

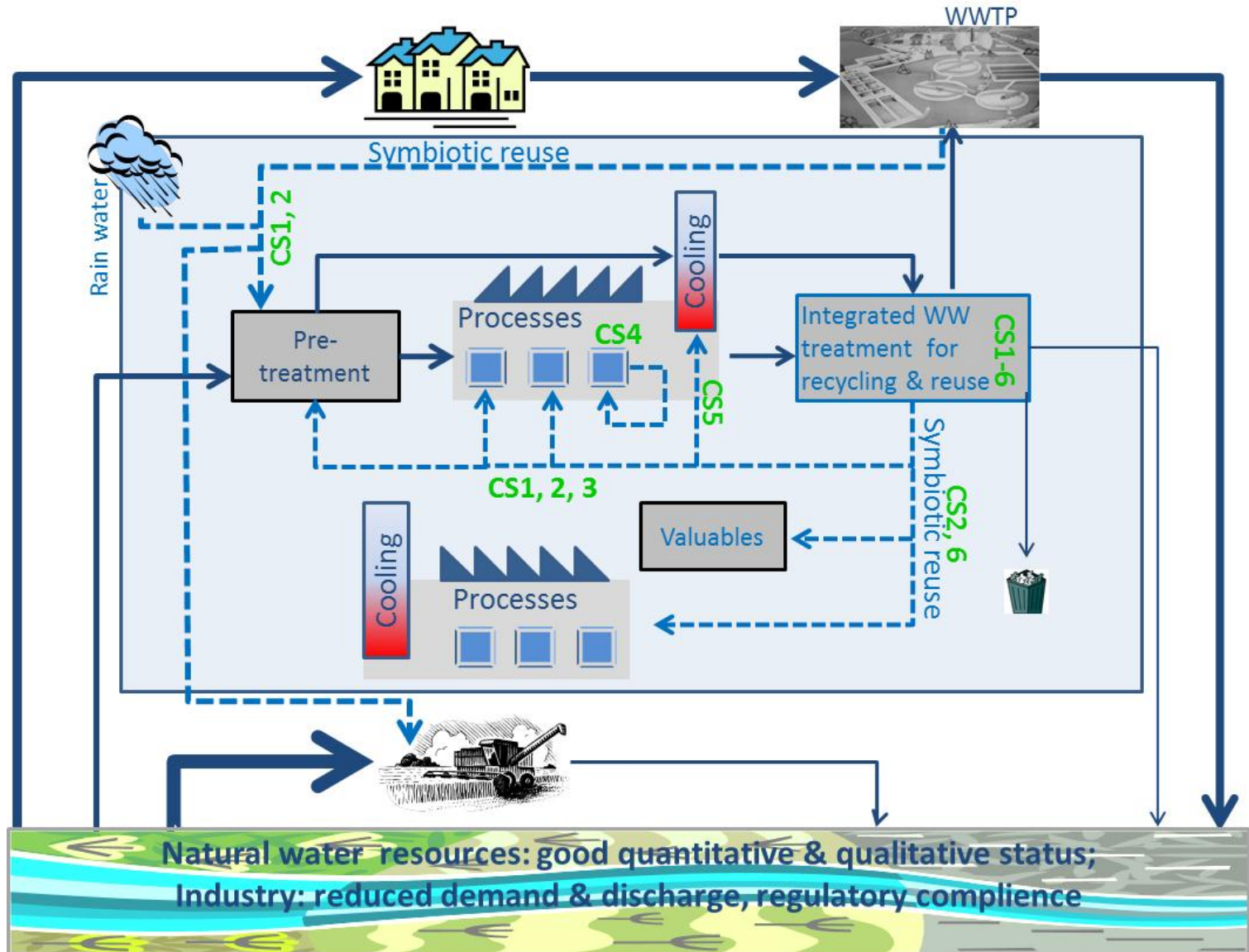
# Reduction of fresh water intake by desalination

Raymond Creusen (TNO)

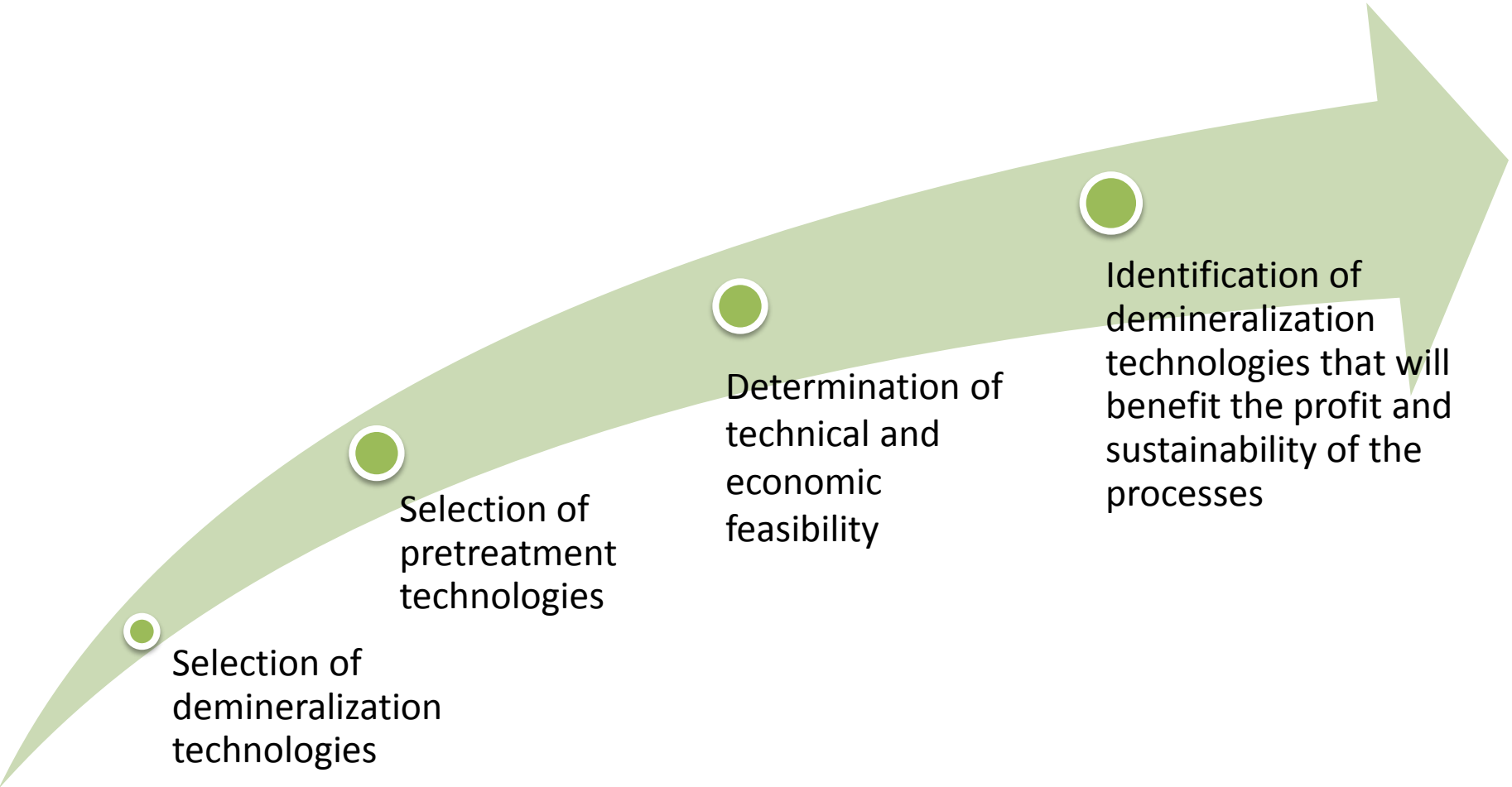
## Content of the presentation

- Introduction
- Approach for the technology selection
- Insight in technologies with cooling tower blow down (CTBD) as the raw water source

# Why desalination?



# How to select the right desalination technology?



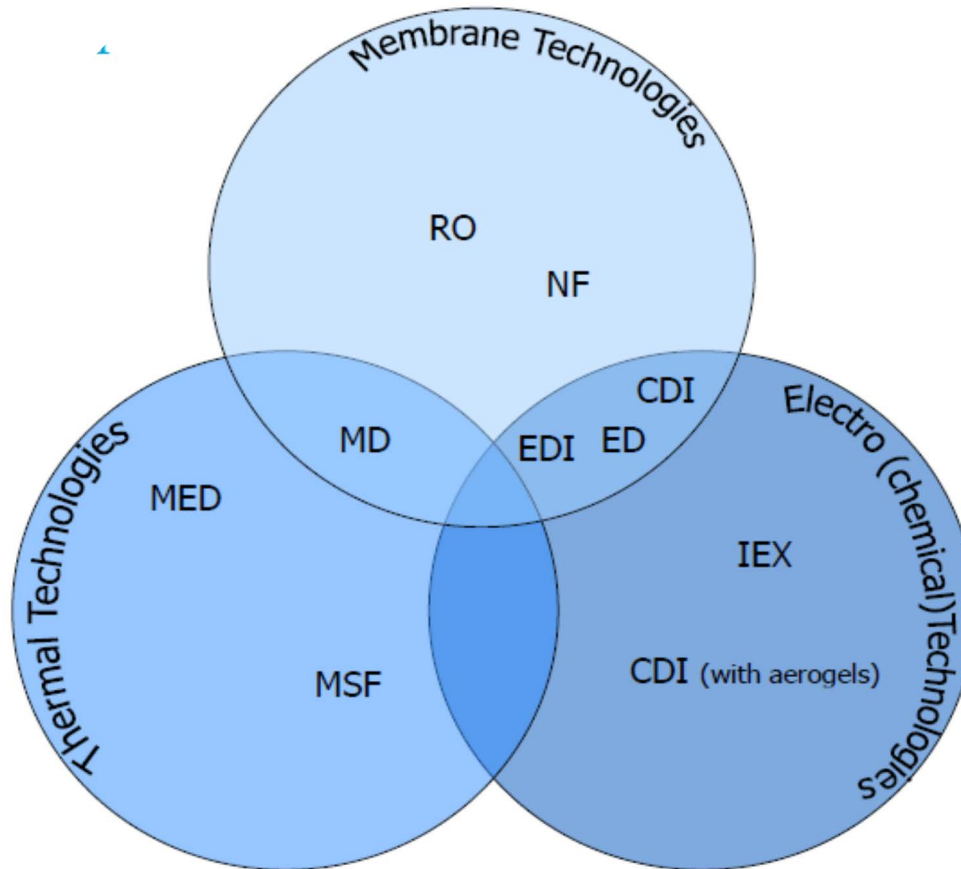
Selection of  
demineralization  
technologies

Selection of  
pretreatment  
technologies

Determination of  
technical and  
economic  
feasibility

Identification of  
demineralization  
technologies that will  
benefit the profit and  
sustainability of the  
processes

# Desalination principles

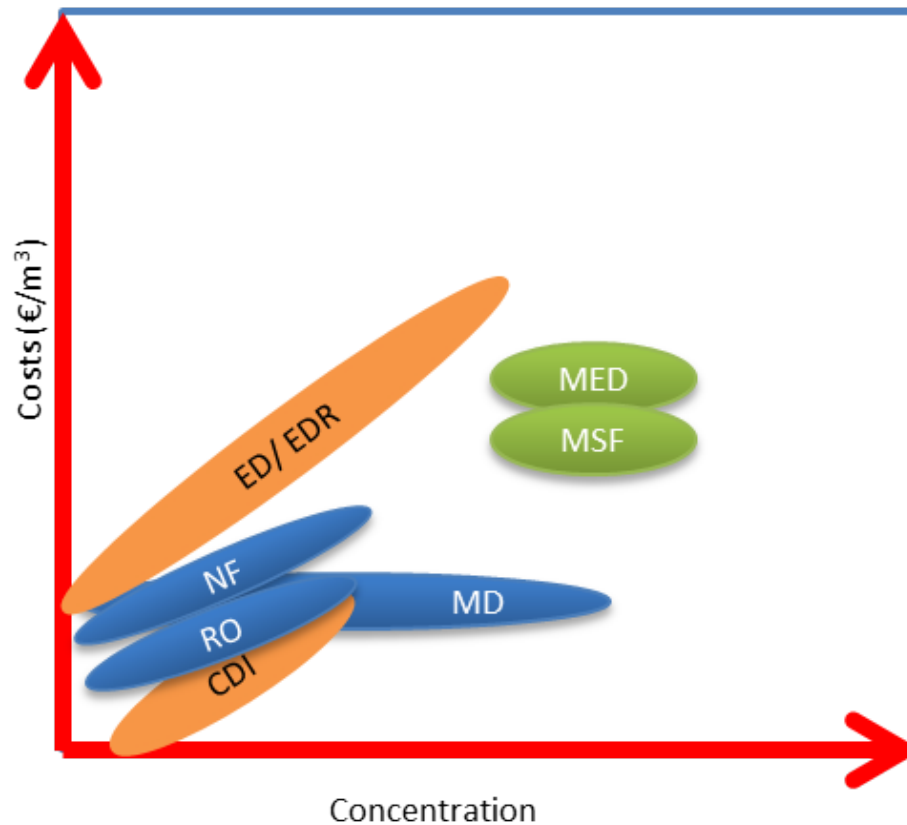


## Selection of desalination technology

- Dependent on quality water source and requirements water reuse
- Extensive desalination
  - Reverse osmosis
  - Evaporation
  - Membrane distillation
- Mild desalination
  - ED(R)
  - Nanofiltration

	Min. influent conductivity (µS/cm)	Max. influent conductivity (µS/cm)	Effluent conductivity possibility (µS/cm)	Reference costs (€/m <sup>3</sup> )	Other considerations	Does technology meet main requirements for different streams
<b>RO</b>	<100	25.000	0.1 - 500	0.21 – 5*	Mature technology, used to desalinate SW/BW	Yes (P,I,D)
<b>NF</b>	500	25.000	500 - 1.000	0.25 - 5*	Mature technology, used to desalinate BW	Not as standalone technology
<b>ED/EDR</b>	1.000	8.000	100 – 8.000	0.13 - 5*	Mature technology used to desalinate BW	Not as standalone technology
<b>MD</b>	<100	near crystallization	<10	0,26 - 5*	Innovative technology, can treat SW and BW	Yes (P,I,D)
<b>MSF</b>	8.000	50.000	<10	0.42 - 5*	Mature technology, generally used for large volumes of SW	Yes (P,I,D), comparable to MED, higher cost expected
<b>MED</b>	8.000	50.000	<10	0.5 - 5*	Mature technology, generally used for large volumes of SW	Yes (P,I,D)
<b>IEX</b>	<100	3.000	<1	no good indication found for desalination example	Mature technology, used as a polishing step	Yes (P)
<b>EDI</b>	<100	50	<1	No good indication available	Innovative technology, used as a polishing step	Not as standalone technology
<b>CDI</b>	<100	8.000		No good indication available	Innovative technology, used to desalinate BW	Not as standalone technology

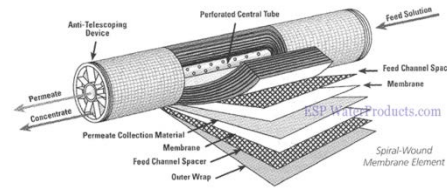
# Costs vs. concentration for desalination technologies





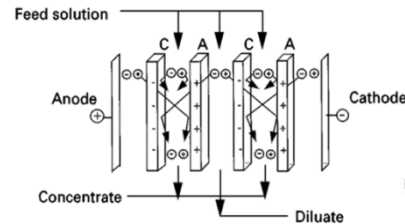
# Final technology selection for selected water sources and water reuse options

- Reverse osmosis



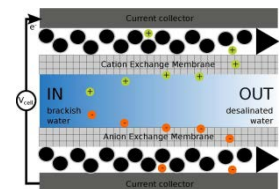
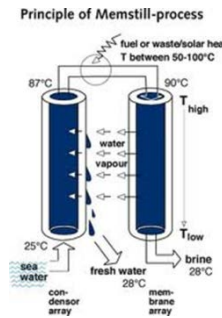
- Nanofiltration

- Electrodialysis



- Membrane distillation

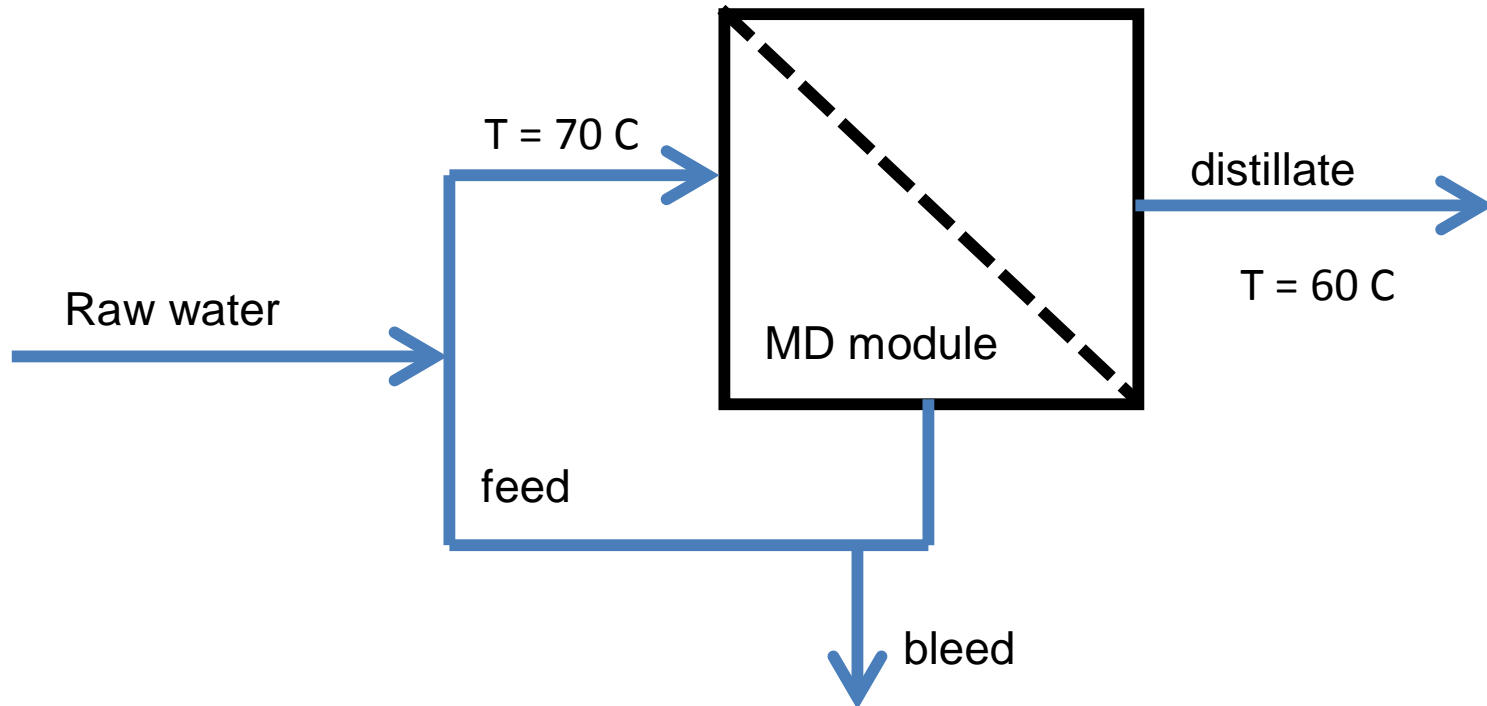
- Capacitive deionization



## Technology-water source selection

Desalination Technology	Dow			INOVYN (B)			INOVYN (S)
	Biox Waste-water	Spuikom Rainwater	Cooling Tower Blow Down	External wastewater (EWW)	Phreatic drainage water and rainwater (FW)	Untreated dock water (DW)	MBR effluent
Ion Exchange	X	X	X	X	X	X	X
Electrodialysis	X		X	X	X	X	X
Capacitive Deionization	X		X	X	X	X	X
Membrane Distillation	X	X	X			X	X
Nanofiltration / Reverse Osmosis			X				X

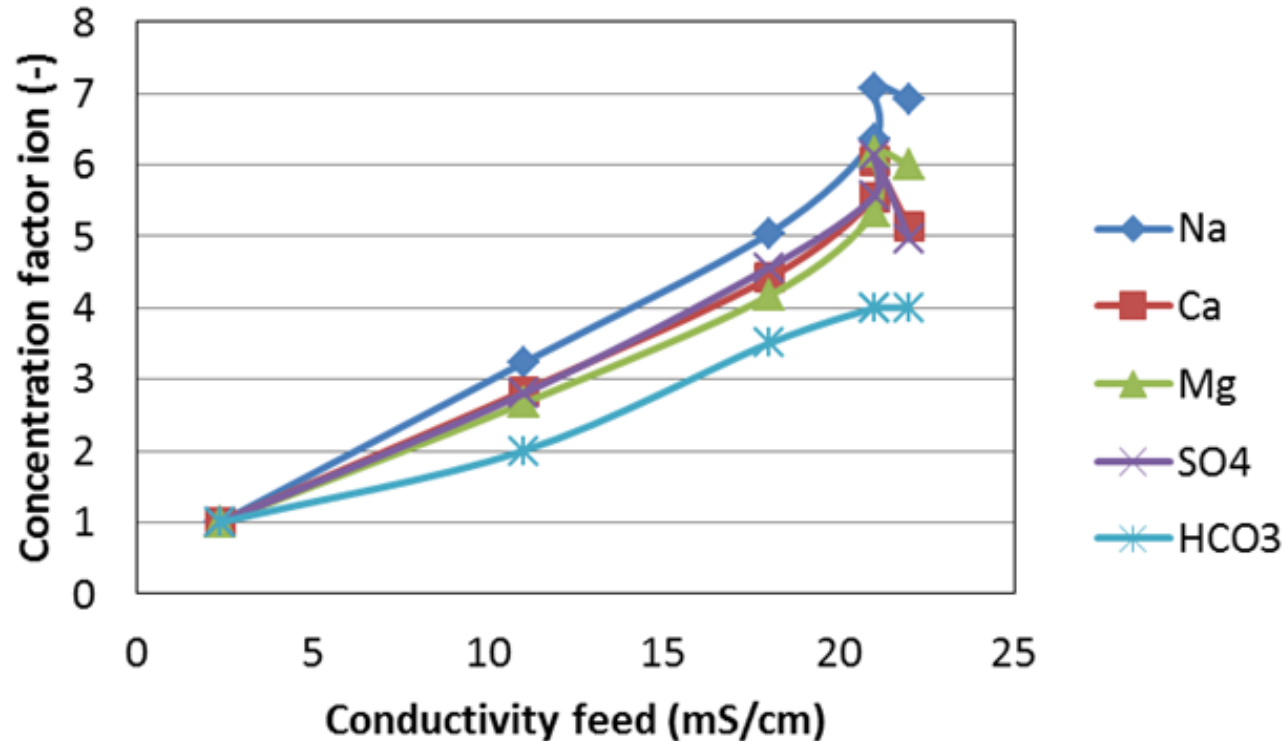
## Laboratory setup MD experiments



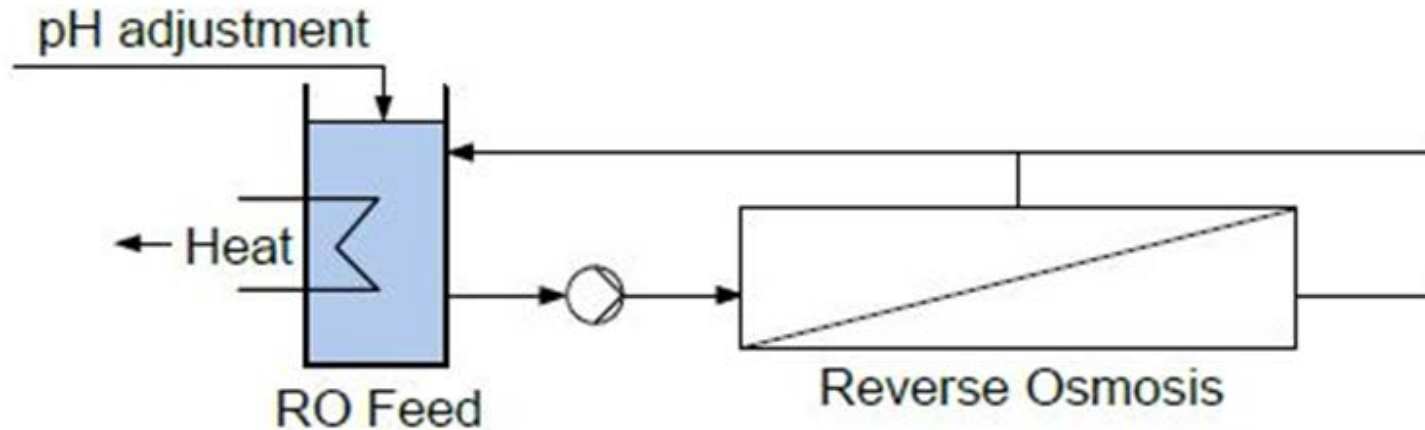
## MD results with different water sources

Water	Membrane	Concentration factor (-)	Recovery (%)
LHC3 CTBD	PTFE	5.3	81
Elsta CTBD	PTFE	5.3	81
Elsta CTBD	PE	9.6	90
Spuikom	PE	6.7	85
Biox effluent	SUPOR R	5.9	83

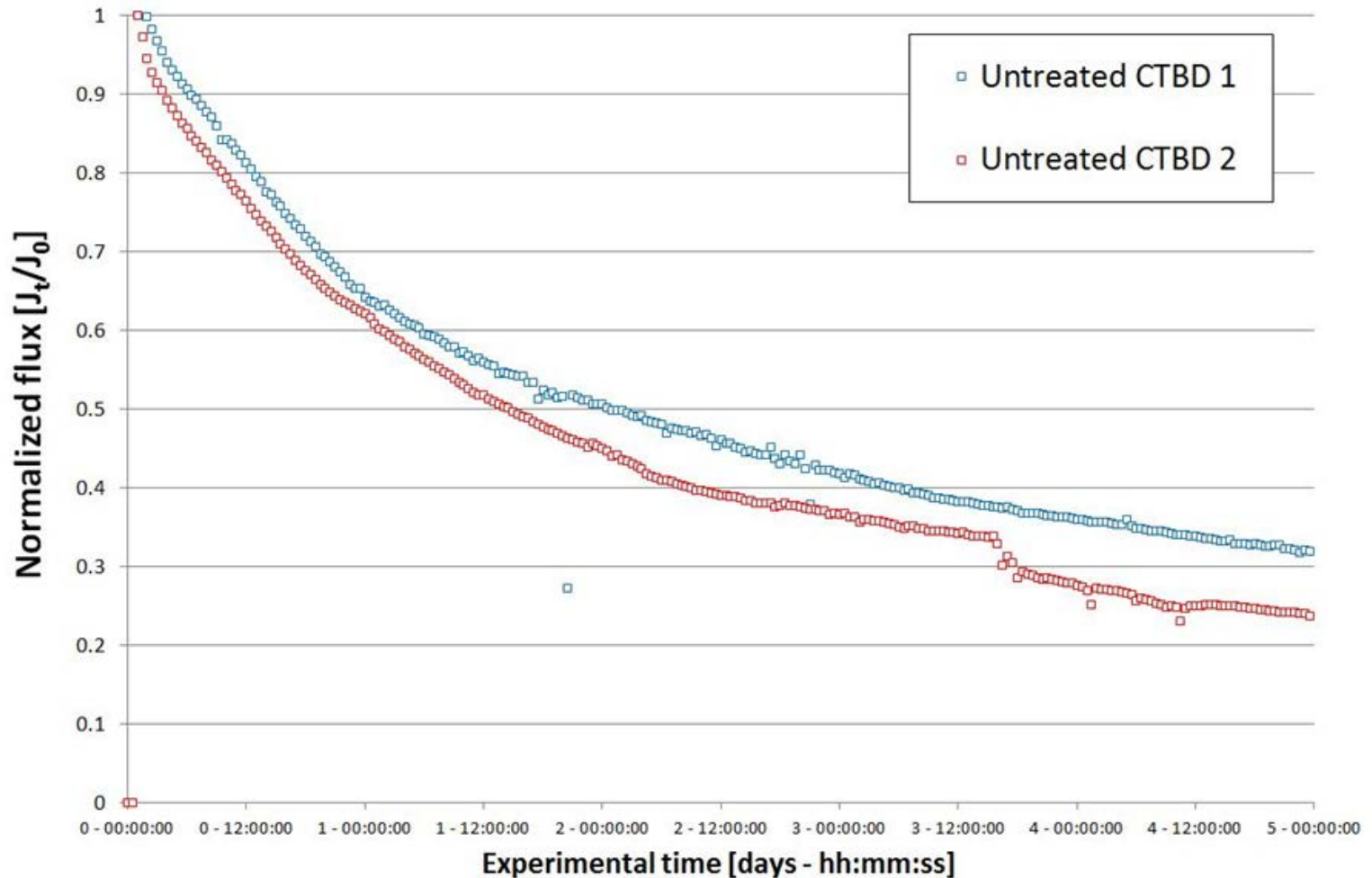
# Element analysis MD experiment with ELSTA CTBD



# Laboratory RO/NF experiments with ELSTA CTBD



# Fouling Filmtec BW30 with ELSTA CTBD

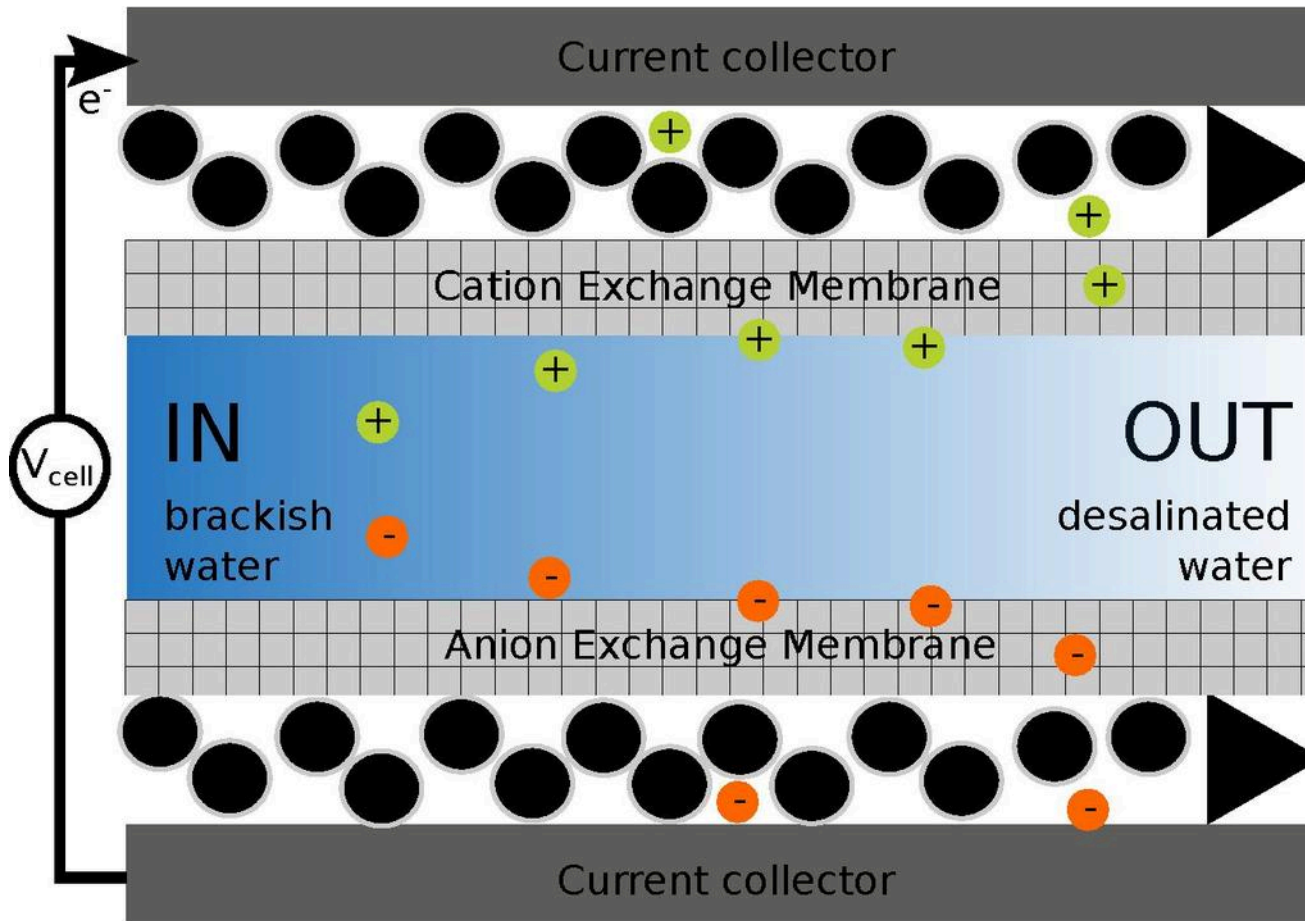


## RO on CTBD with different pretreatments

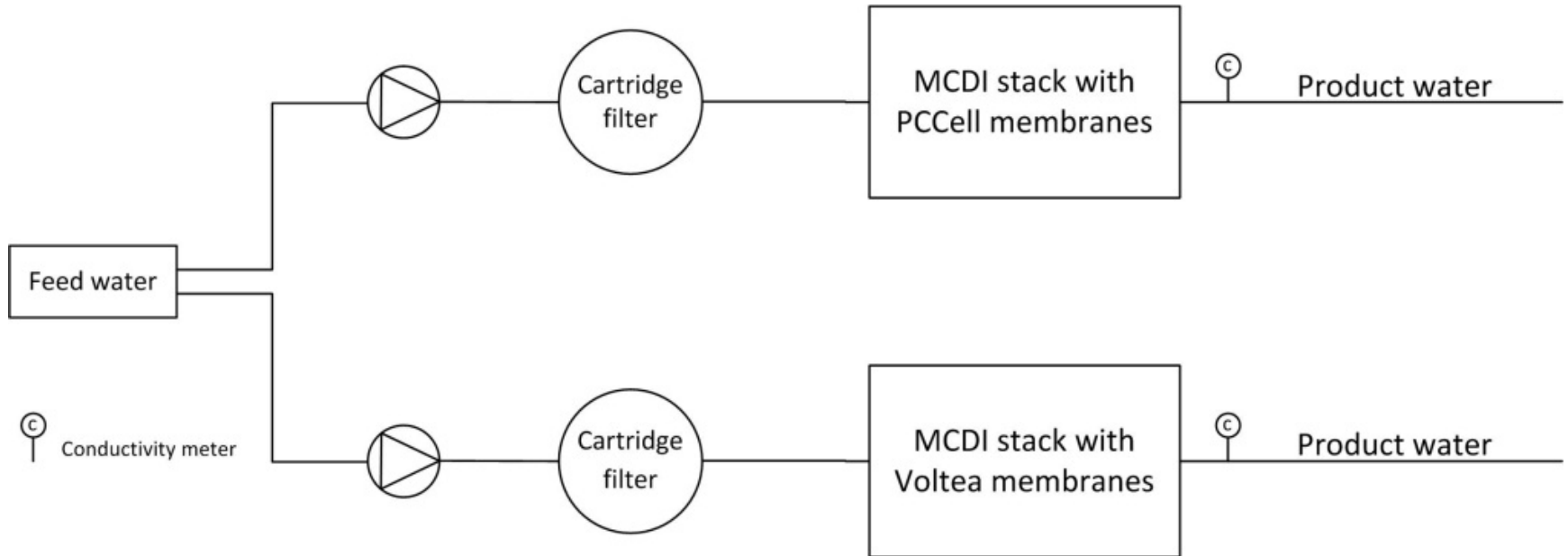
	Normalized flux after 5 days [ $J_5/J_0$ ]	Permeate produced [kg]	Flux decline per Permeate [%/kg]
Raw CTBD 1	0.23	9.9	7.7
Raw CTBD 2	0.32	10.8	6.3
UF 1	0.41	12.0	4.9
UF 2	0.43	12.9	4.4
UF 2	0.41	11.6*	5.1
PAC/UF	0.53	14.4	3.3
PAC/UF	0.62	17.6	2.2
Fe <sup>3+</sup> 2	0.37	10.7	5.9
Fe <sup>3+</sup> 3	0.29	8.6*	8.3
Fe <sup>3+</sup> 4	0.37	9.4**	6.7



# Capacitive deionisation (CDI) of CTBD

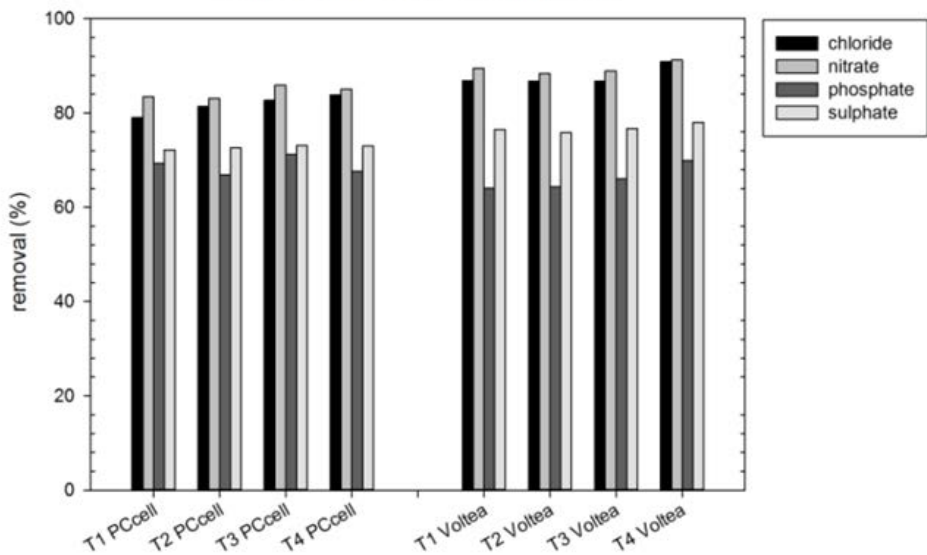


## Laboratory setup CDI experiments

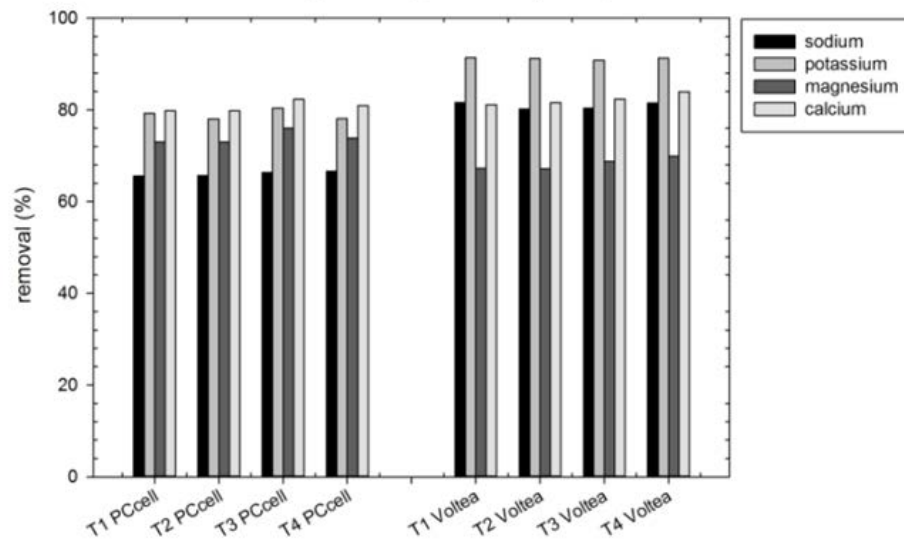


# Removal of ions from CTBD with CDI

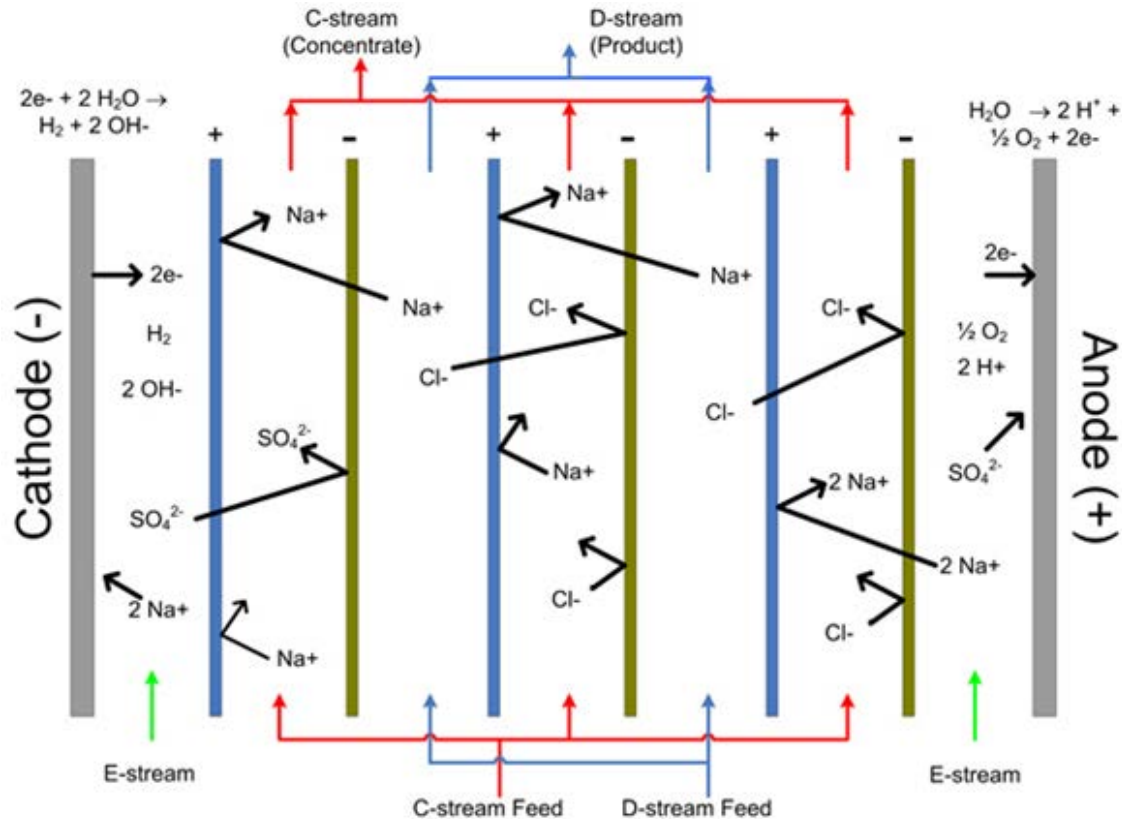
Removal percentage anions (MCDI)



Removal percentage cations (MCDI)



# Laboratory experiments Electrodialysis reversal (EDR) of CTBD



## Electrodialysis, overall results (1)

	Exp. 1	Exp. 2	Exp. 3	Exp. 4	Exp. 5
Recovery	80%	87%	87%	87%	87%
with:			reversal	anti-scalent	GE IEM
Precipitation?	NO	YES	YES	YES	YES
Energy [kWh/m <sup>3</sup> ] <sup>1</sup>	0.31	0.61	0.53	0.70	0.31
CE	80%	80%	89% (62%)	83%	77%

### › Selectivity towards ions :

- ›  $\text{Ca}^{2+} > \text{Mg}^{2+} > \text{K}^{+} > \text{Na}^{+}$
- ›  $\text{NO}_3^{-} \approx \text{Cl}^{-} > \text{SO}_4^{2-} \approx \text{HCO}_3^{-}$  for GE membranes:  $\text{SO}_4^{2-} > \text{NO}_3^{-} \approx \text{Cl}^{-}$
- ›  $\text{PO}_4^{3-}$  too low ( $\text{P} < 0.05 \text{ mol/l}$ )

<sup>1</sup> Retrieved experimental energy usage corrected for the electrode reactions by subtracting 1.8 V from the cell potential

## Electrodialysis, overall results (2)

	Exp. 1	Exp. 2	Exp. 3	Exp. 4	Exp. 5
Recovery	80%	87%	87%	87%	87%
with:			reversal	Anti-scalent	GE IEM
EC <sub>start</sub> [mS/cm]	3.8	3.8	3.5	3.9	3.7
EC <sub>diluate</sub> [mS/cm]	1.0	1.1	1.1	1.0	1.0
EC <sub>concentrate</sub> [mS/cm]	11.9	16.0	13.0	17.0	14.2
pH <sub>start</sub>	7.8	7.5	7.4	6.9	7.6 <sup>d</sup> 3.7 <sup>c</sup>
pH <sub>diluate</sub>	7.4	6.1	6.7	4.8	7.0
pH <sub>concentrate</sub>	8.0	7.8	7.8	8.0	4.3

## Conclusions

- Selection of desalination technology based on raw water quality, requirements for reuse and additional defined KPI's (e.g. maturity, costs, scale of operation)
- Desalination technologies may require different pretreatment steps, which have taken into account in the final selection procedure.
- Supporting laboratory experiments have been useful for the final selection of desalination technology on demo scale.

## Acknowledgements

- Dechema
- UCM
- VITO
- INOVYN
- Solvin
- Dow
- FHNW
- Evides
- TUD



This project has received funding from the European Union's Seventh Programme for research, technological development and demonstration under grant agreement No 280756.