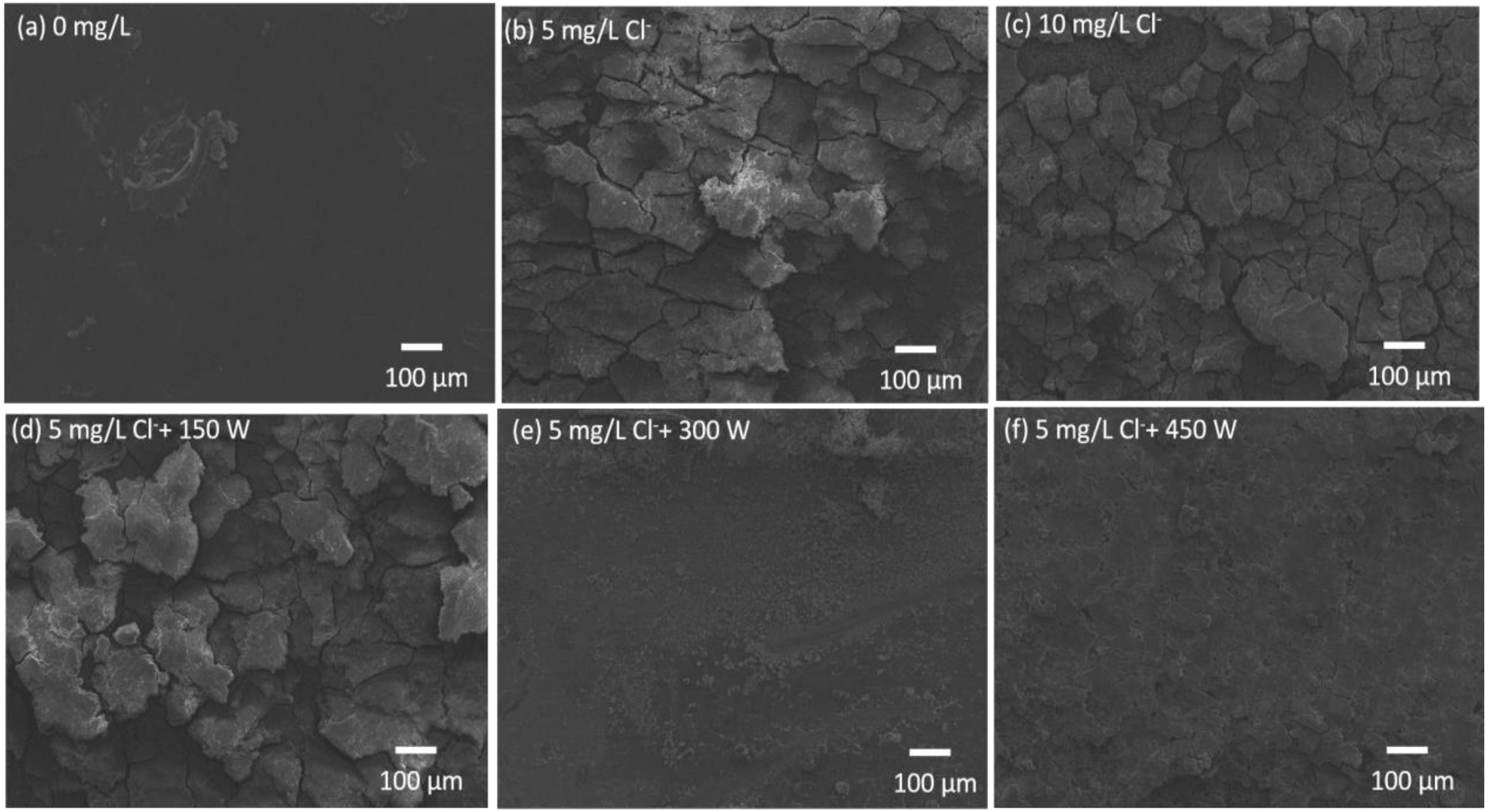
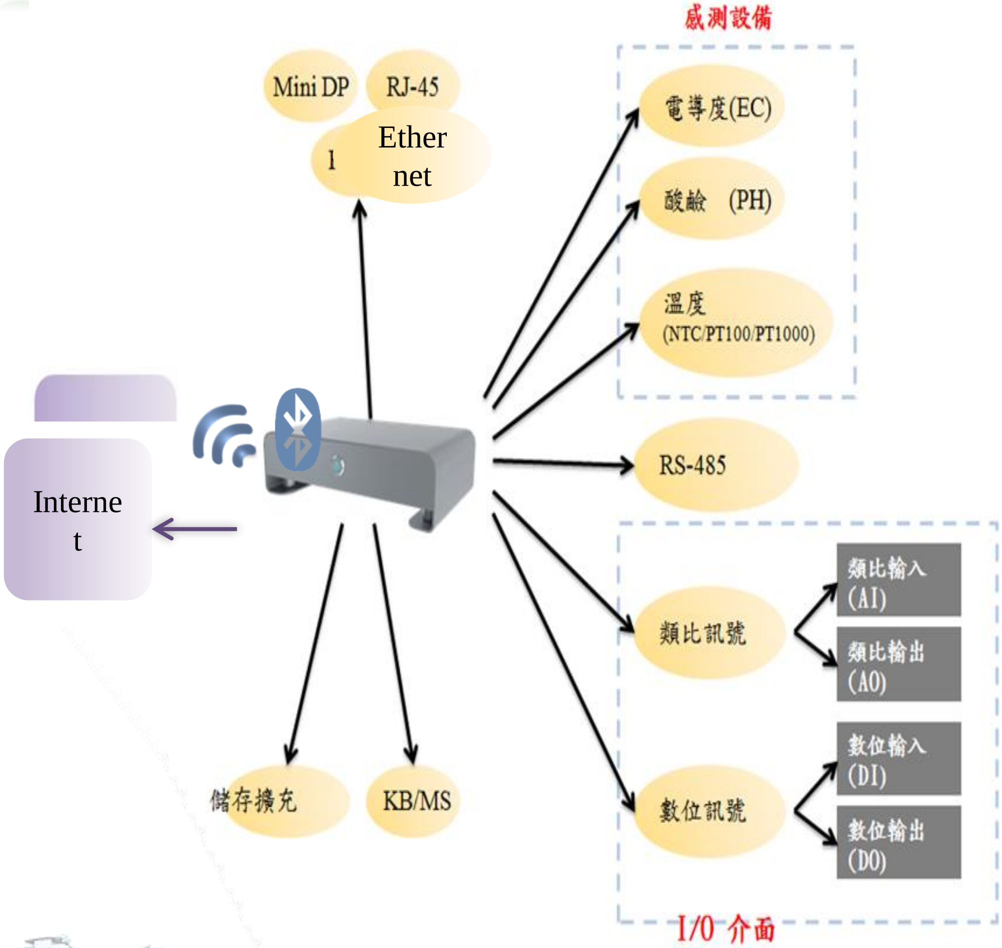


Fig. 16. Micrographs of aluminum anodes after electrolysis in solutions containing different Cl- concentrations and ultrasound (magnification: 100). Electrolyte: NaHCO3 (0.01 M) (a) 0 ppm Cl-, (b) 5 ppm Cl-, (c) 10 ppm Cl-, (d) 5 ppm Cl-+ 150 W, (e) 5 ppm Cl-+ 300 W, (f) 5 ppm Cl-+ 450 W, pH=7, V = 60 V, Time= 30 min, aluminum electrodes.

雲端智慧水環境監測技術

「雲端智慧水環境監測記錄器」為現今物聯網(IOT)趨勢應用產品，最初的外觀設計遵照「Less is More」的概念，外部捨棄非必要的細節，僅一開關按鍵及連接孔，且能防水防塵，簡約外型內部搭載多功能電子元件，以銀灰色金屬外殼強調科技感，希望扭轉一般人對於污水處理廠自動連續水質檢測系統設備連接複雜、設備繁多、無設計感等印象。

將水質感測器數據轉換、數據蒐集、監控伺服器、數據分析等眾多功能整合於同一設備，加上原有技術優點，有效降低建置成本，此系統可整合市面上各種感測器，針對不同品牌水質感測器進行整合、上傳數據並儲存數據於雲端伺服器，並應用於各類水體使用，以提供更加穩定、安全及潔淨之水質，並可減少人為疏失對於環境之影響，使用者可以透過網路連線取得主機即時監控數值，支援多系統，透過參數設定功能自行校正、能隨時查找歷史資料及放流水監測資料自動上傳，且兼具異地備援之功能，兼具數據採擷及處理系統功能。

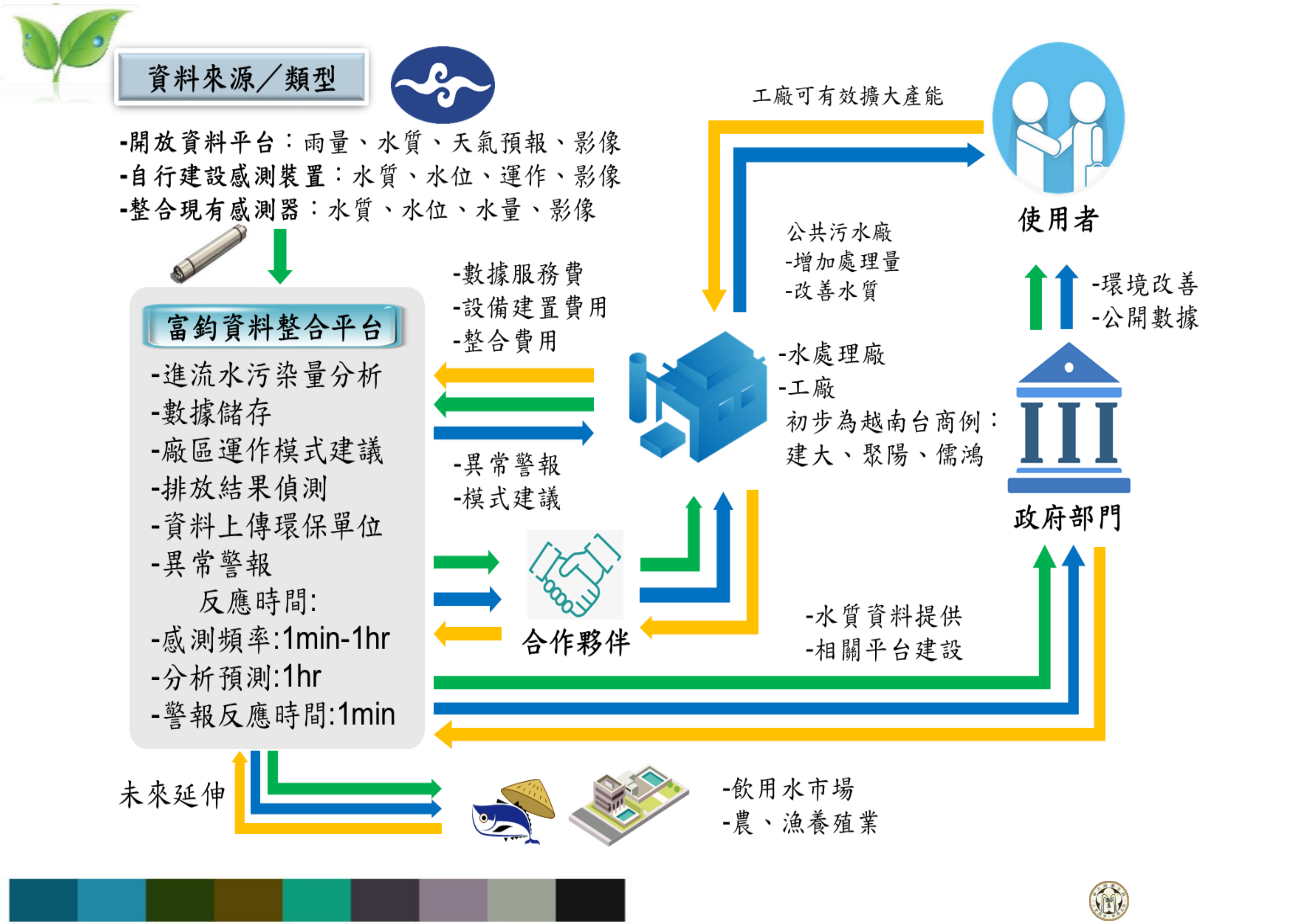


Less is More

僅一電源開關按鍵

- ✓ 金屬外殼
- ✓ 簡約造型
- ✓ 邊角圓弧造型避免接觸割傷

各式接頭標示清楚組裝容易


資料來源／類型
-開放資料平台：雨量、水質、天氣預報、影像
-自行建設感測裝置：水質、水位、運作、影像
-整合現有感測器：水質、水位、水量、影像
富鈞資料整合平台
-進流水污染量分析
-數據儲存
-廠區運作模式建議
-排放結果偵測
-資料上傳環保單位
-異常警報
反應時間:
-感測頻率:1min-1hr
-分析預測:1hr
-警報反應時間:1min
-數據服務費
-設備建置費用
-整合費用
-異常警報
-模式建議
合作夥伴
工廠可有效擴大產能
公共污水廠
-增加處理量
-改善水質
-水處理廠
-工廠
初步為越南台商例：
建大、聚陽、儒鴻
使用者
-環境改善
-公開數據
政府部門
-水質資料提供
-相關平台建設
未來延伸
-飲用水市場
-農、漁養殖業

Thank You

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National Taiwan University

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CRUNCH
The Food-Water-Energy Nexus

MOST 科技部
Ministry of Science and Technology

臺北市政府環境保護局