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廢水零排放與資源循環利用

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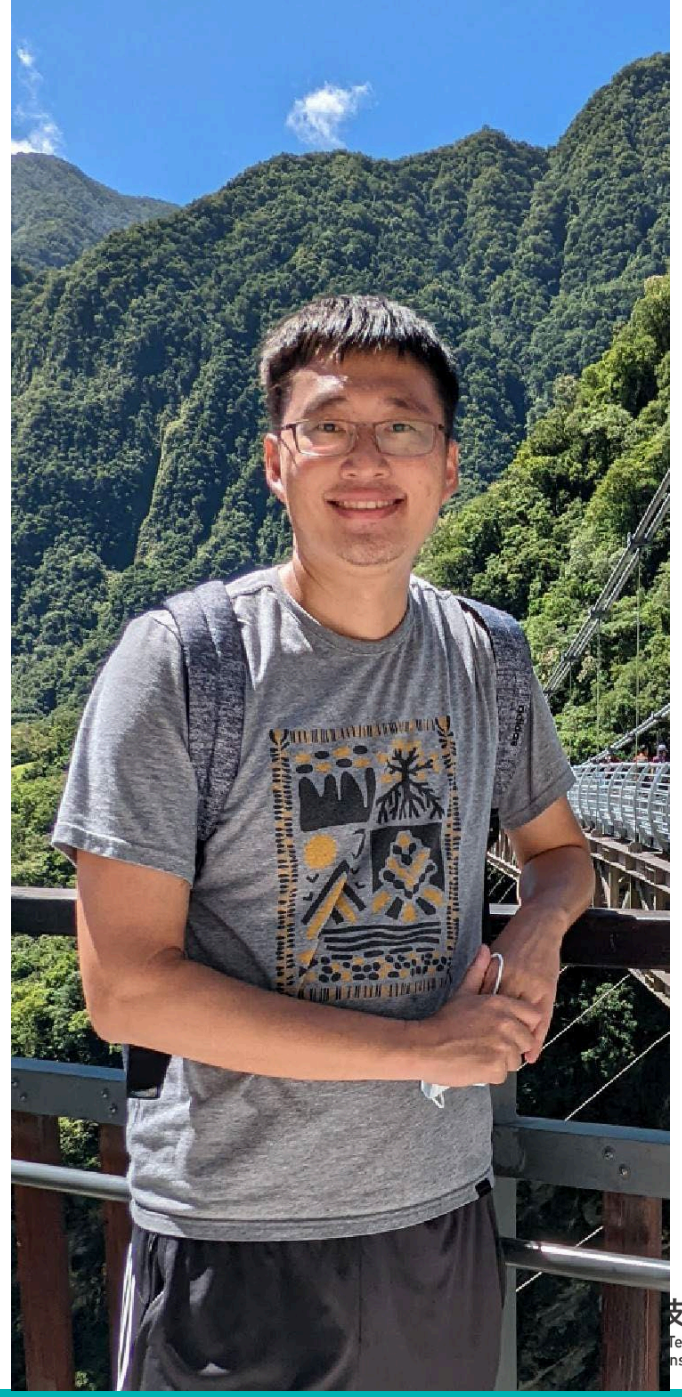
簡歷

- **學歷**
  - ✓清化大學化學系 學士 (2000-2004)
  - ✓清華大學化學系 博士 (2004-2009)

✓**經歷**

- ✓工研院材化所水科技組 研究員 (2010-2019)
- ✓工研院材化所水科技組 經理 (2020~)

- **執行研究計畫**
  - ✓CIGS濕式製程有價原料回收技術開發 (2012)
  - ✓污水處理系統之新型固態碳源微孔材料開發 (2015-2016)
  - ✓國產脫鹽濾膜與新型脫鹽系統開發 (2015-2020)
  - ✓離子篩分水裂解產酸鹼系統開發 (2020~)
  - ✓高鹽溶液零排放技術開發 (2020~)
  - ✓海淡鹵水產酸鹼技術開發 (2021~)



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廢水零排放定義

Desalination, 2022

零液體排放是指在廢水處理過程中完全消除液體廢棄物的一種技術，其目標是從含鹽進水中回收所有水分，最終僅留下固體作為廢棄物。

"Zero liquid discharge (ZLD) refers to the complete elimination of liquid waste in wastewater treatment, where all the water is recovered from the saline feed stream, leaving only solids as waste."

Nature reviews clean technology, 2025

零液體排放是一項關鍵的鹵水管理策略，其目標是去除或回收100%的水分，並將鹽晶體作為固體廢棄物處理或作為**可加值利用的資源加以回收**。

"Zero liquid discharge (ZLD) is a critical brine management strategy that aims to remove or recover 100% of the water and obtain salt crystals as either a solid waste for disposal or a resource for valorization."

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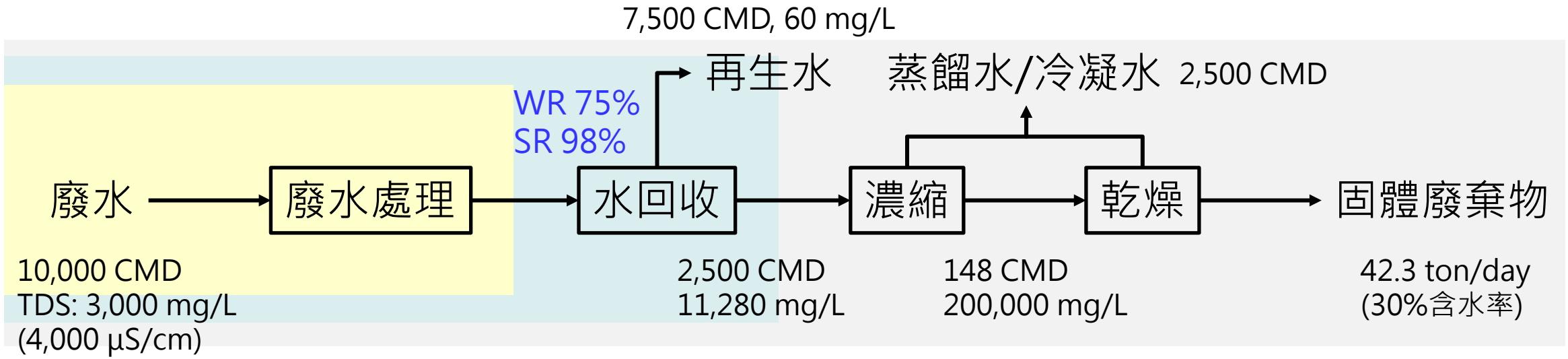
廢水零排放程序



程序	廢水處理	水回收	廢水零排放 (佔比)
水量 (m^3/day)	10,000	10,000	10,000
能耗 (kWh/day)	10,000	21,250	139,156 (84.7%)
單位處理能耗 (kWh/m^3)	1.0	2.1	13.9
電費 (NTD/day)	50,000	106,250	695,780
廢棄物清運費 (NTD/day)	0	0	211,500
總花費 (NTD/day)	50,000	106,250	907,280 (88.3%)

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實施廢水零排放動機

用水需求

- 淡水資源短缺日益加劇
- 對淡水的需求持續上升
- 尋找替代水源
- 同時回收水及其他有用資源

大眾環境意識

- 大眾對鹵水排放不良影響的認知日益提高
- 針對鹵水排放採取更嚴格的法規限制，包含導電度、TDS或特定污染物 (PFAS, 新興污染物等)

回收有價資源

鹵水排放法規標準

實施廢水零排放目標及好處

1. 水源廠內自主
2. 降低工廠營運風險
3. 降低廢棄物排放體積
4. 降低環境衝擊
5. 降低廢棄物管理成本
6. 降低健康風險
7. 提高環境效益

https://hk.xfastest.com/99404/tsmc-supply-water-from-waterwheel/

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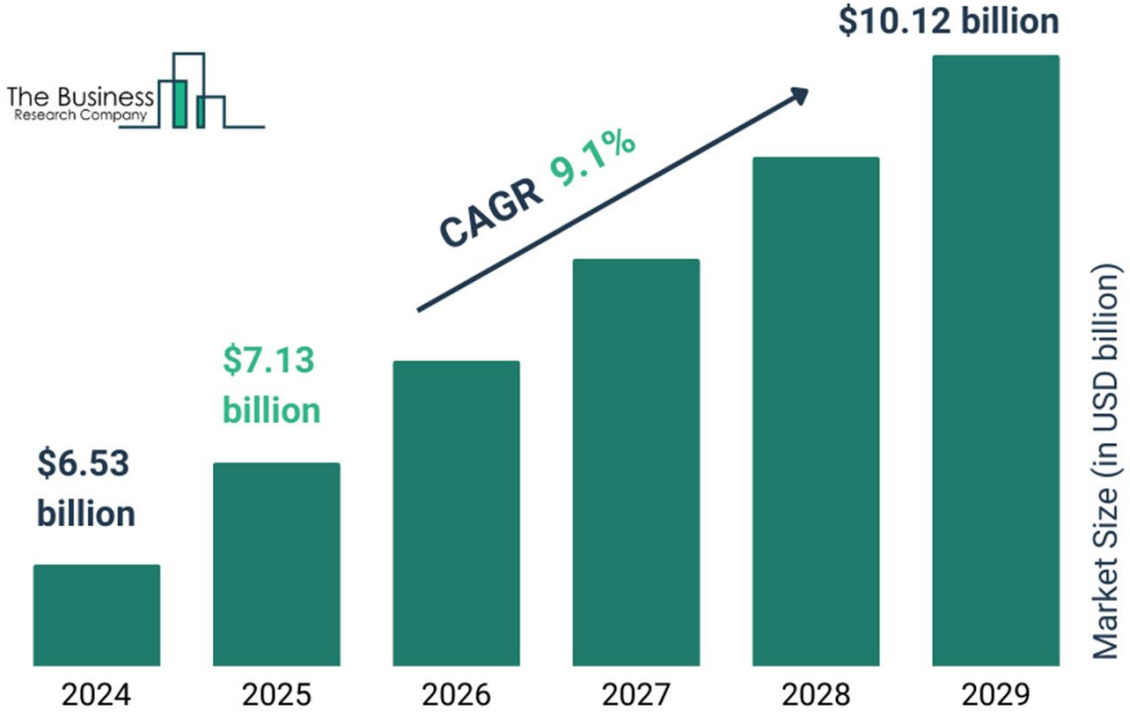
ZLD國際市場趨勢

- 2024年全球零排放市場達65.3億美元，每年以9.1%成長，預估2029年達到101.2億美元。
- 全球零排放市場以亞洲 (中國、印度)最大，其他為北美 (美國)、中東、歐洲。



Key players:

- Veolia Water Technologies (FR)
- IDE Technologies Ltd (IL)
- Toshiba Infrastructure Systems & Solutions Corporation (JP)
- Doosan Hydro Technology (KR)
- Lenntech B.V. (NL)
- Saltworks Technologies Inc (CAN)
- Aquatech International (US)

https://www.thebusinessresearchcompany.com/report/zero-liquid-discharge-systems-global-market-report

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全球零排放地圖

美國 (1972, Clean Water Act.)
火力電廠、石化、採礦、化工

歐洲
義大利 染整業、金屬加工
德國 化工

中東地區
未明確立法要求ZLD，
但因水資源缺乏，產業
自主實施
(沙烏地阿拉伯最積極)

中國 (2005, 中國節水技術政策大綱)
煤化工、火力發電
印染園區 (江蘇、浙江)

印度 (2014, Namami Gange Programme, 潔淨恆河旗艦計畫)
紡織染整、皮革、化學與染料

南美
巴西 染整、造紙
智利 礦業

南非
電廠、礦業

澳洲
礦區推動中

美國

- 1972-淨水法案，目標全面禁止污染物排放至水道。
- 1974-EPA發布蒸汽電力發電產業排放限制指南 (2024-Steam Electric Power Generating Effluent Guidelines, ELGs, 40 CFR Part 423)，規範電廠廢水排放標準。
- Clean Water Act第306條，要求新設施(New Source Performance Standards, NSPS)採用「最佳可行控制技術」(Best Available Demonstrated Control Technology, BADCT)。

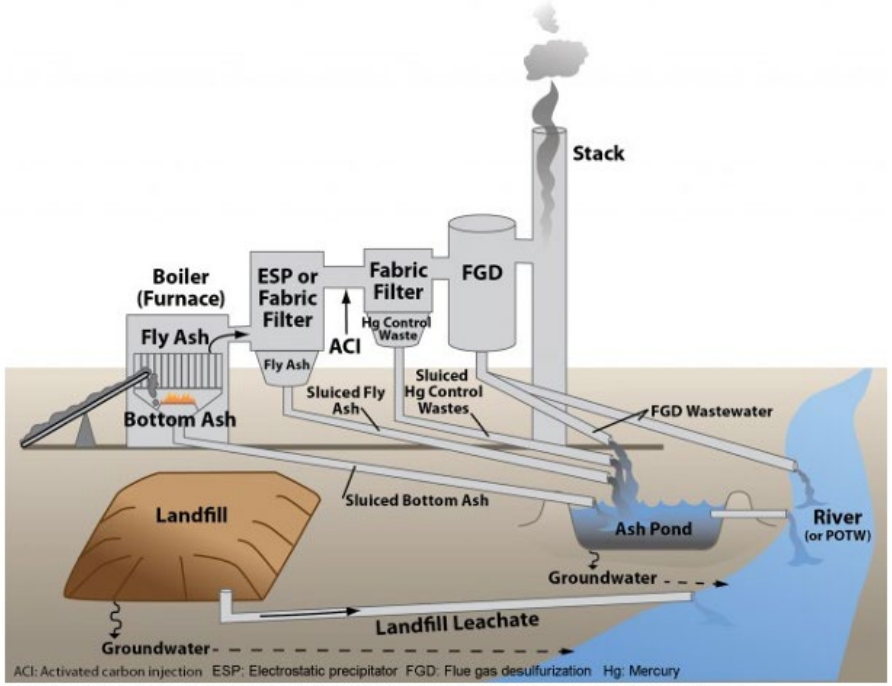

Diagram 1. Key wastewaters produced by coal-fired steam electric power plants.

Steam Electric Power Generating Effluent Guidelines - 2024 Final rule

This regulation establishes a zero discharge of pollutants limitation for three wastewaters generated at coal-fired power plants: flue gas desulfurization (FGD) wastewater, bottom ash transport water (BATW), and combustion residual leachate (CRL).

美國有146座燃煤電廠實施廢水零排放。

(Electric Power Research Institute (EPRI), Summary of Zero Liquid Discharge Water management Installation at U. S. Power Plants, 2008)

https://www.epri.com/

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中國

- 2005 發布中國節水技術政策大綱。” 3.1.3 发展外排废水回用和“零排放”技术。鼓励和支持企业外排废（污）水处理后回用，大力推广外排废（污）水处理后回用于循环冷却水系统的技术。在缺水以及生态环境要求高的地区，鼓励企业应用废水“零排放”技术。”
- 2007 國家環境保護十一五規劃通知。” 在钢铁、电力、化工、煤炭等重点行业推广废水循环利用，努力实现废水少排放或零排放。”
- 2012 國家環境保護十二五規劃，完善環境經濟政策” 研究鼓勵企業廢水“零排放”的政策措施。”

寶鋼廣州湛江鋼鐵-2019年實施全場廢水零排放

- 寶武水務承接工程業務 (BOO)
- 設計處理水量5,000 CMD
- 程序採用UF, RO, NF, AOP, MVR處理電廠脫硫廢水、焦化廢水及納濾濃水
- 分鹽取得工業氯化鈉及硫酸鈉

https://baike.baidu.com/item/%E5%AF%B6%E9%8B%BC%E6%B9%9B%E6%B1%9F%E9%8B%BC%E9%90%B5%E6%9C%89%E9%99%90%E5%85%AC%E5%8F%B8/4647812#reference-2
https://www.h2o-china.com/news/326174.html?utm_source=chatgpt.com
https://szztee.com/info-detail/i-95.html

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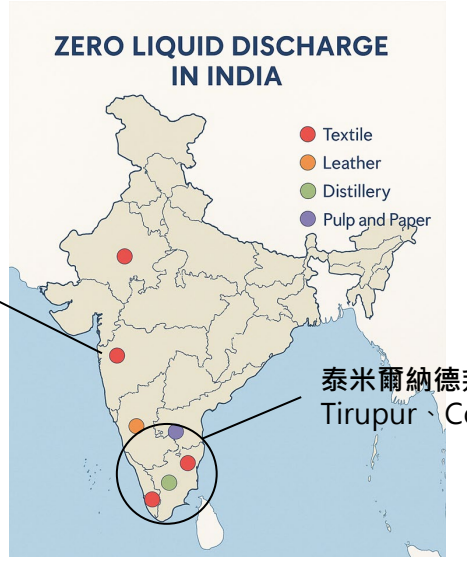
印度

- 1986 印度發布環境保護法The Environment (Protection) Act，制定環境保護規則The Environment (Protection) Rules。中央污染控制委員會（CPCB）或州污染控制委員會（SPCBs）可在環境敏感或關鍵區域，要求大型獨立工業單位實施 ZLD。

  "All efforts shall be made by the industry for zero discharge of service wastewater"

- 2015 中央污染控制委員會（CPCB）發布《水污染行業實施零液體排放技術經濟可行性指南》(Guidelines on Techno-Economic Feasibility of Implementation of Zero Liquid Discharge for Water Polluting Industries)。涵蓋紡織、皮革、釀酒和紙漿等高污染行業，旨在推動這些行業實施 ZLD 系統，以實現廢水的完全回收和再利用。



馬哈拉施特拉邦 (Maharashtra)
孟買

泰米爾納德邦 (Tamil Nadu)
Tirupur、Coimbatore、Erode

CETP (Common Effluent Treatment Plant)

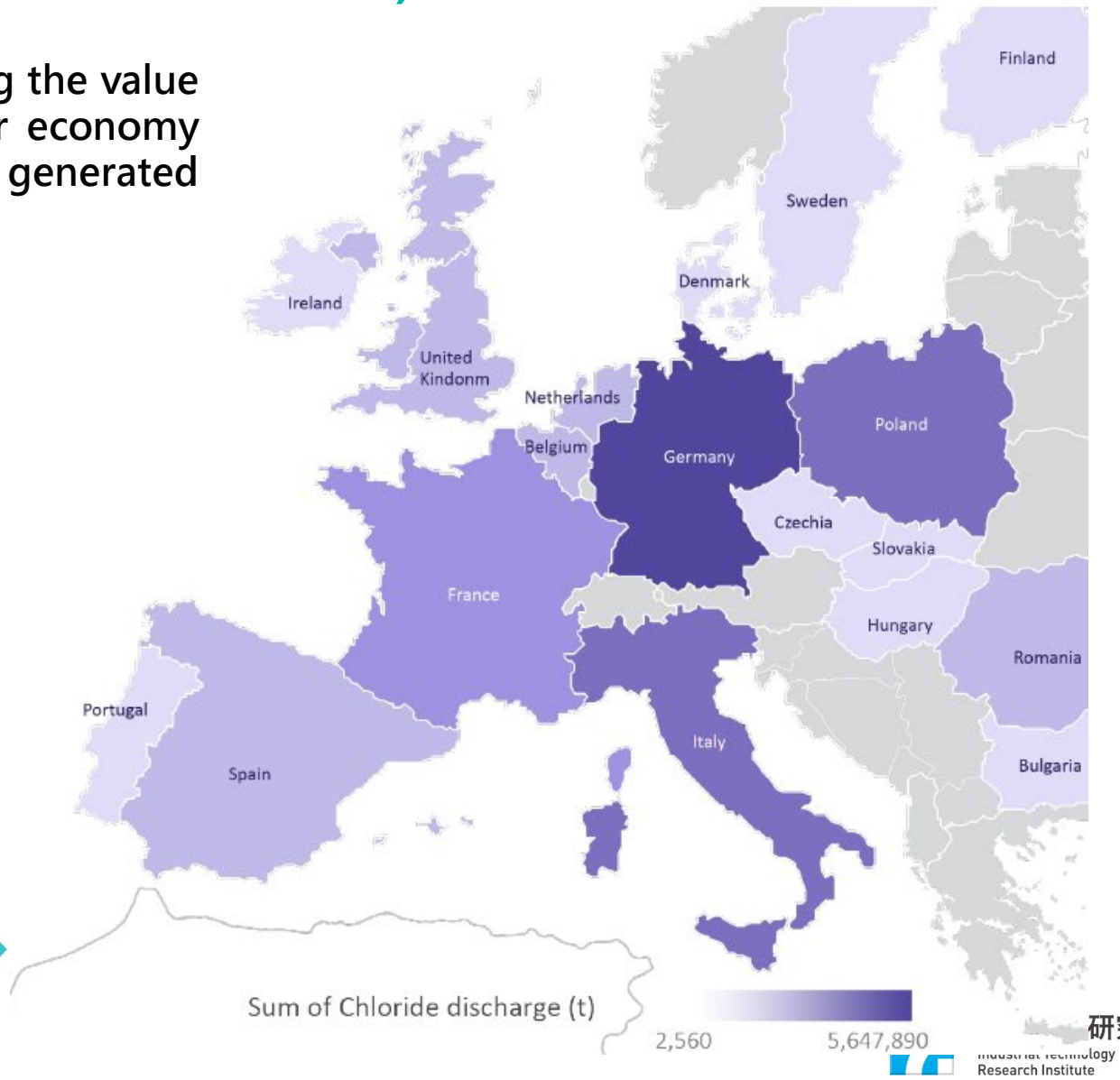
歐盟-Zero Brine Project (2017-2021)

Coordinated by TU Delft, **ZERO BRINE – Re-designing the value and supply chain of water and minerals: A circular economy approach for the recovery of resources from brine generated by process industries**

18Mt
Chloride releases (2017)

713
facilities

Industrial Wastewater | Resource Recovery | Circular Economy



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THE ZERO BRINE PILOT PROJECTS

Demineralized Water Plant (DWP) in Botlek, an industrial port area of Rotterdam, **Netherlands**.

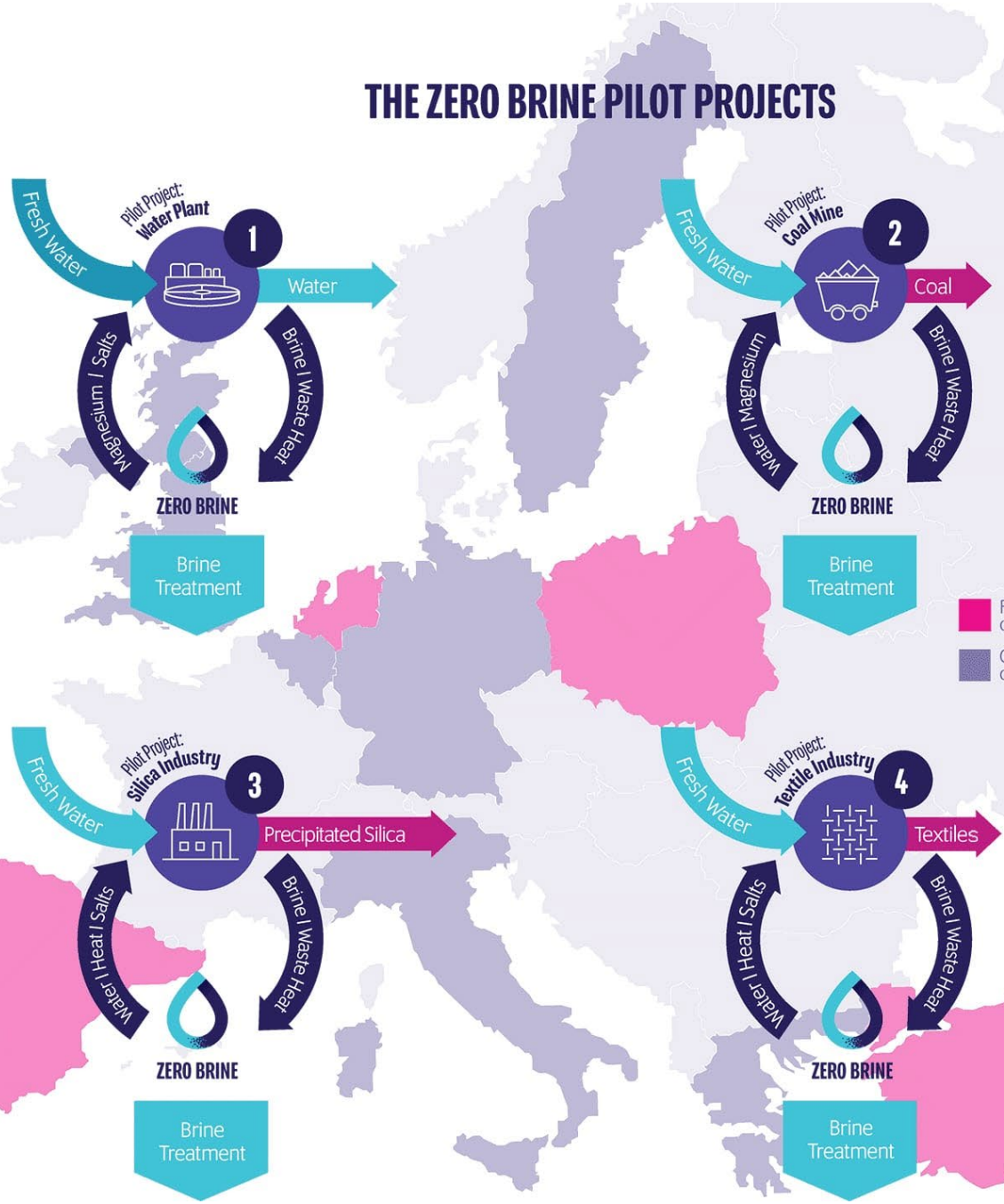
- Site I pilot treated the spent regenerant solution of the IEX unit to recover high purity **calcium, magnesium, salt, and clean water**.
- Site II will aim to use an innovative design to treat the reverse osmosis (RO) concentrate of the DWP using a combination of new and existing technologies to **recover sulphate salts, sodium bicarbonate**, regeneration solution.

(NF, EFC)

Silica industry to recover water, sodium sulphate, waste heat and alkalis in Zaragoza, **Spain**.

- First membrane-based process using tailor-made membranes produced by regenerating **end-of-life reverse osmosis (RO) elements** from desalination plants otherwise destined for a landfill.
- Treatment of the concentrate stream produced in the first stage by crystallization to achieve Zero Liquid Discharge.

(RO, BPED)



Coal mining industry in Laziska Górne, **Poland**.

- Salinity of ca. 23 g/L and rich in calcium sulphate, will be treated using integrated system consisting of nanofiltration, reverse osmosis and electrodialysis with the aim to recuperate valuable raw materials, such as concentrated brine, **magnesium hydroxide**, and high quality RO permeate.

(NF, RO, EDR, EFC)

Textile industry with the aim to recover concentrated salt solutions for reuse in the textile dyeing process baths by TUBITAK MRC in cooperation with ZORLU Textile and Energy Groups at Büyükkarıştıran- Lüleburgaz, Kırklareli, **Turkey**.

- The pilot system involves a pretreatment stage with **ozone oxidation, nanofiltration, concentration stage with reverse osmosis and, as a precaution, a softening unit by an ion exchange column**. The pilot plant is capable of treating 300 L/hr of RO retentate discharged from advanced wastewater treatment facilities of Zorlu Textile.

https://zerobrine.eu/pilot-projects/

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國際鹵水資源化計畫 (Horizon 2020)

ZERO BRINE

- €11.0 M
- Jun 2017 – Nov 2021
- Technische Universiteit Delft, Netherland

Re-designing the value and supply chain of water and minerals: A circular economy approach for the recovery of resources from brine generated by process industries

4 pilot project for industry to reach the zero brine.

water mining
value for society

- €19.1 M
- Sep 2020 – Aug 2024
- Technische Universiteit Delft, Netherland

Identifying sustainable methods for treating wastewater and obtaining alternatives sources of usable water

- Sea mining: Mg, Ca Na, Cl
- Urban mining
- Industrial mining
- Living Lab

SEArcular MINE

- €5.8 M
- Jun 2020 – May 2024
- University of Palermo, Italy (UNIPA)

*Urgent need for technological innovation, allowing for **critical raw material** production in Europe*

Extraction from SW: Mg, Li and other trace-elements (Rb, Sr, Cs, Ga, Ge, Co)

SEA4 VALUE
Mining value from brines

- €7.0 M
- Jun 2020 – Nov 2024
- Eurecat, Spain

Development of radical innovations to recover minerals and metals from seawater desalination brines

Separating, concentrating and crystallizing from seawater brine: Mg, Sc, V, Ga, B, In, Li, Mo, Rb, Ca

EBrineR

Life BRINE MINING

LIFE zerosili BRINE

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台灣廢水零排放及導電度管制

2015 桃園龍潭友達
廢水排入霄裡溪

2020 苗栗銅鑼園區
廢水排入西湖溪

https://news.ltn.com.tw/news/local/paper/931036

2018 台南新吉工業區
環評承諾零排放

2019 高雄興達電廠
FGD廢水零排放

科管局：專管可望2027年完工
竹科管理局副局長胡世民表示，銅鑼園區設置汙水專管放流入海已獲中央核定，若工程順利發包，可望於2027年完成，在完成之前，廠商排放到區內汙水廠。

工業區/科學園區	導電度限值 (μS/cm)
排入灌溉渠道	750
銅鑼園區納管 (一期)	750
銅鑼園區納管 (二期)	9,000
彰化中科二林園區納管	1,500
南科污水廠納管	16,000

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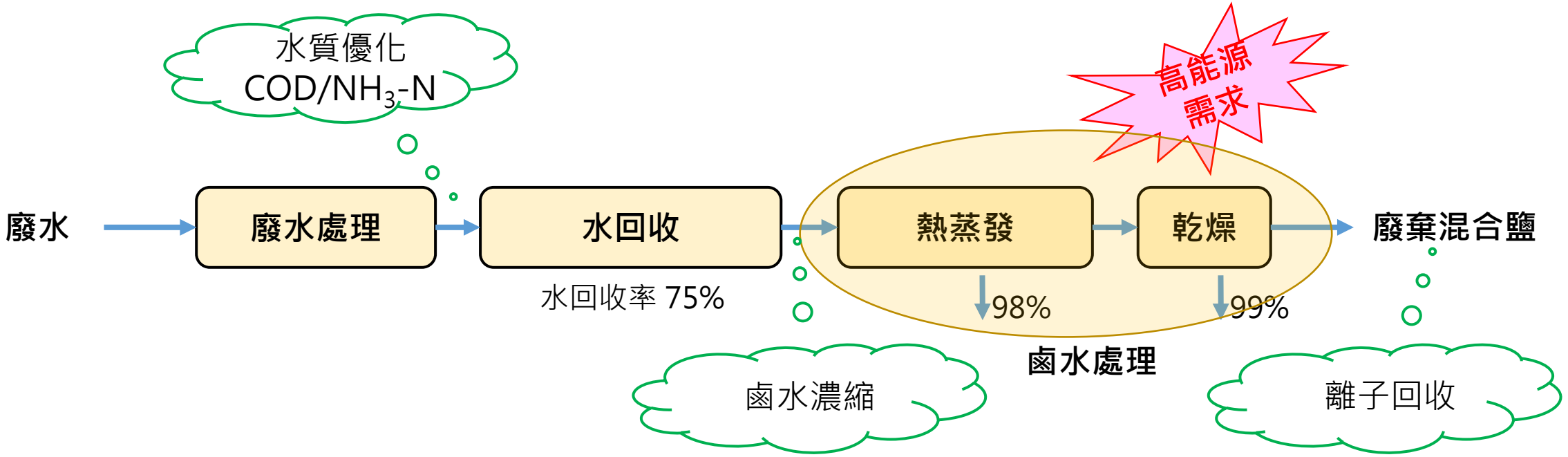
傳統廢水零排放程序



現況問題

1. 水質雜質導致程序難以穩定運轉。(合適前處理技術需求)
2. 熱蒸發程序處理量大，導致每噸水成本太高，包含系統建置及操作成本。(濃縮技術需求)
3. 廢棄混合鹽只能清運，無法再利用。(分鹽及循環技術需求)

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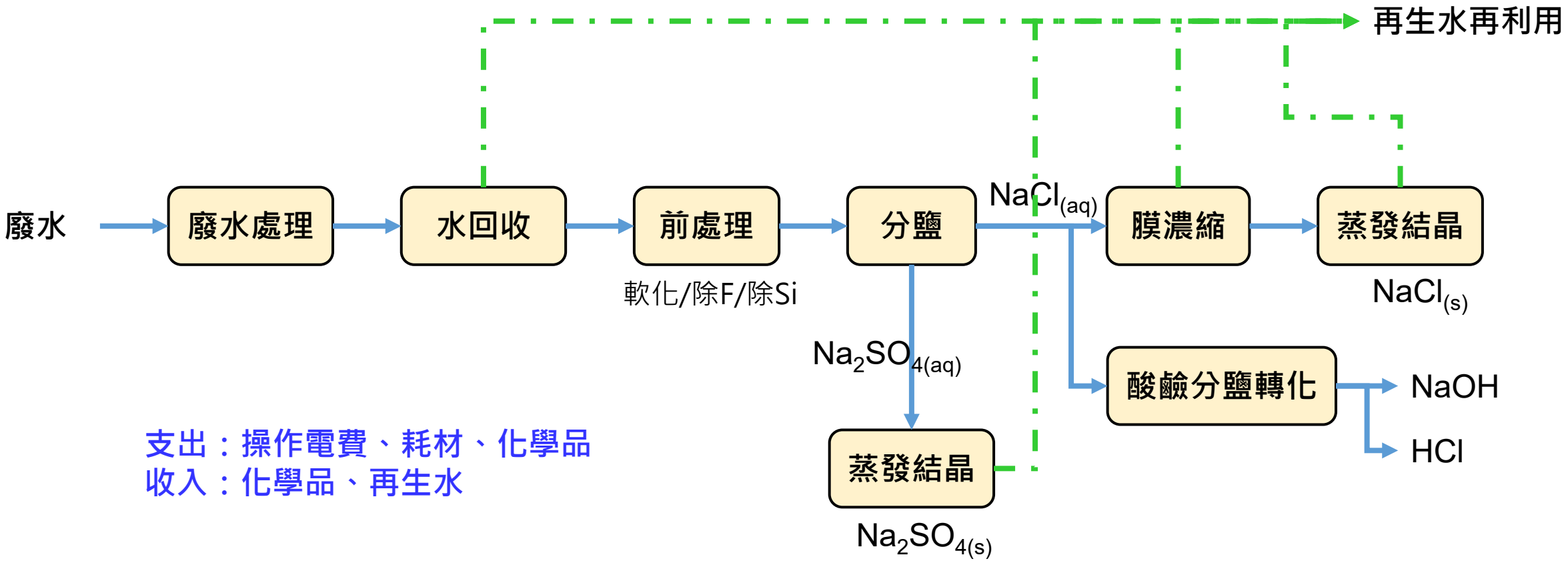
資源循環零排放系統



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實施零排放考量點

1. 高能耗、碳排
2. 高建置成本
3. 系統複雜
4. 專業操作人員
5. 化學藥品使用與副產品
6. 固體廢棄物
7. 系統運轉穩定性

https://www.auo.com/zh-TW/News_Archive/detail/News_Archive_Product_20211110

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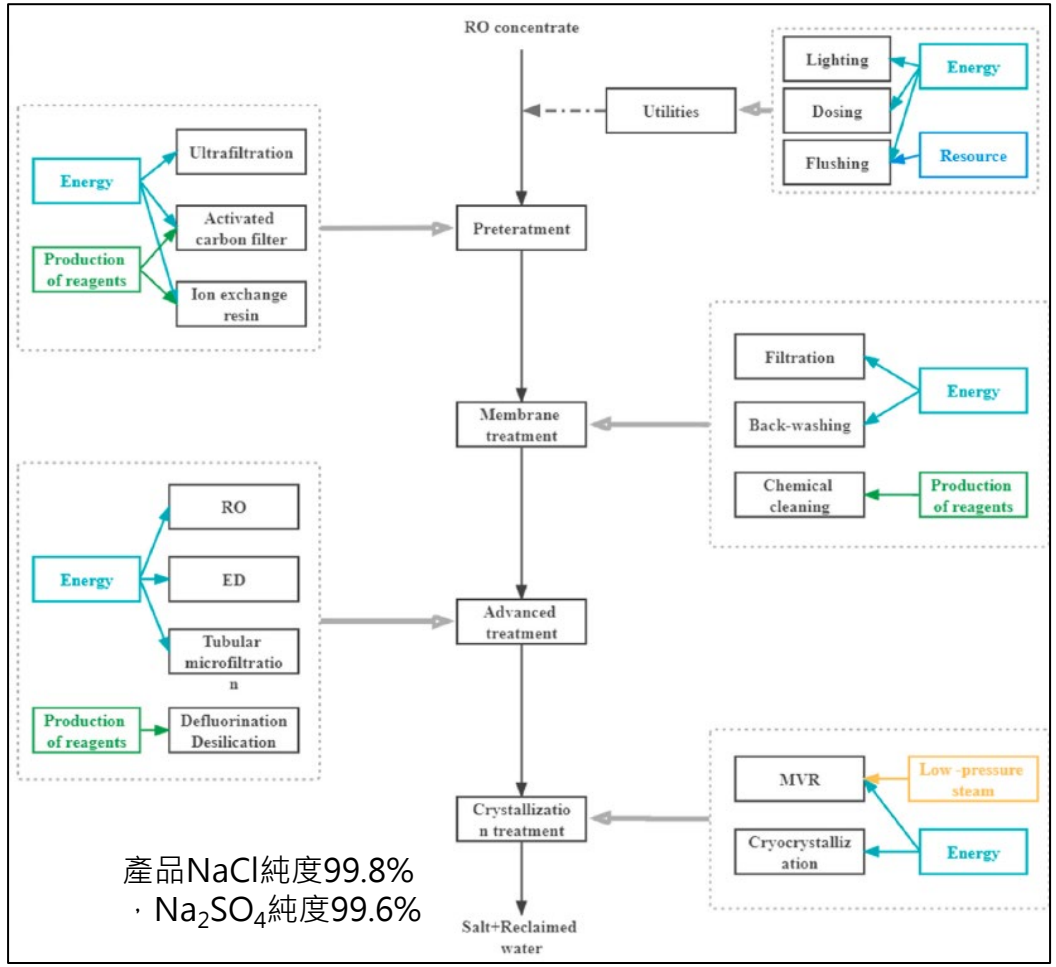
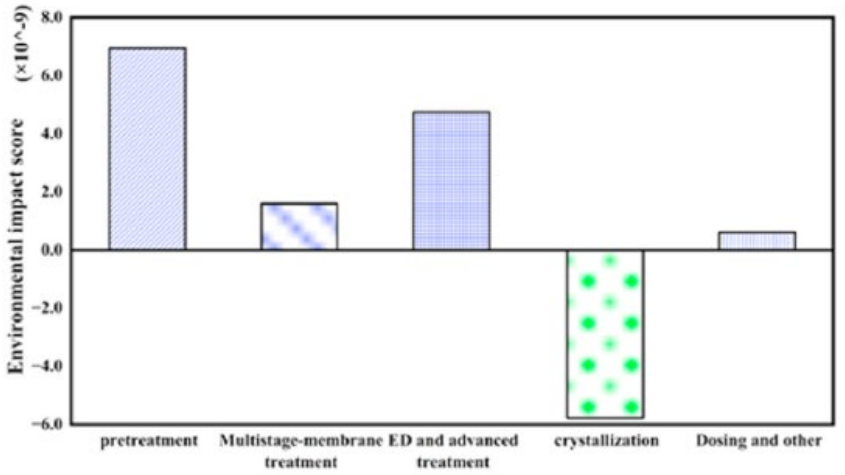
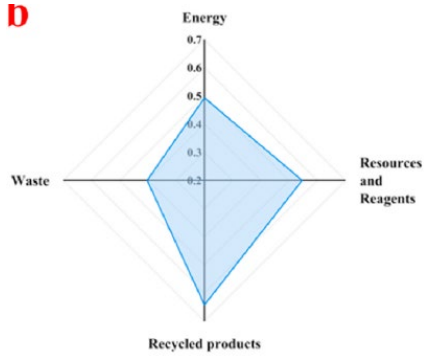
零排放環境影響評估

The consumption and output are represented by the positive and negative list data. Use the **eFootprint platform (產品碳足跡及生命週期評價與管理系統)** for statistics and editing of inventory data. Electric energy consumption is based on the thermal power generation data of the East China Power Grid. The background database is mainly based on the CLCD database, and part of the data is based on the ELCD database, the Ecoinvent database, and some research data in the eFootprint platform.



產品NaCl純度99.8%
，Na_2SO_4純度99.6%





1. 前處理主要化學品利用造成環境影響。
2. 高級處理主要為能源使用造成環境影響。
3. 結晶鹽回收可大幅抵銷能源使用環境影響。
4. 能源如能結合綠能，或者是利用能源效率高設備、程序，可讓零排放系統更加環境友善。

Journal of Cleaner Production 424 (2023) 138736

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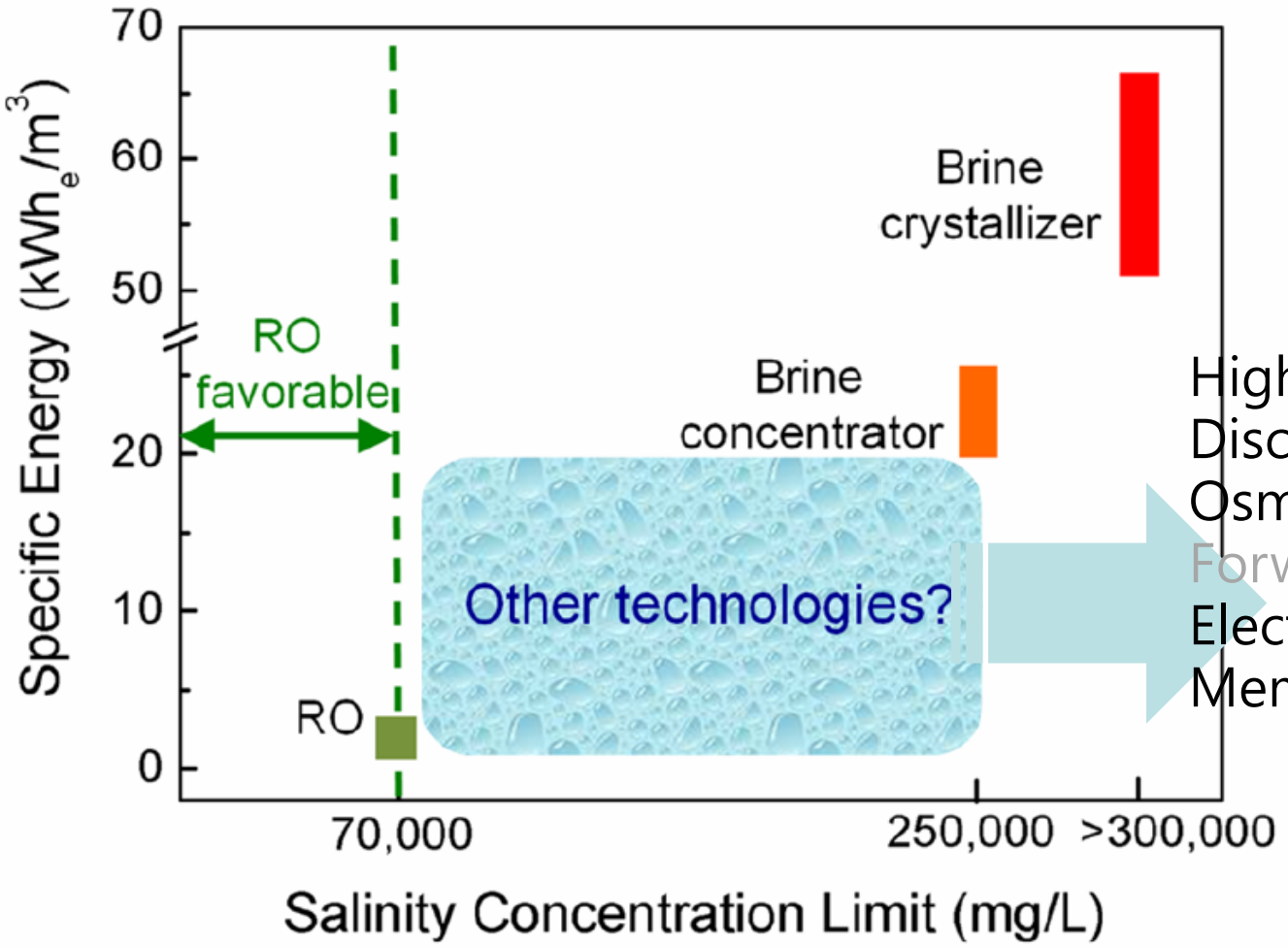
技術與能耗



High pressure reverse osmosis, HPRO
Disc tubular reverse osmosis, DTRO
Osmosis assisted reverse osmosis, OARO
Forward osmosis, FO
Electrodialysis/Electrodialysis reversal, ED/EDR
Membrane distillation, MD

Environ. Sci. Technol. 2016, 50, 6846−6855

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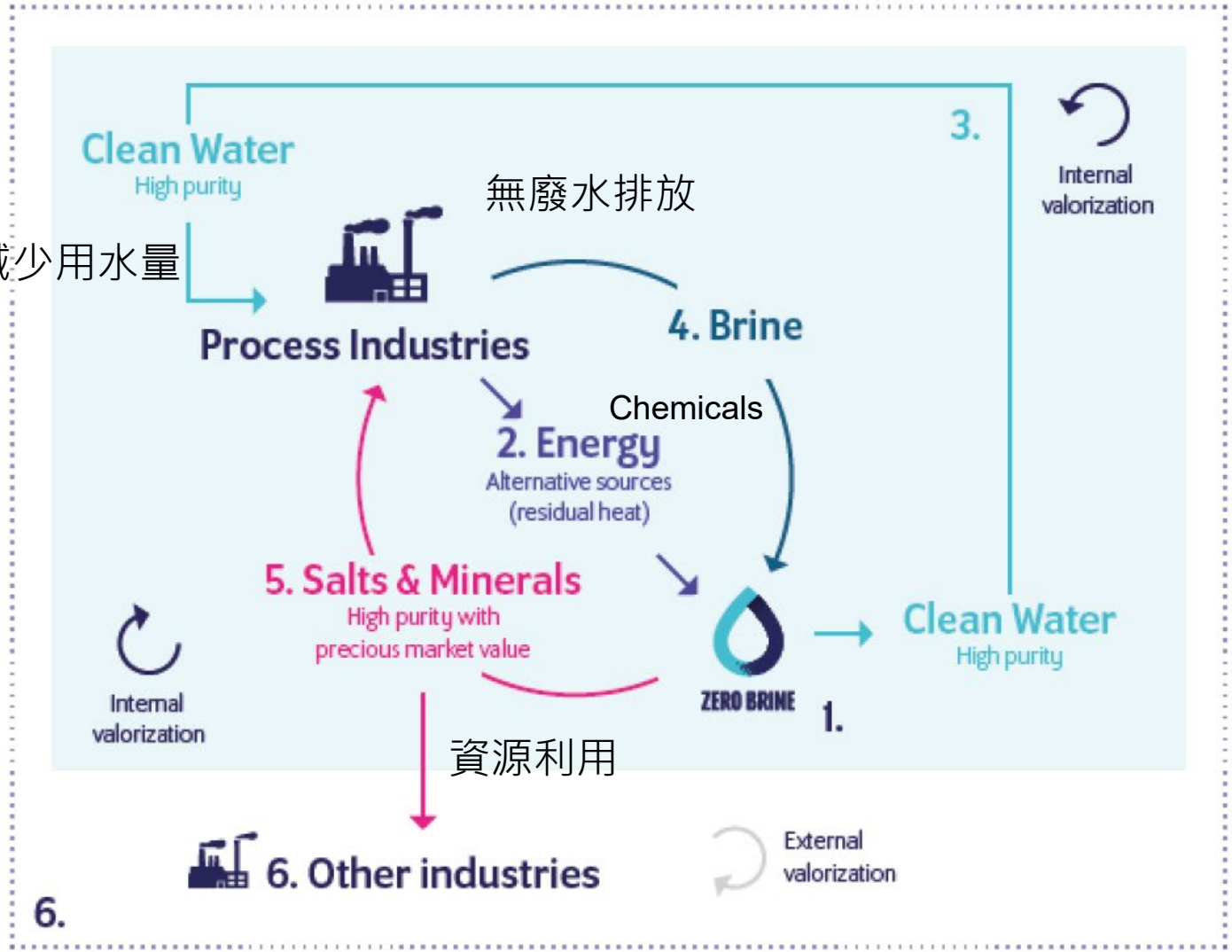
成本支出與效益分析



1. ZERO BRINE technology

- High CAPEX / Low OPEX
- Required lower energy compared to current treatment practices

2. Energy

- Alternative and cheaper energy source to reduce CAPEX

3. Clean Water

- Lower water consumption by reusing the recovered water

4. Brine

- No water required for dilution
- No brine discharge
- No environmental levies

5. Salts & Minerals

- Internal use of salts and minerals
- Trading salts and minerals as a new source of revenues

6. Other Industries

- New supply chain of water and minerals lead to lower water pollution and potentially would lead to lower carbon emission on global scale

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工研院廢水零排放完整評估方案

具備廢水零排放完整流程設計經驗，已協助國內半導體廠、鋼鐵廠完整評估零排放程序

廢水 → 預處理 → 膜分鹽及濃縮 → 蒸發 → 結晶/乾燥

廢水全分析
水回收率、水回收量、結垢潛勢與副產品組成

預處理技術評估
COD, Si, Ca, Mg, F....etc.

膜系統測試
水回收率、水質水量

蒸發系統評估

副產鹽品質評估

物料與能量平衡結算、初設與操作成本分析

管式UF

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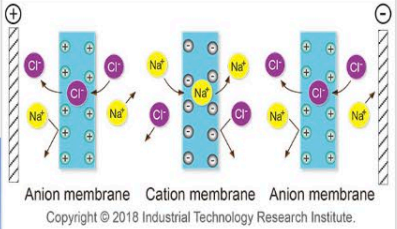

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