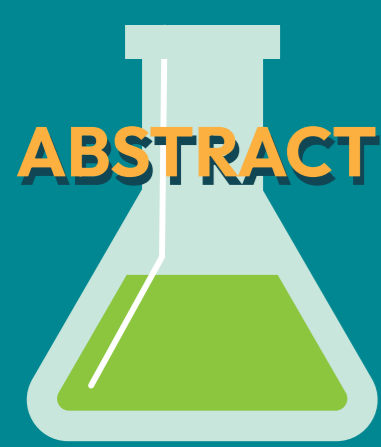


Laboratory-scale evaluation of capacitive deionisation for efficient desalination and industrial

F. Corona^{1,2}, R. Timmers¹, J. Martín-Marroquín^{1,2}, F. Berride¹, F. Burgoa¹, D. Hidalgo^{1,2}

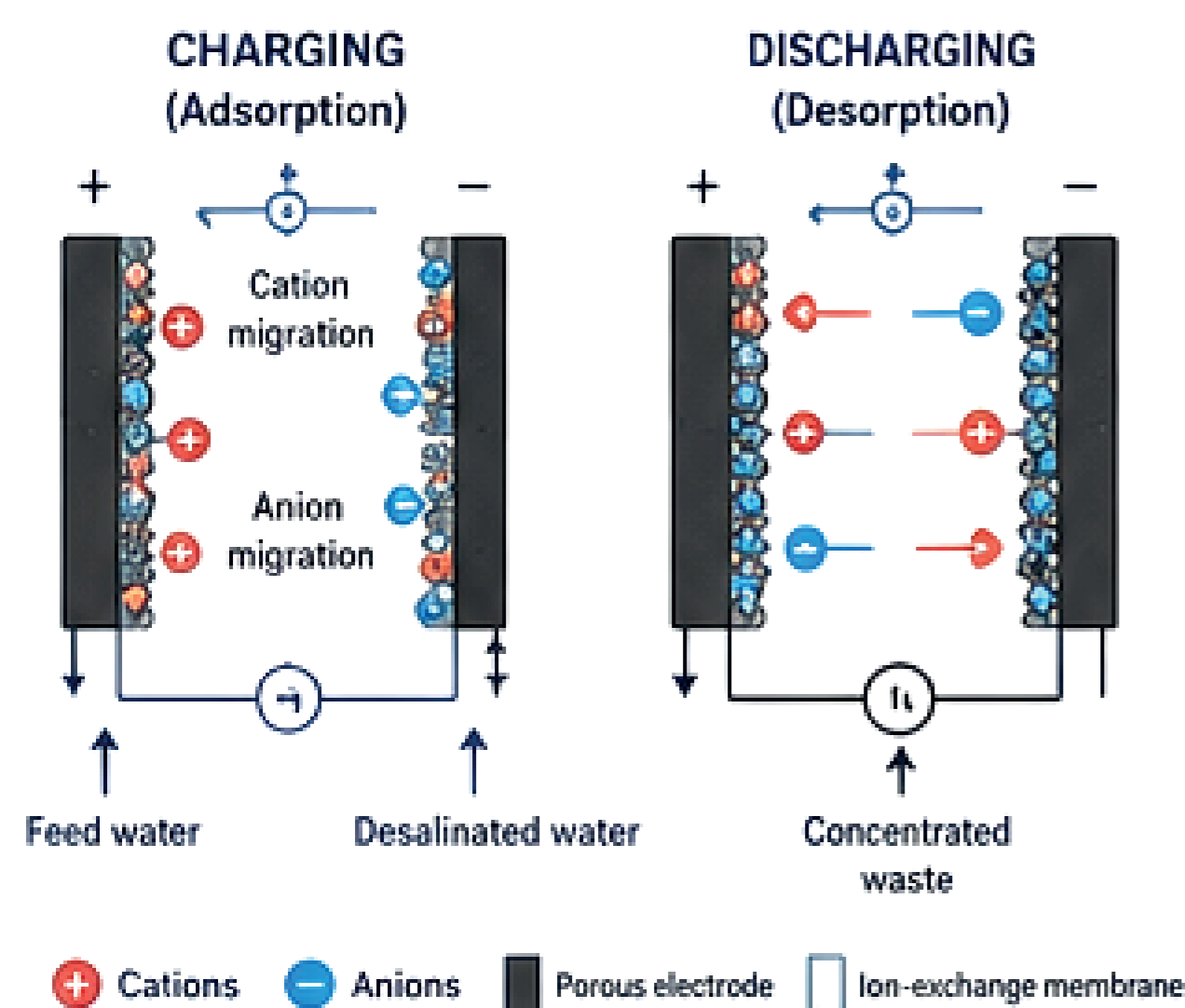
¹CARTIF Centro Tecnológico, Boecillo, Valladolid, 47151, Spain | ²ITAP Institute, University of Valladolid, Valladolid, 47010, Spain



CDI and MCDI are promising electrochemical technologies for low-to-moderate salinity water desalination. Compared with reverse osmosis and electrodialysis, these systems offer lower energy consumption, low-voltage operation, selective ion removal, and energy recovery potential. Recent advances in electrode materials, reactor configurations, and AI-driven optimization have improved salt adsorption capacity, selectivity, and operational stability. However, membrane fouling, electrode degradation, scalability limitations, and reduced performance at high salinity remain major challenges. Current technology readiness is estimated at TRL 5–7, with pilot-scale demonstrations and emerging niche applications.

1 CDI & MCDI BASICS

- Electrostatic adsorption removes ions from water.
- MCDI uses ion-exchange membranes to improve selectivity.
- Charging = ion adsorption;
→ Discharging = regeneration (ion desorption) and energy recovery)



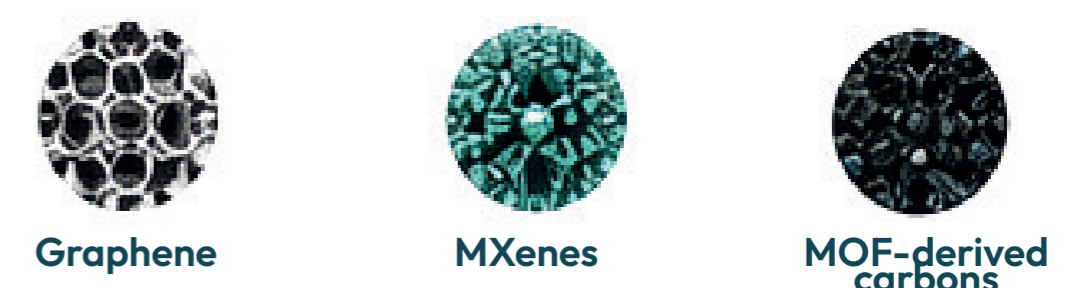
2 KEY ADVANTAGES

- Low energy consumption**
0.1 – 0.2 kWh/m³ for brackish water vs
0.9 – 1.6 kWh/m³ for reverse osmosis [1]
- Low operating voltage**
~1–1.4 V [2]
- Ambient-pressure operation** [1,2]
- Selective ion removal** [3,4]
- Potential for energy recovery** [1,5]

3 RECENT ADVANCES

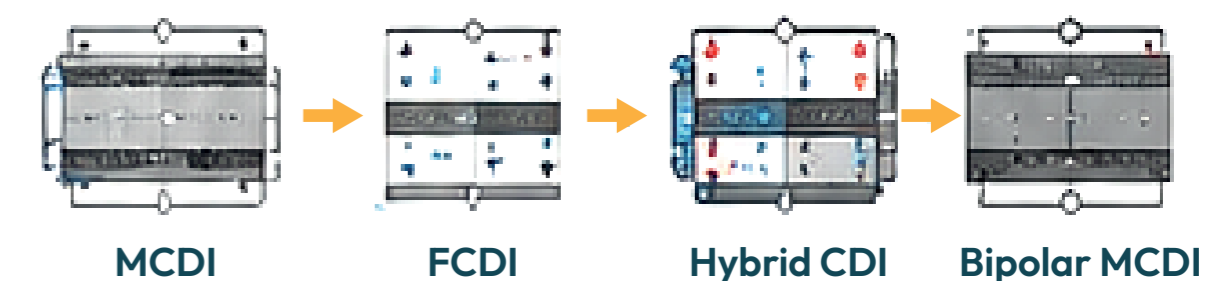
Advanced Electrode Materials improve SAC, stability, and selectivity

Graphene, MXenes, MOF-derived carbons



Advanced System Architectures enhance efficiency and enable continuous operation

MCDI, Flow-electrode CDI (FCDI), Hybrid CDI, Bipolar MCDI



Data-Driven Optimization of operation

AI and machine learning, Predictive Modelling, Process Optimization, Material Screening



4 APPLICATIONS

Brackish water desalination
Low to moderate salinity waters (< 5 g/L TDS)

Resource recovery
Li⁺ NH₄⁺ PO₄²⁻ K⁺ Mg²⁺ etc.

Water softening
Ca²⁺ Mg²⁺

Very Heavy metal removal

Industrial wastewater treatment: Polishing and reuse applications

Selective ion removal

5 CURRENT TRL STATUS

CDI and MCDI technologies are currently estimated at TRL 5–7. Most systems are at pilot-scale demonstration level with early commercial niche applications.

Technology	Current Status	Typical TRL
Conventional CDI	Pilot-scale, niche commercial systems	5–6
MCDI	More mature, pilot demonstrations	5–7
FCDI	Early pilot stage	4–5
Hybrid/Selective CDI Systems	Lab & pilot validation	3–5

TRL Scale (Technology Readiness Level)



Overall: CDI & MCDI are emerging technologies at TRL 5–7, transitioning from laboratory research toward pilot-scale deployment and early commercialization.

6 FUTURE OUTLOOK

High salinity Limitation
Lower salt adsorption and efficiency at high salinity operation [1,2,5]

Electrode degradation:
Faradaic reactions at higher voltages cause carbon oxidation and capacity loss [3,4]

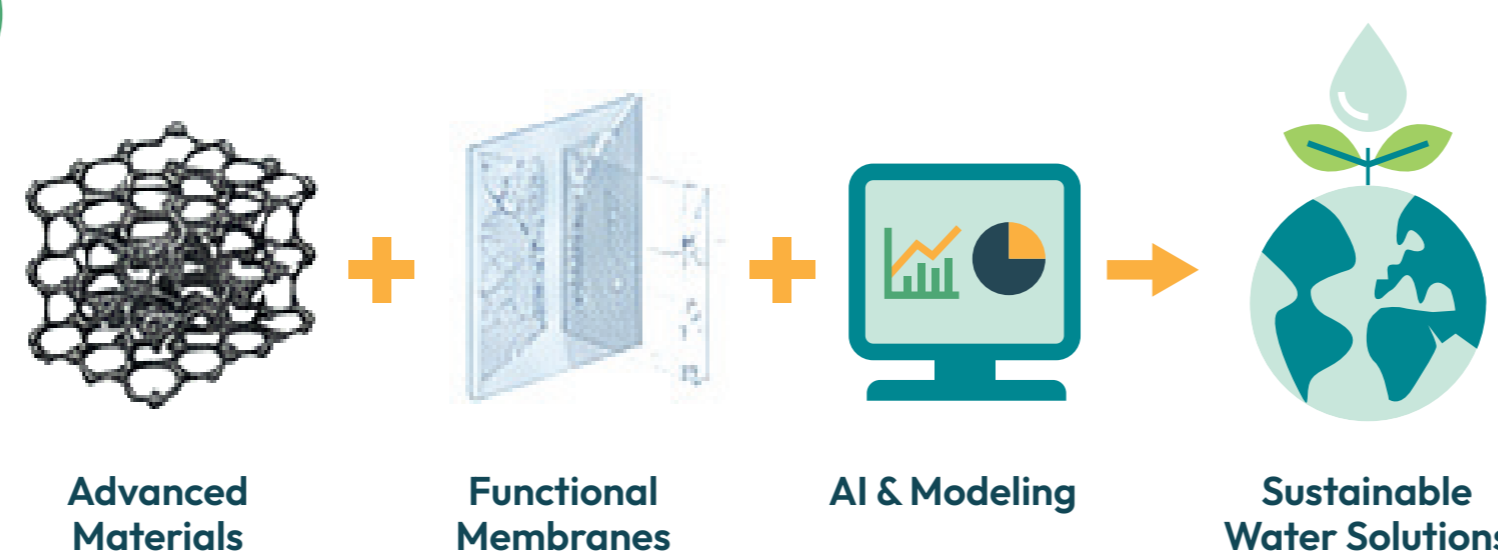
Membrane fouling and cost [1,2]

Scalability constraints:
Challenges in hydraulic design, uniform flow distribution and stable stacking [2,5]

Performance Trade-offs:
Balancing SAC, selectivity, stability, and energy efficiency remains difficult [4,5]

7 FUTURE OUTLOOK

Future work should focus on advanced electrode materials, low-cost antifouling functional membranes scalable reactor design, hybrid systems, energy recovery, and AI-assisted optimization.



KEY MESSAGE

CDI and MCDI offer a promising path toward low-energy, selective and sustainable desalination and resource recovery. Continued innovation in materials, system design, and modeling is essential to achieve large-scale impact

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