



# Herausforderungen für die Behandlung salzhaltiger Abwässer

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Industriewassertag, 04. März 2026

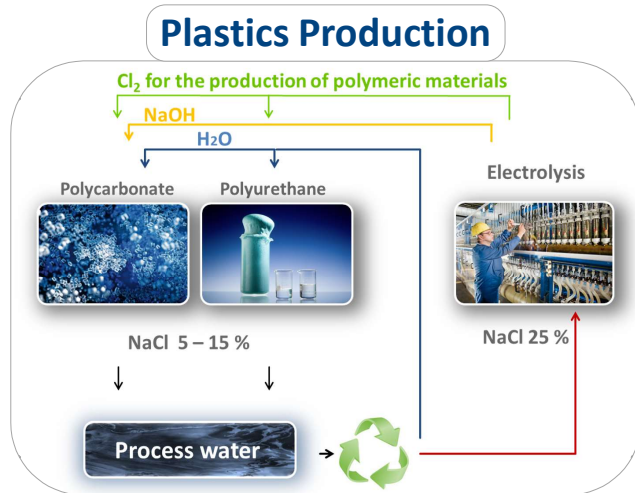


Department of Mechatronics and Mechanical Engineering  
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Cologne Membrane Lab  
TH Köln – University of Applied Sciences Cologne

# Relevant industrial brines & membrane process innovations



**Lithium Extraction & Recycling**



energyrecovery.com/lithium/

## High-Pressure Reverse Osmosis (HPRO):

**Energy efficient brine concentration**  
to up to 115 g/L NaCl →  $\pi = 100$  bar

## High-pressure (Extra) Low-Salt Rejection RO (HP-(E)LSRRO):

**Concentration up to saturation**  
to up to 283 g/L NaCl →  $\pi \approx 330$  bar

## High-Pressure Nanofiltration (HPNF) and Forward Osmosis (FO)

### Case 1:

**Energy efficient ion separation and concentration**

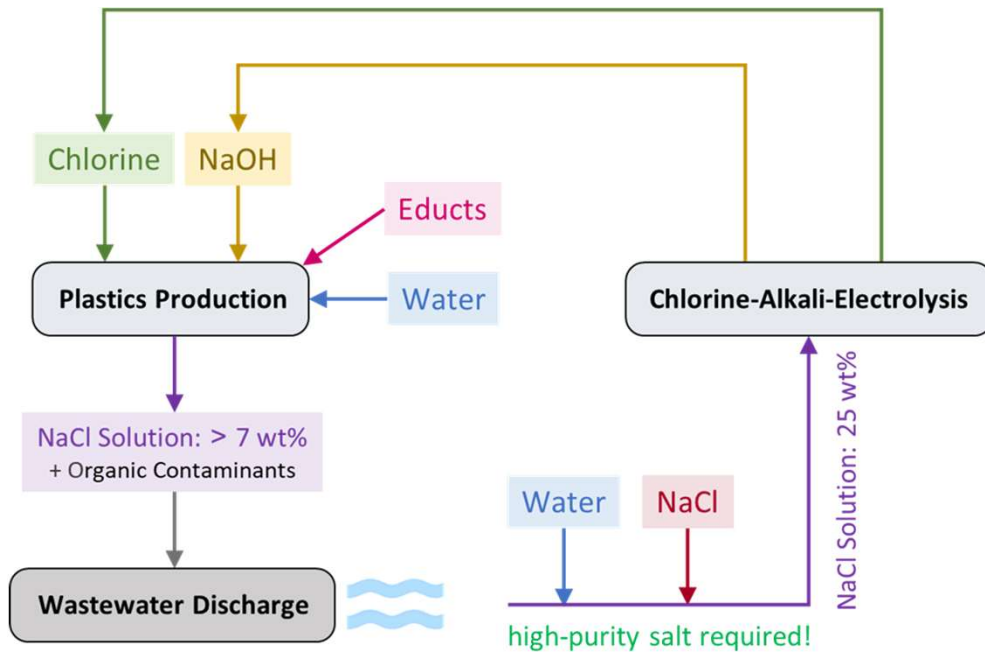
for feed solutions with extremely  
high osmotic pressures (up to 500 bar)

### Case 2:

**Energy efficient ion separation and concentration**

for lithium-containing brines (up to 400 bar)

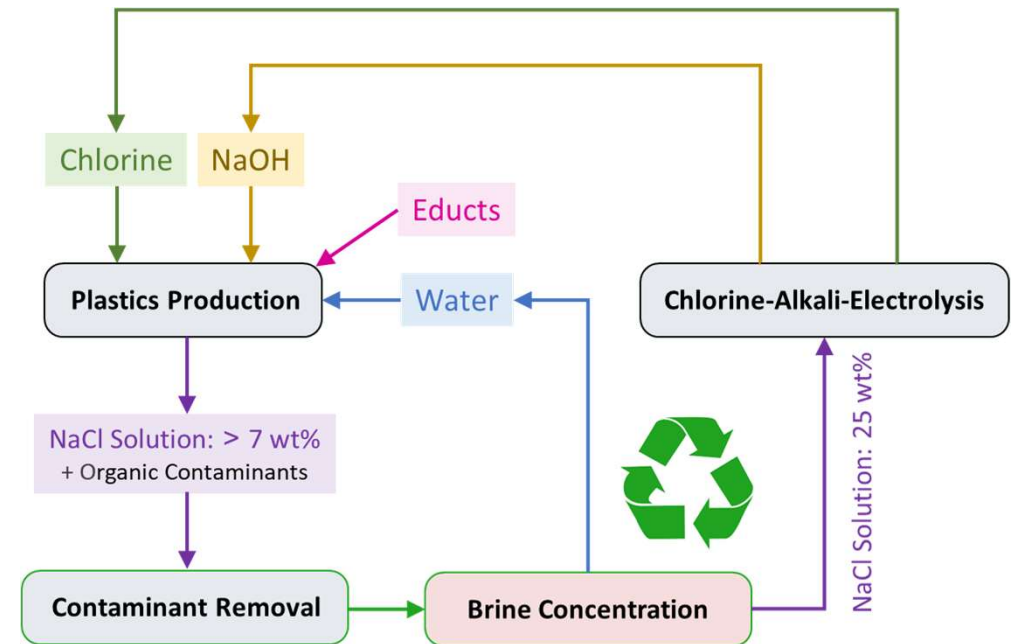
# An example of circular potential



German industry releases  $\approx 6\text{M t/a}$  chlorides into water bodies (NaCl, HCl)

**Problem:** Available thermal evaporation processes are not viable!

**Energy demand:** Drawbacks ( $\text{CO}_2$  emissions) outweigh existing disadvantages (environmental impact, no recycling).



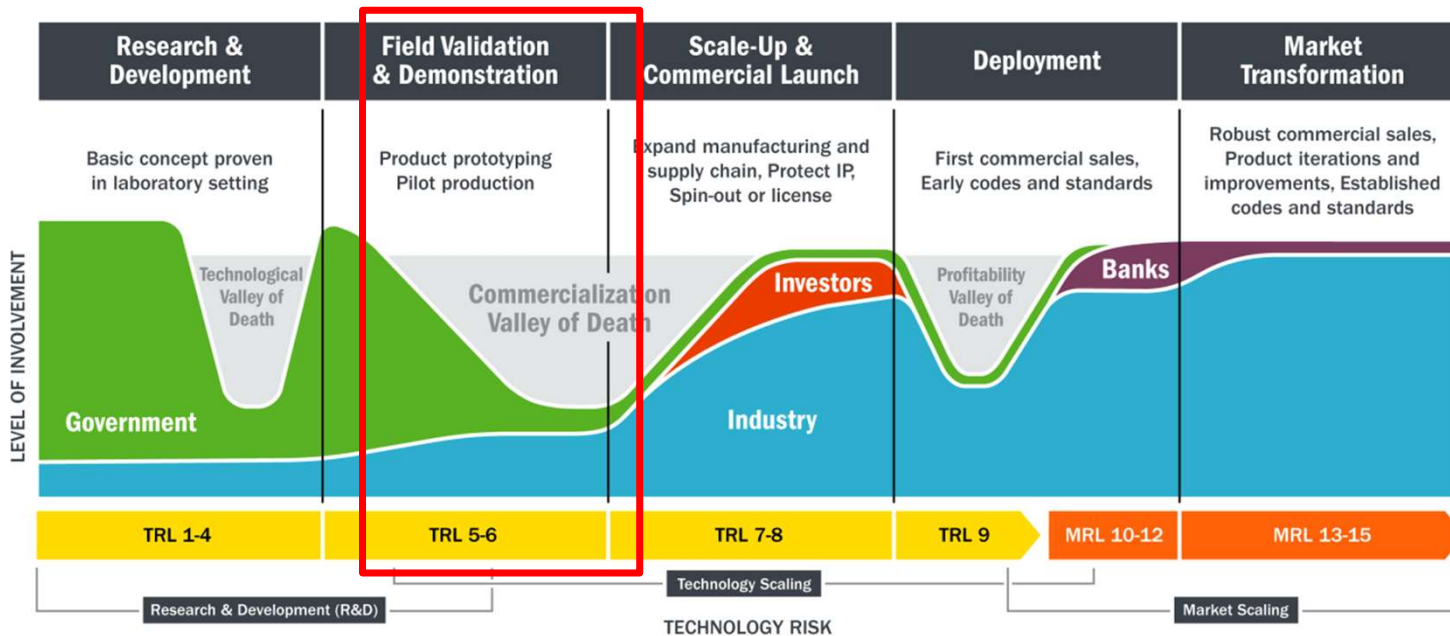
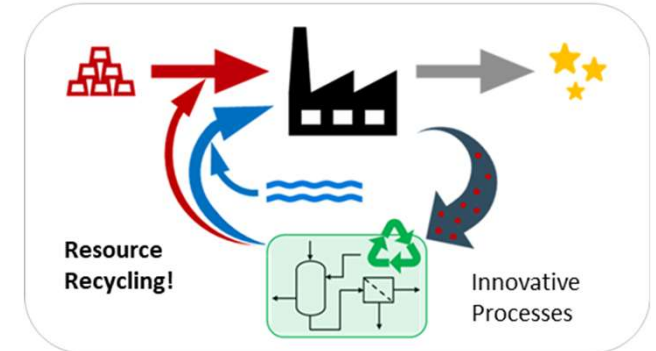
**Goal:** Economically and ecologically viable process technologies for brine concentration

- CAPEX and OPEX
- Carbon footprint vs. water footprint
- Availability & Scalability

# Applied R&D: Tackling the Valley of Death from the end

## Bridging the innovation gap through goal-oriented reverse design:

- What is the **problem** & the **driver** for the implementation of a solution?
- What technical solution is **available** & **proven** elsewhere?
- How far can we **push** the technology's and/or processes **limitations**?
- What adaptations are required to **improve efficiency**? → Basic research



<https://www.energy.gov/eere/buildings/technology-market>

TRL = Technology Readiness Level MRL = Market Readiness Level

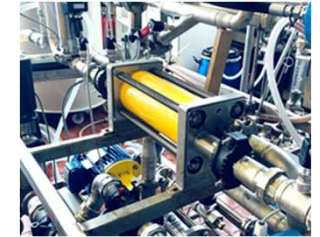
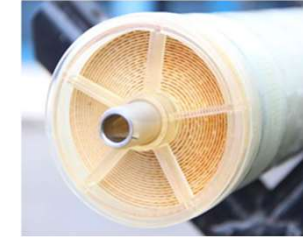
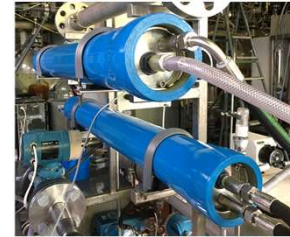
## Provide data that support a sound assessment of the process potential at scale:

- Experimental validation of technology at **relevant scale**
- **Demonstration** in industrially relevant environment  
→ Technology users
- Inclusion of all **key process components**  
→ Technology providers

# High-recovery - Ultra-high operating pressures: 120 bar

**Reliable technical equipment for ultra-high pressure operation required:**

- ✓ Specified elements
- ✓ Energy recovery devices (ERD)
- ✓ Pressure vessels
- ✓ Pumps (High-pressure, booster)



## Sea Water Reverse Osmosis (SWRO):

**Feed Pressure:** Max. 83 bar

**Water recovery:** Max. 50 %

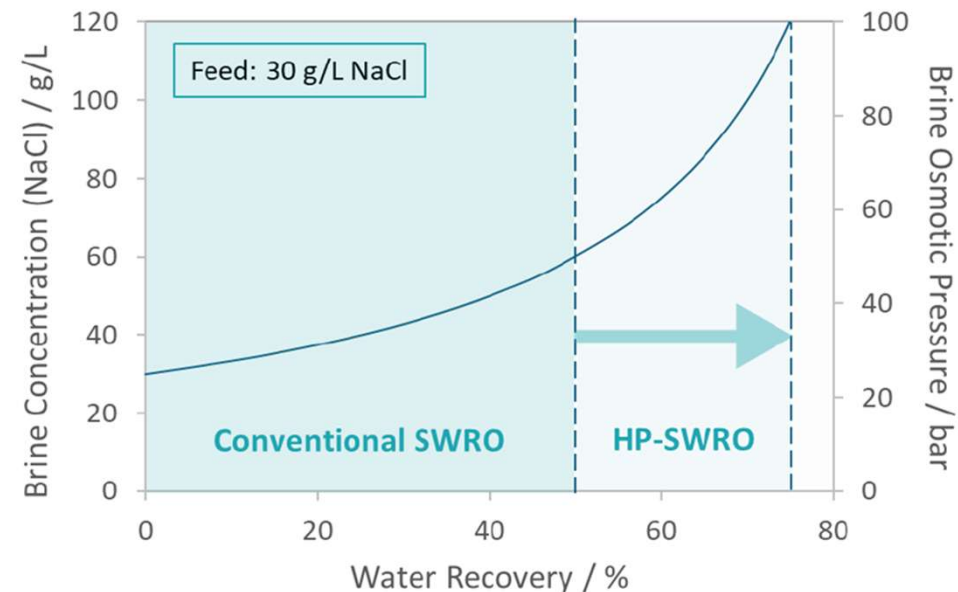
**Brine condition:** Max. 70 g/L NaCl

## High-Pressure Sea Water Reverse Osmosis (HP-SWRO):

**Feed Pressure:** Max. 120 bar

**Water recovery:** Max. 75 %

**Brine condition:** Max. 120 g/L NaCl



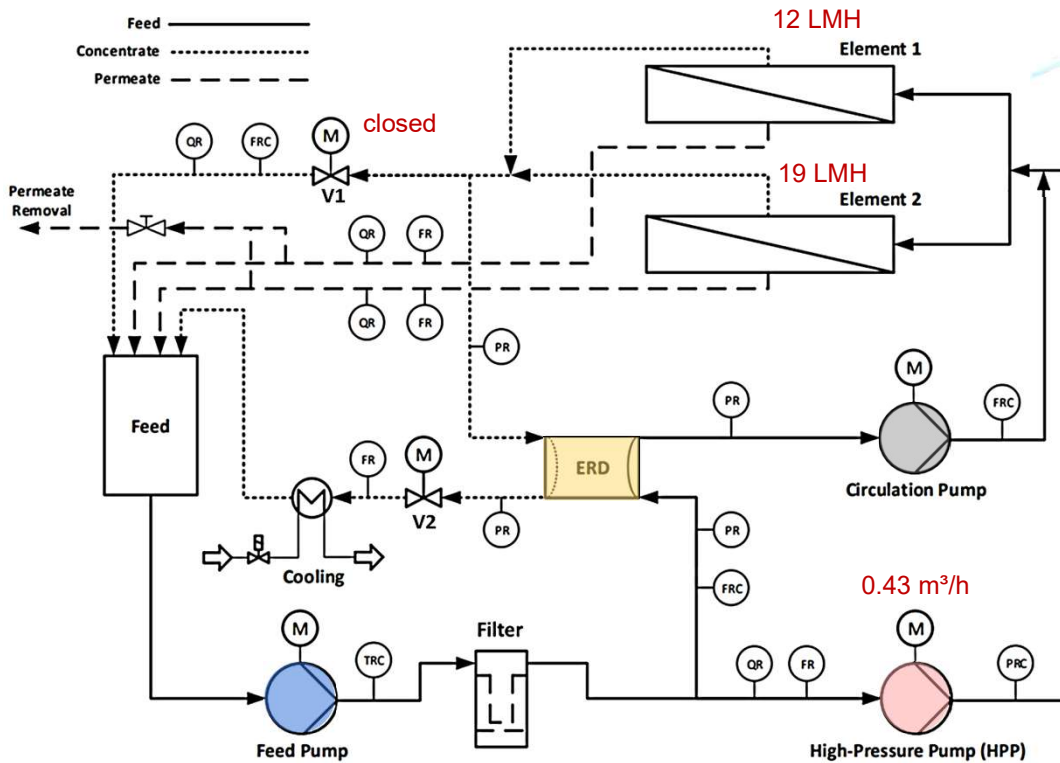
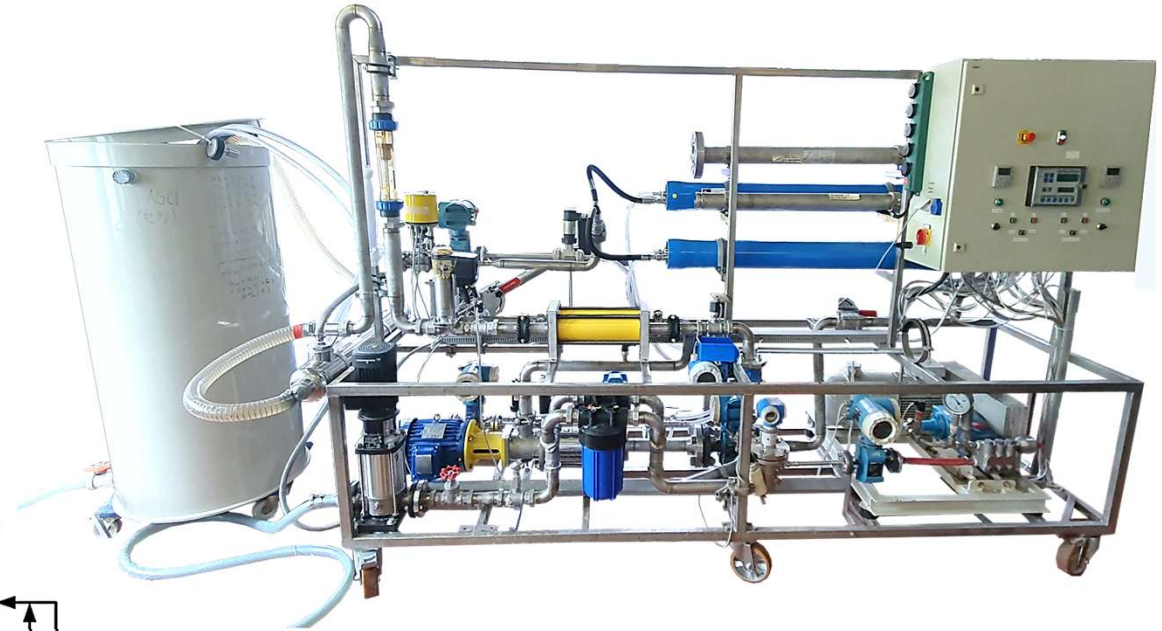
## Benefiting brine valorization pathways:

Brine mining for resource recovery or Ocean Alkalinity Enhancement (OAE)

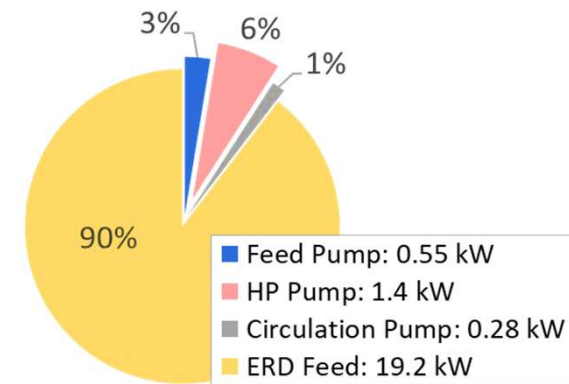
Adapted pretreatment required to reduce scaling potential!

# Experimental demonstration

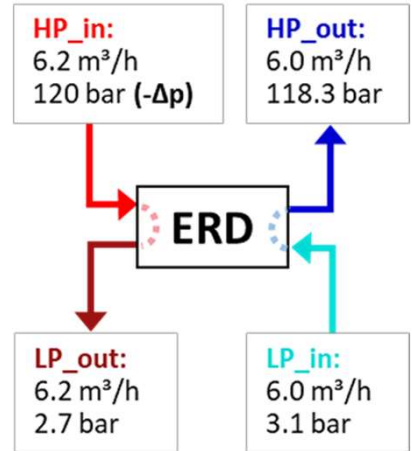
- 2 x 4" spiral-wound elements
- Max. feed pressure: **120 bar**
- Max. feed flow rate: **6 m<sup>3</sup>/h**
- Feed pressure and temperature control
- Fully automated operation, PLC



## Hydraulic Energy Balance:

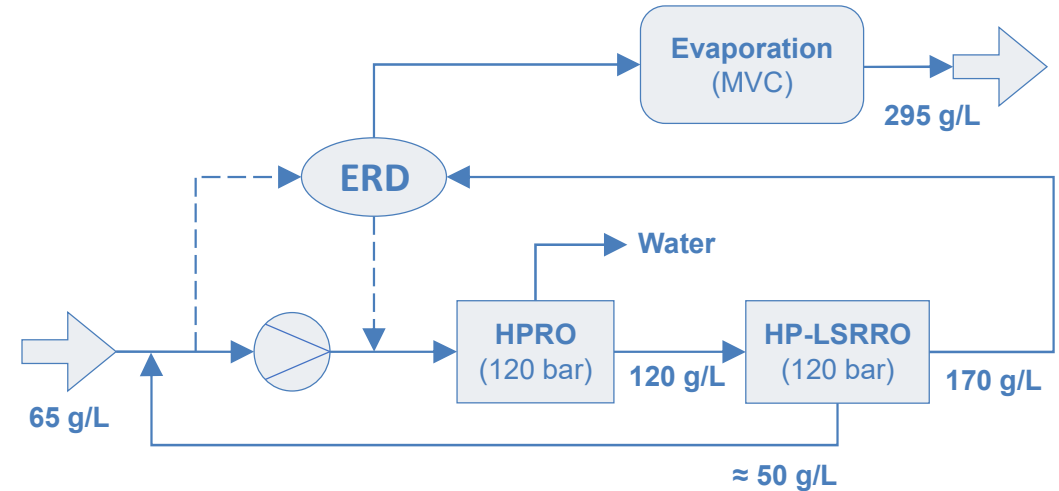


Min. Efficiency: 95.3 %



# High-Pressure Low-Salt Rejection RO

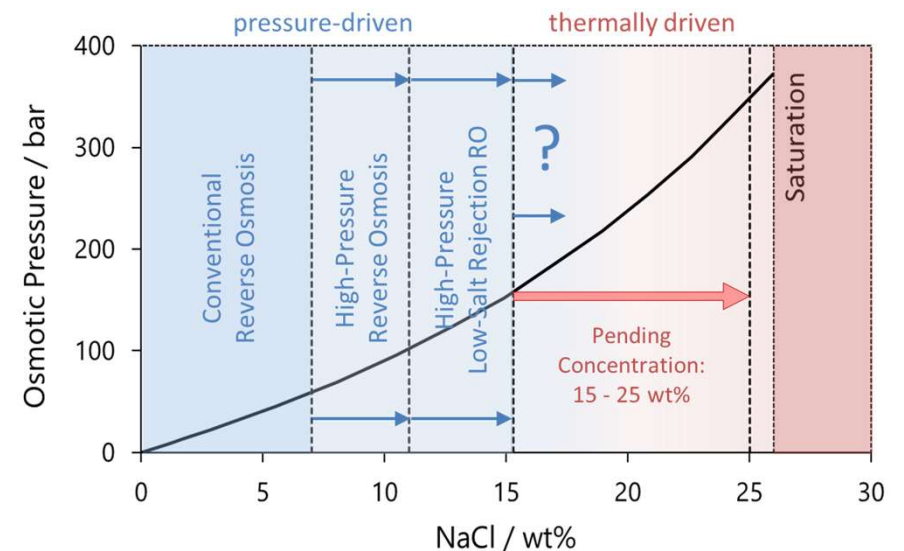
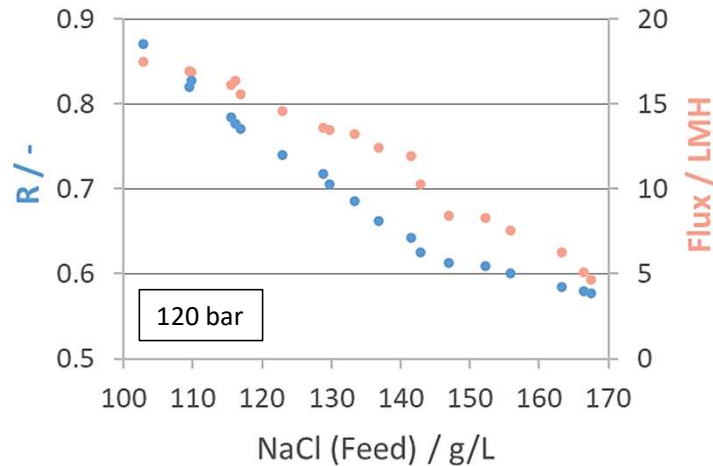
- HP-LSRRO at 120 bar enables energy-efficient brine concentration reaching **170 g/L NaCl (@ 4 LMH)**
- **59% < R < 88%** (depending on operating conditions)
- Permeate with **max. 70 g/L (@ 4 LMH)**: Recycled to HPRO → **Min. volumes & concentrations!**
- **Prototype!** Available membrane elements are specified for max. 83 bar
- **51% energy savings, 60% water reuse**



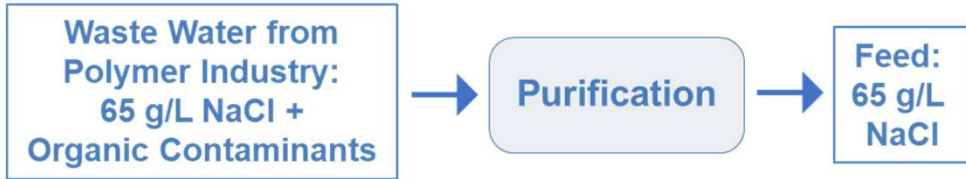
**Specific energy demand HPRO + HP-LSRRO + ERD (65 - 170 g/L):**

**6.3 kWh/m<sup>3</sup> WATER REMOVED**

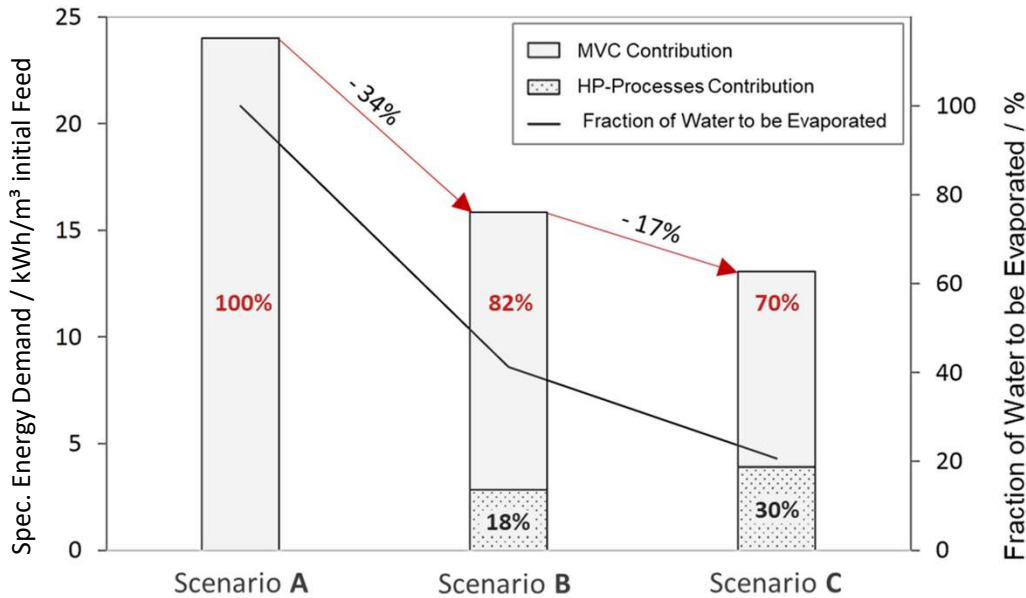
**3.9 kWh/m<sup>3</sup> TREATED FEED**



# Let's face the numbers!



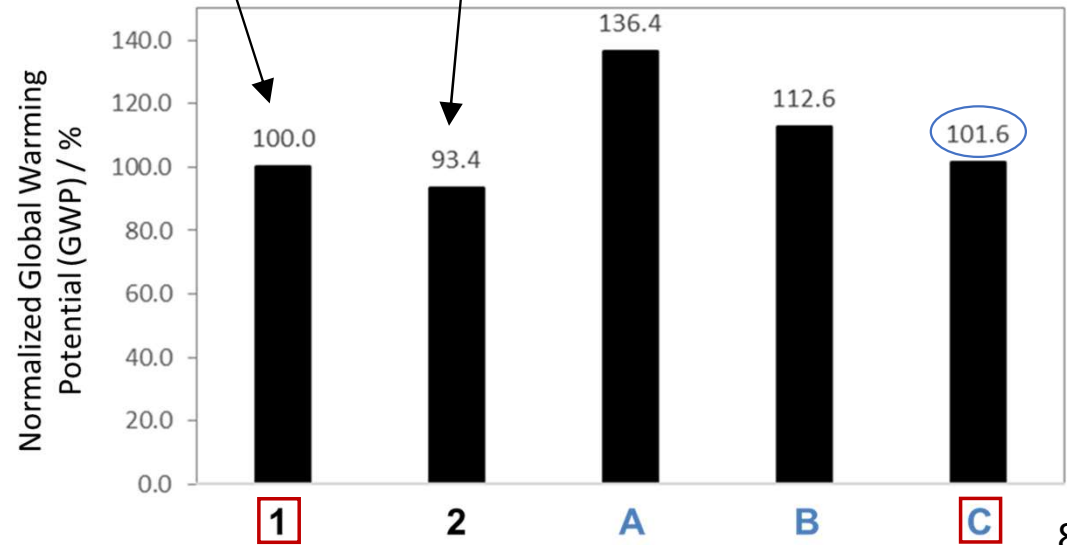
Even after **prior concentration** by factor of  $\approx 2.5$ , energy demand for **evaporation** still makes up the **lion's share**  $\rightarrow$  Further elimination required!



**Do nothing:** No reuse, wastewater discharge

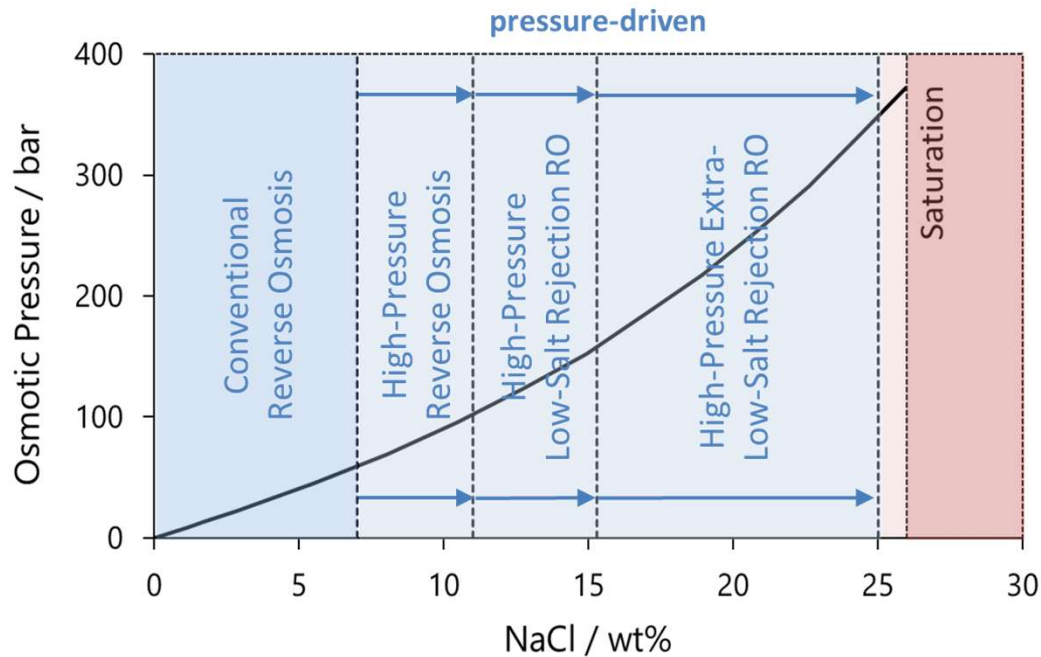
**Purification & NaCl reuse, no concentration**

**Case 1 vs. C: Environmental impact "only"!**

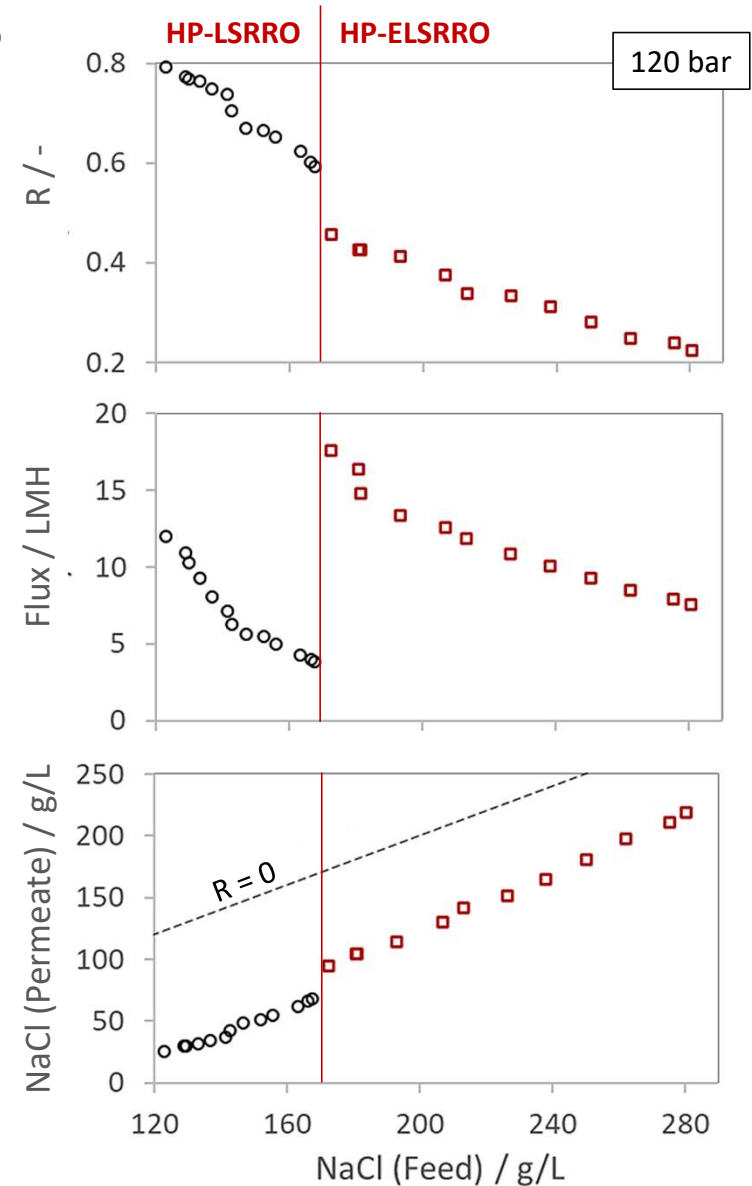


# High-Pressure Extra-Low Rejection RO?

- High-Pressure Extra-Low Rejection RO (**HP-ELSRRO**) @ 120 bar enables brine concentration reaching **283 g/L NaCl** (@ 7.5 LMH)
- **22% < R < 52%** (depending on operating conditions/time)
- Permeate with **max. 218 g/L** (@ 7.5 LMH) → Mix. permeate ≈ 130 g/L
- **Prototype!** Available membrane elements are specified for max. 83 bar



**Yes!**



# Effluent brines from potash production: What is the problem?



**Crude salt** extracted from underground only contains **up to 30% valuable substances**.

Remainder are **residues that cannot be used economically** and must be disposed of - either as liquids or solids.

Most of the residues are put on **tailings piles**.

**Backfilling** and **discharging/injecting** are also common disposal methods.

## No potash without saline wastewater:

**Potash production wastewaters**, and the **leachate** generated by precipitation on the tailings piles, must be disposed of. **Around the world, this is mainly done by discharging into rivers or oceans.**

Effluent brine from Thuringian/Hessian potash district:  
**≈ 5.5 M m<sup>3</sup>/a**

# The challenge: This brine packs a punch!



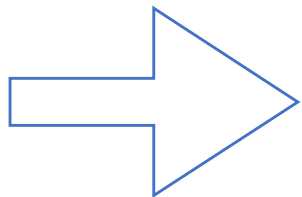
Typical brines		Typical brines	
1. Analysis of higher saturated brine		2. Analysis of lower saturated brine:	
Component	Mass concentration [g/L]	Component	Mass concentration [g/L]
KCl	45	KCl	33
MgCl <sub>2</sub>	293	MgCl <sub>2</sub>	65
MgSO <sub>4</sub>	41	MgSO <sub>4</sub>	76
NaCl	27	NaCl	187
CaSO <sub>4</sub>	0.3	CaSO <sub>4</sub>	n.a.
H <sub>2</sub> O	885	H <sub>2</sub> O	889
<b>Osmotic Pressure: 800 bar</b>		<b>Osmotic Pressure: 440 bar</b>	



Concentrations/osmotic pressures are **extremely high!**  
 Brines are **saturated** regarding several mixed salts.  
 The salt loading levels **fluctuate!**



Far beyond the application limits of conventional processes — yet a sustainable technical solution must be found:



## A TREATMENT must provide:

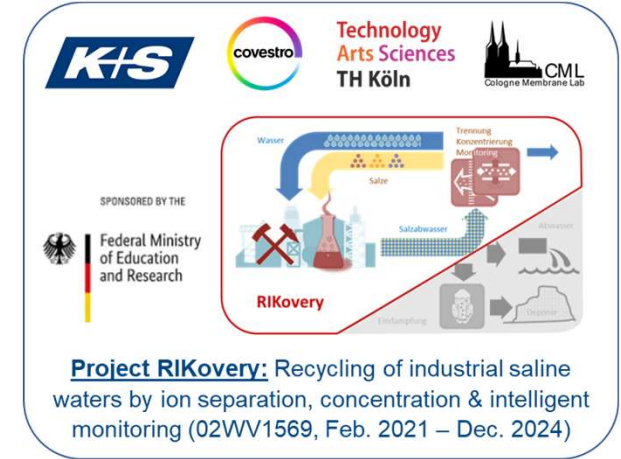
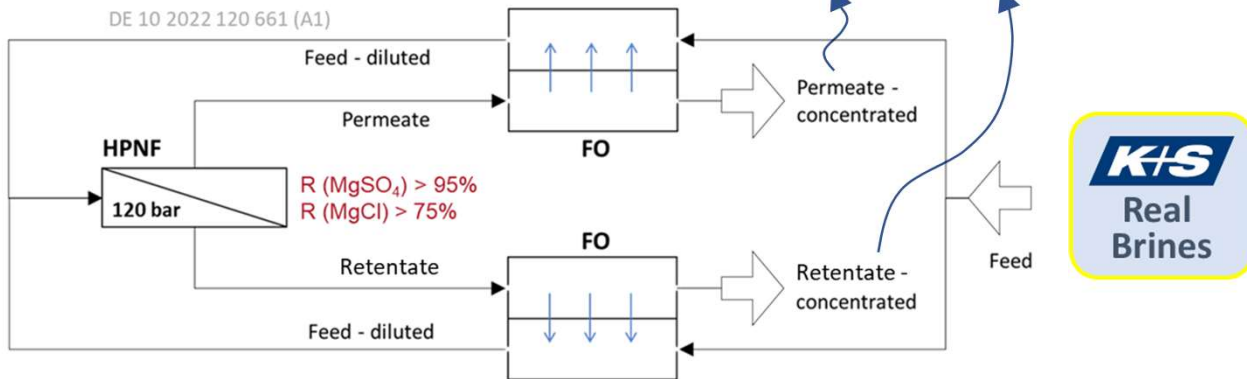
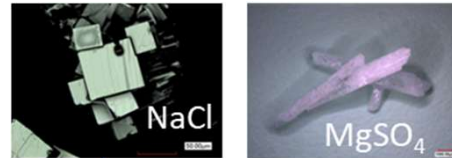
1. Ion separation
2. Concentration

## A feasible TECHNOLOGY must be:

- Energy- & resource-efficient
- Available & scalable
- Sufficiently flexible
- Environmentally compatible

# A membrane process that unlocks the brines' potential

**Patented** (pending): Method and device for separating highly concentrated salt solutions  
(TH Köln – University of Applied Sciences Cologne & K+S)



**Development & pilot demonstration of an innovative membrane-based process concept for brine treatment:**

- ✓ **Forward Osmosis (FO):** Product concentration up to saturation
- ✓ **High-Pressure Nanofiltration (HPNF):** Effective ion separation
- ✓ Application of **only available** technologies & components (TRL ≥ 5)

**Salt recovery from effluent brines:**

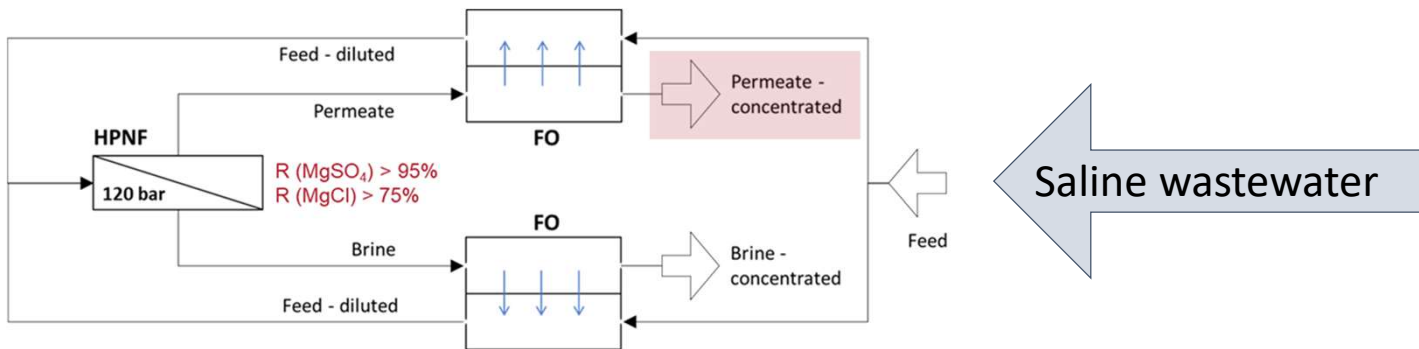
A cross-sectoral approach to the industrial circular economy?

**Feasibility study:**

**NaCl recovery for reuse in Chlor-Alkali-Industry**

# A cross-sectoral approach to the circular economy?

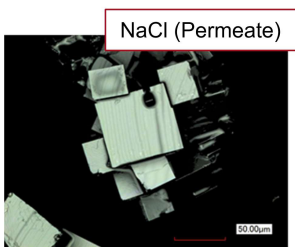
Innovative membrane process: HPNF & FO



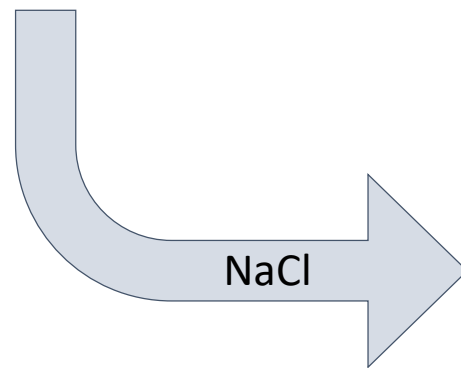
Mining industry: Potash production



Concentrated HPNF permeate



→ Selective crystallization



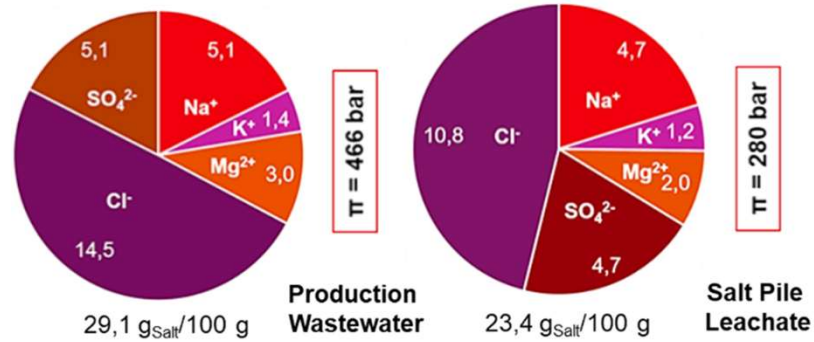
Chemical industry:  
Chlor-alkali electrolysis



NaCl 25 % ↑

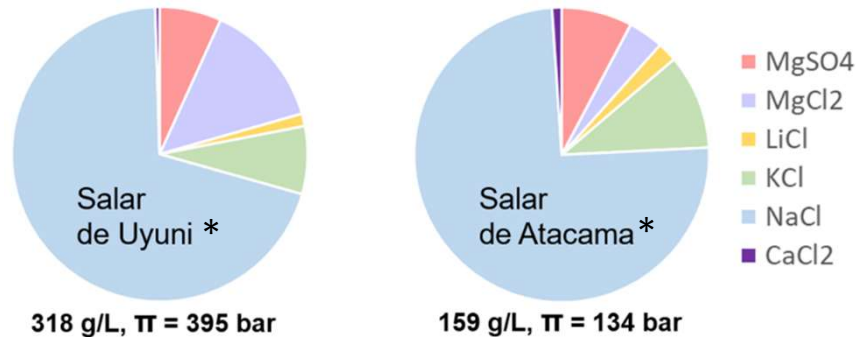
Membrane processes open new perspectives for sustainable resource recycling in industry!

# Cross-application: Lithium mining & battery manufacturing



## Lithium Mining

## Potash Mining



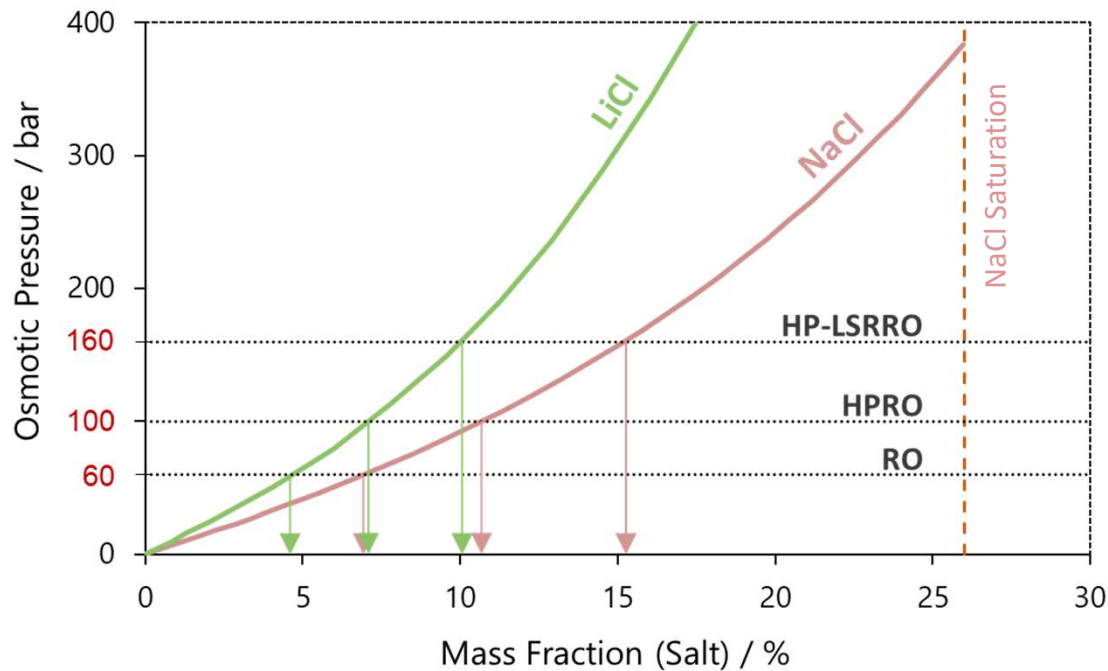
\*Compositions of residual salt pans given in <https://doi.org/10.1016/j.earscir>

# No surprise: Concentrating LiCl works.

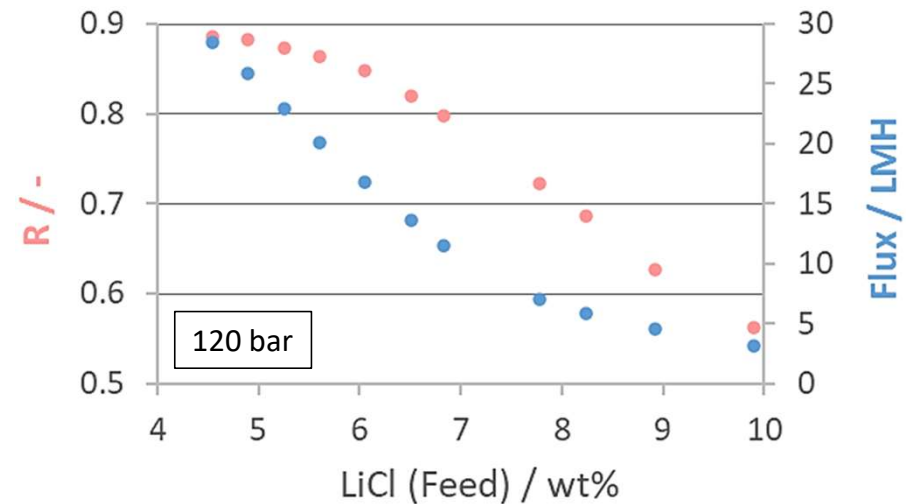
**HPRO & HP-LSRRO** combination is applicable to allow energy-efficient concentration of different monovalent ions (here reaching **10 wt% LiCl**).

**Available technologies** can be effectively applied under **extreme operating conditions** to enable further concentration for monovalent ions:

→ **Same performance, same limits, same specific energy demand!**



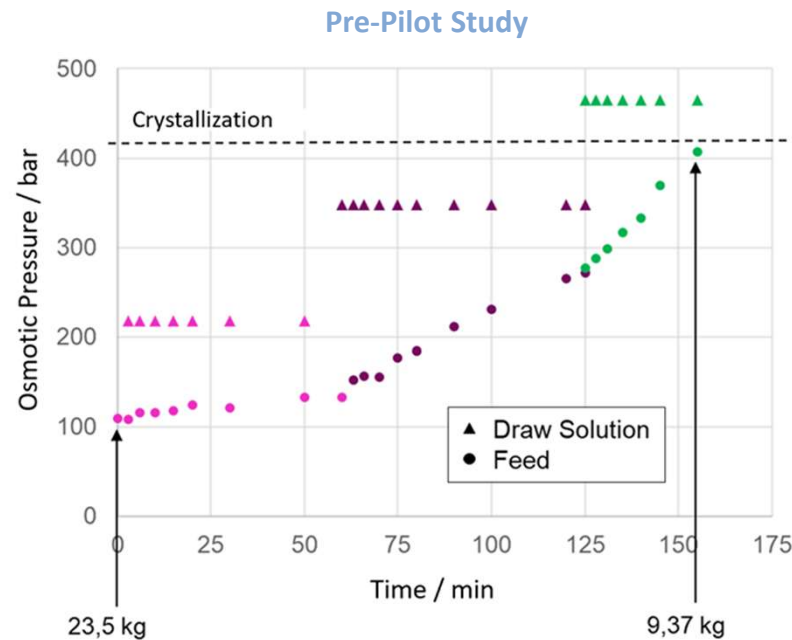
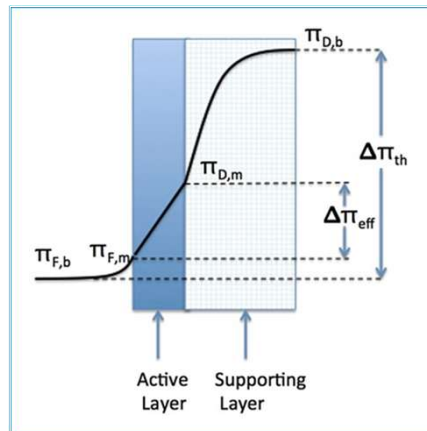
**HP-LSRRO: 56% < R (LiCl) < 89%**  
Permeate: Max. 4% LiCl ( $\approx$  RO brine) → **HPRO!**



# Forward Osmosis – A low-flux process with specific potential

- Use of **production wastewater as draw solution** allows a concentration **up to saturation!**
- Achieving adequate performance requires **very high driving forces**
- **High pressure drops** hamper realization of an industrial-scale process → Element design

- Hollow fiber (ID: 0.2 mm)
- Counter-current: Feed 400 L/h, Draw 200 L/h
- **Permeability: 0.48 LMHB**  
(Standard: DI water, 2.9% NaCl)

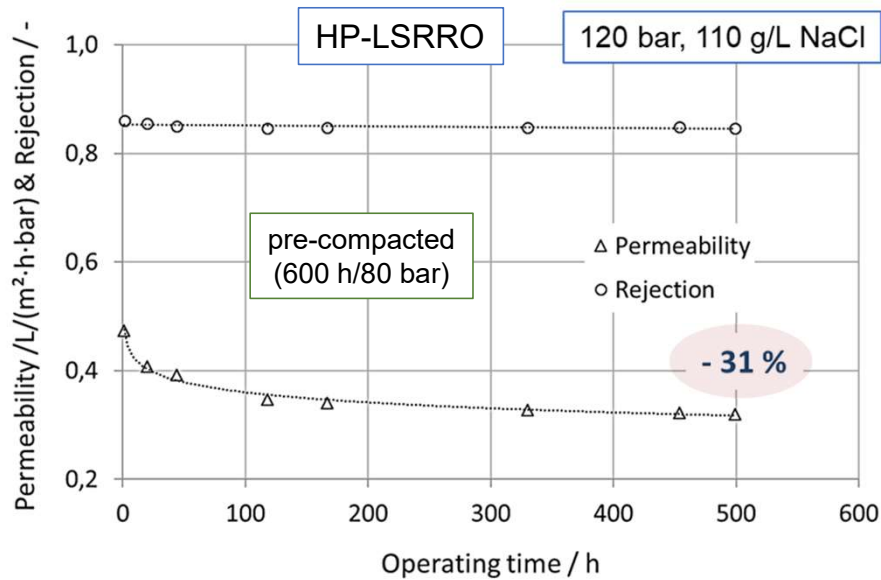


# Performance limiting effects

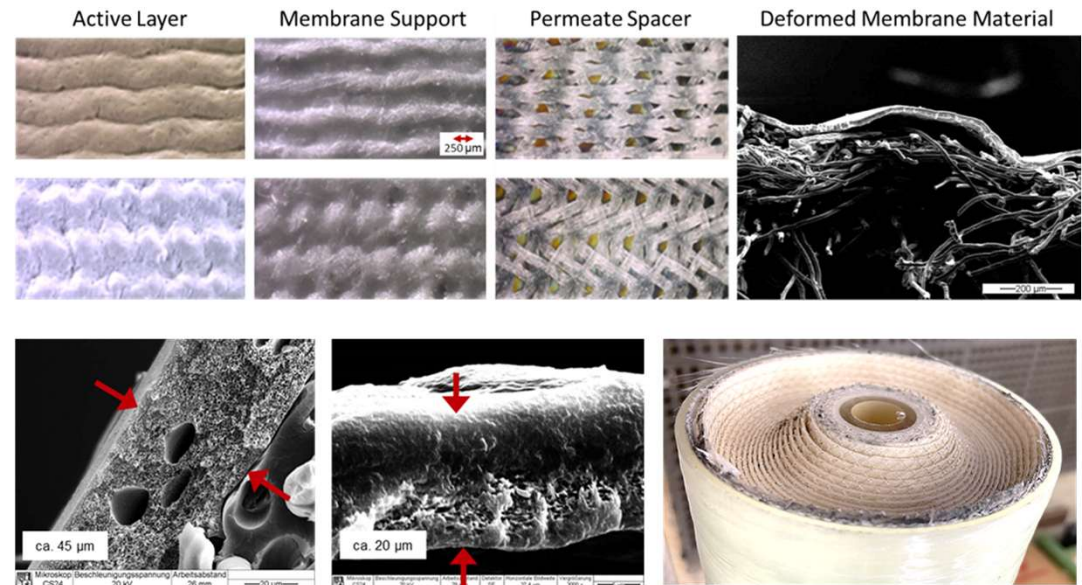
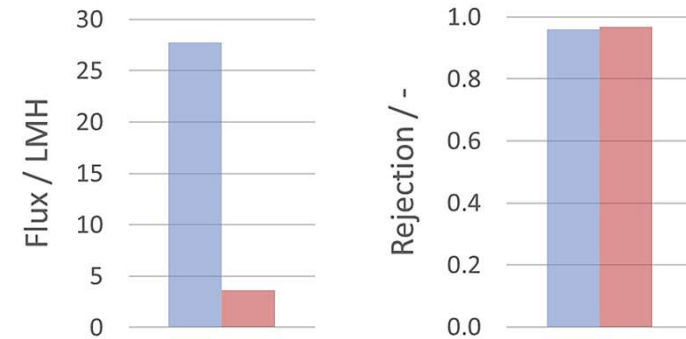
Mechanical stress intensifies performance-limiting effects induced by **membrane deformation**:

- **Membrane intrusion**: Direct reduction of net driving pressure (increased pressure drop in permeate channel)
- **Membrane compaction**: Microporous polysulfone layer (-50%)

→ Significant permeability decline over time:  
**Process design!**

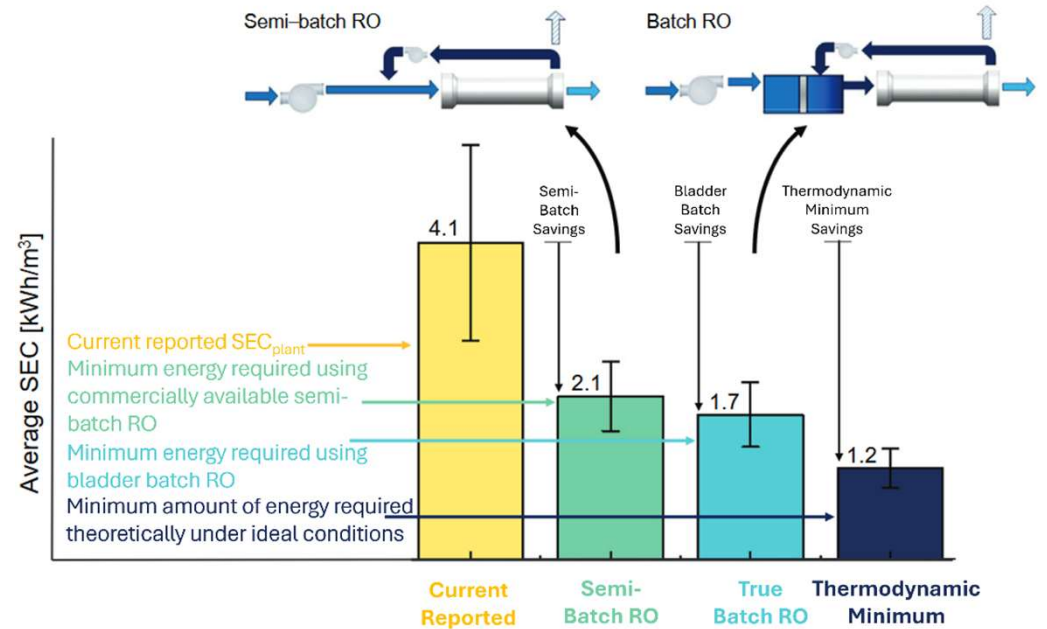
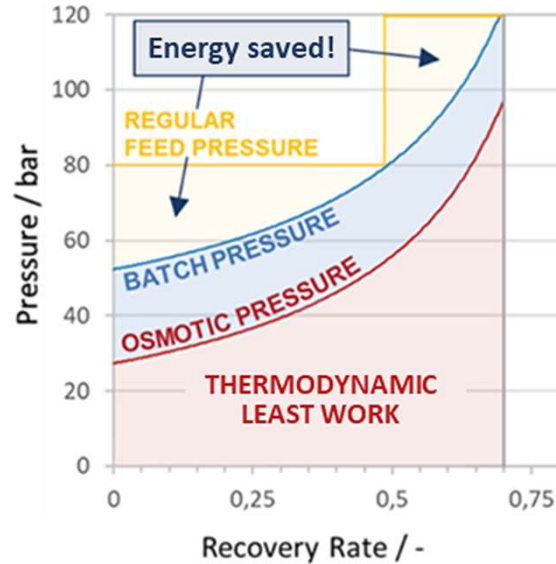


Standard tests: **Before** & **after** high-pressure exposure (5 bar, 2 g/L MgSO<sub>4</sub>)



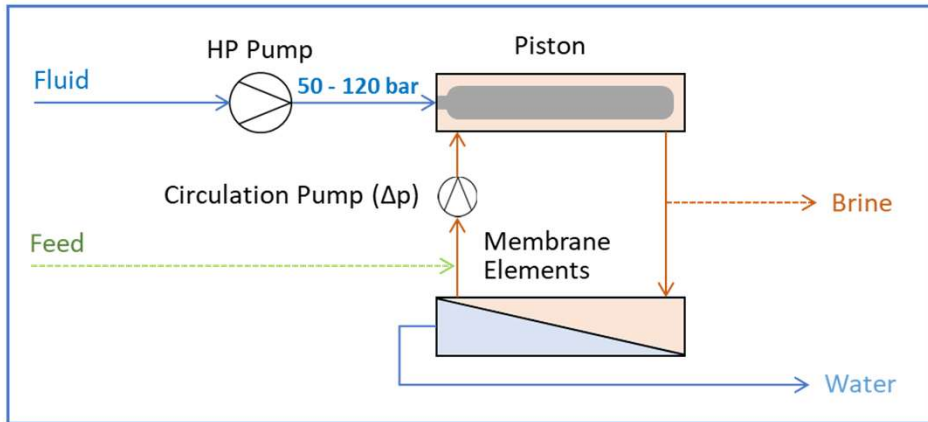
# What is next? Even higher feed pressures and ... dynamic desalting!

- Highest energy efficiency with infinite stages and no need for ERD's
- Min. scaling/ fouling potential & max. recovery
- Dynamic processing adjusts to fluctuating feed conditions



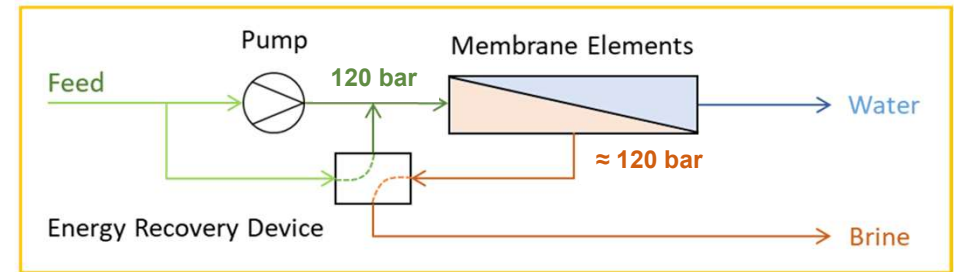
[S. Alnajdi et al., Practical Minimum Energy Use of Seawater Reverse Osmosis, Joule, Vol. 8, 11, 20 pp. 3088-3105, 2024]

## HP BATCH RO



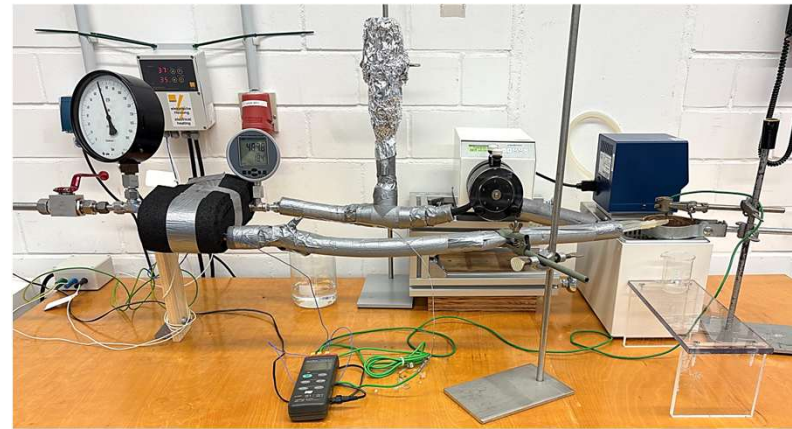
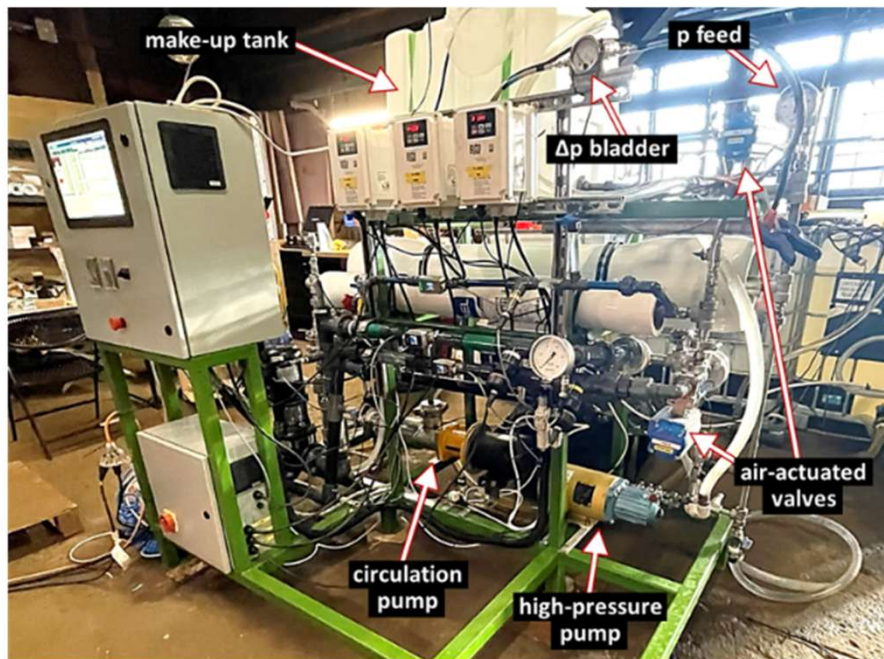
VS.

## HPRO + ERD



# Pushing the limits of process efficiency and performance

The XPRIZE Team *Renaissance Water* is developing **tailored spiral-wound elements** designed for ultra-high-pressure seawater desalination and **improved performance under both continuous and true batch RO operation**:

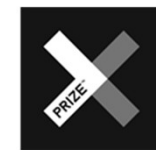


Left: Batch RO desalting skid, 1 x 4" element

Right: Lab-scale ultra-high-pressure permeate channel test cell

- Sustainable resource management and circular approaches require **extraordinary conditions**
- To **boost recoveries**, we must push process boundaries and **rethink element design**

## Team Renaissance Water:

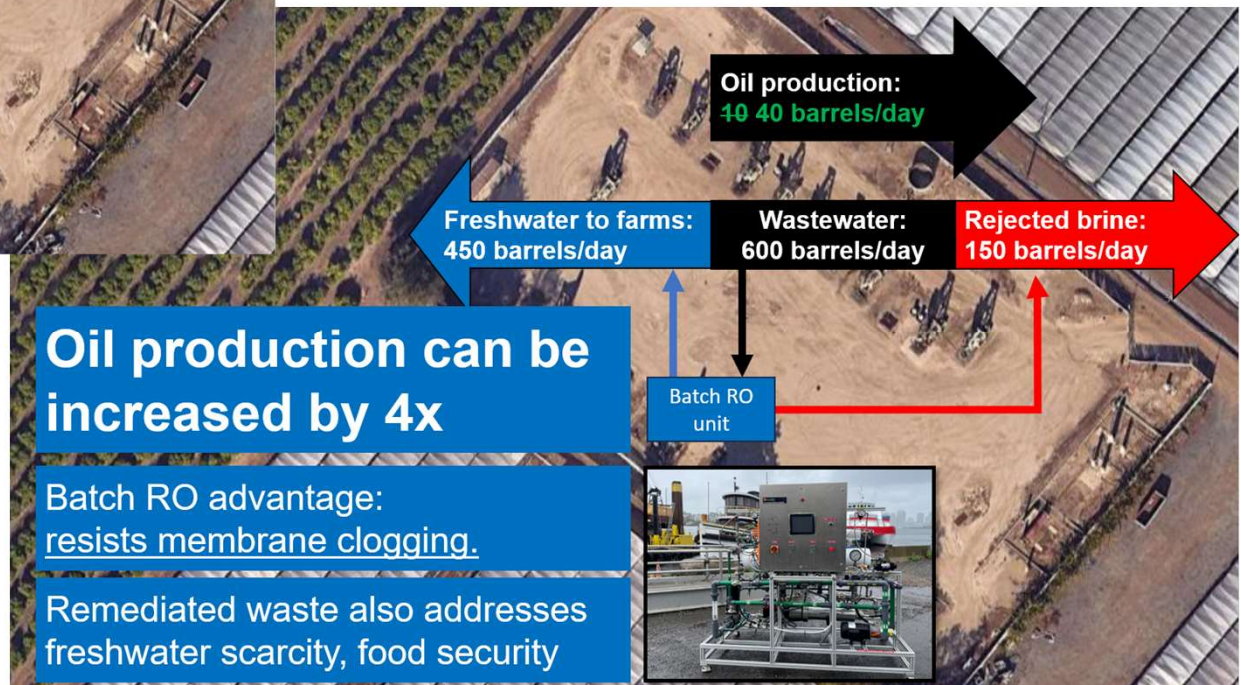


# Advanced dynamic desalting for produced water treatment



Water sources with **complex geochemistry**: saturated in sparingly soluble minerals & metals, poor microbiological/organic quality. Various **combinations of physical/chemical pre-treatments** (disinfection, softening, coagulation, filtration, pH adjustment, anti-scalings addition) needed to mitigate RO membrane fouling & scaling. → **High CAPEX & OPEX**

Advanced **dynamic desalting processes** could reduce costs, footprint, freshwater recovery, and operational complexity, while maintaining stable operation when facing feed waters with **high fouling and scaling potential**:  
**5 m<sup>3</sup>/day @ max. 83 bar, Feed TDS: 40,000 mg/L**



**Oil production can be increased by 4x**

Batch RO advantage: resists membrane clogging.

Remediated waste also addresses freshwater scarcity, food security