UNIVERSITÀ DEGLI STUDI DI PALERMO
Dipartimento di Ingegneria Chimica, Gestionale, Informatica, Meccanica (DICGIM)

REAPower
www.reapower.eu

REAPower: Use of Desalination Brine for Power Production through Reverse Electrodialysis

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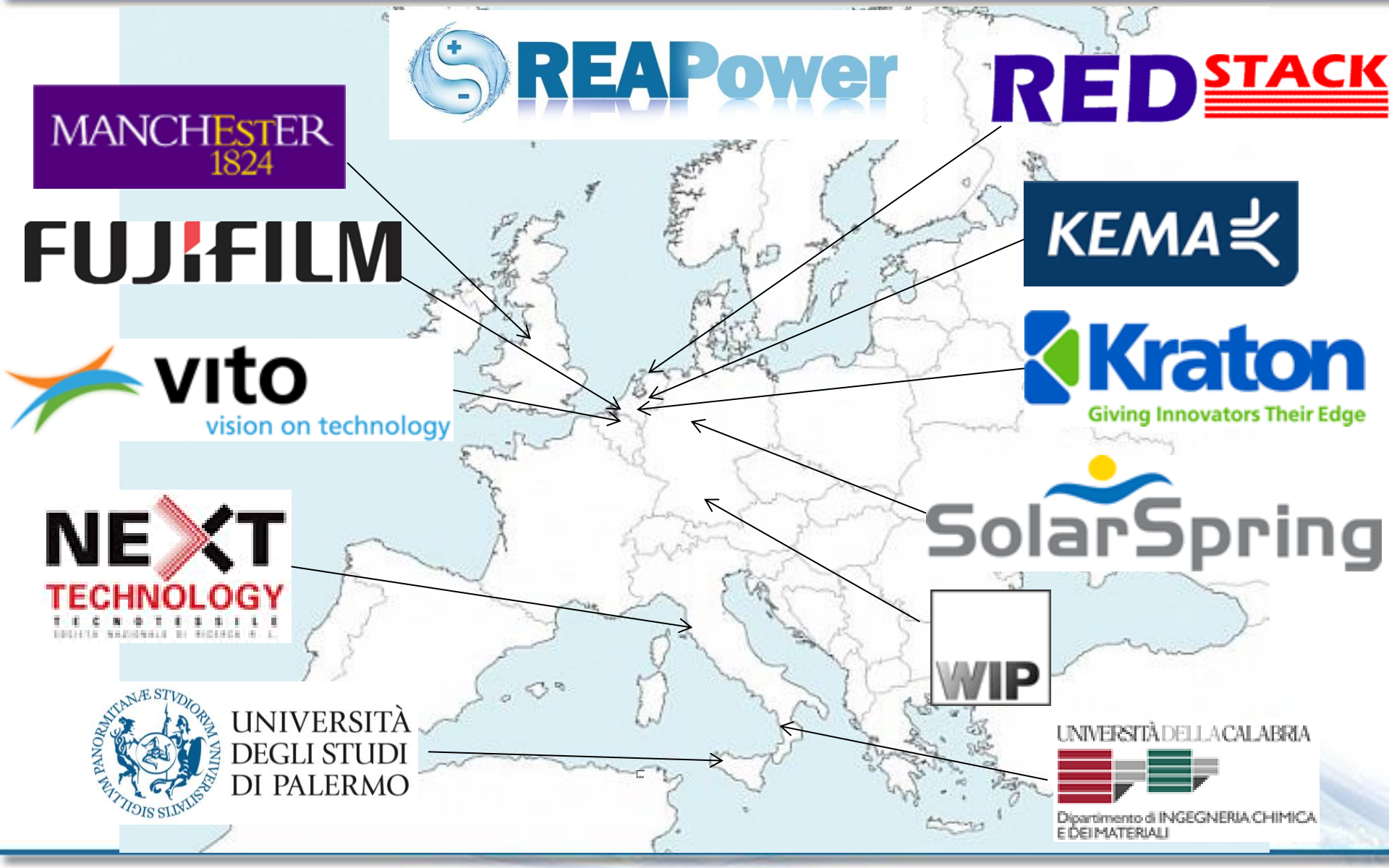
International Conference *WIN4Life*
Tinos Island (Greece) – 19th-21st September 2013

The REAPower Project

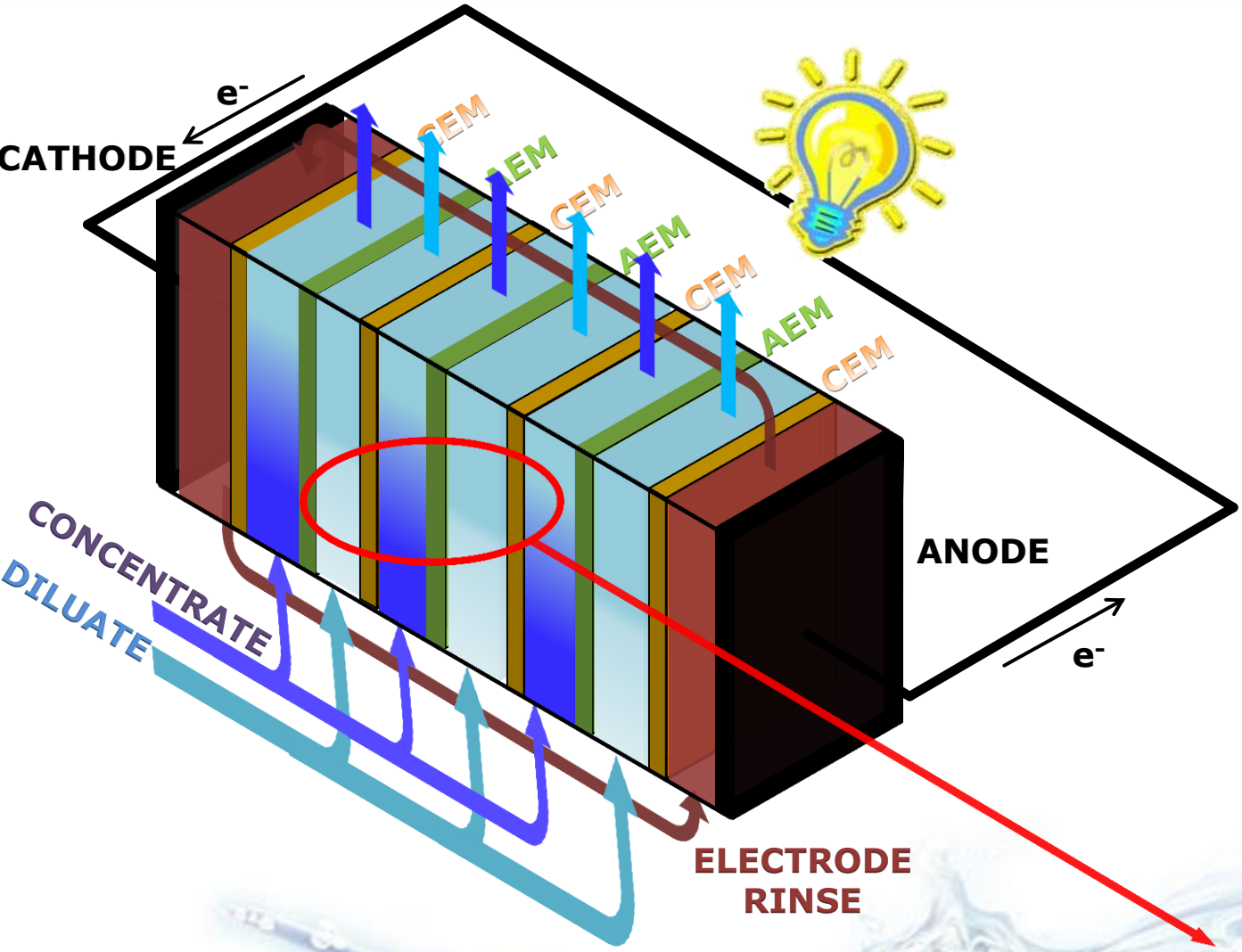
Main facts:

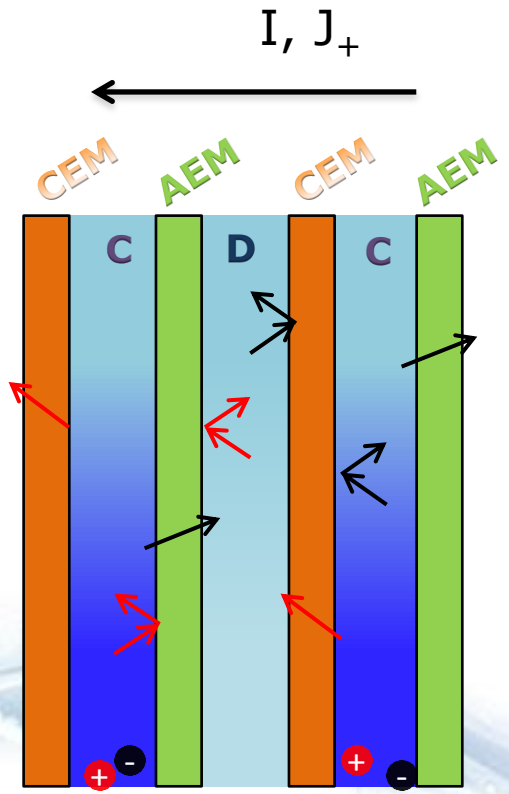
- Project title: *Reverse Electrodialysis Alternative Power Production*
- Call identifier: FP7-ENERGY-2010-FET (Future Emerging Technologies for Energy Applications)
- Starting date: 1 October 2010
- Closing date: 30 September 2014

The REAPower Project Consortium



The Reverse Electrodialysis technology





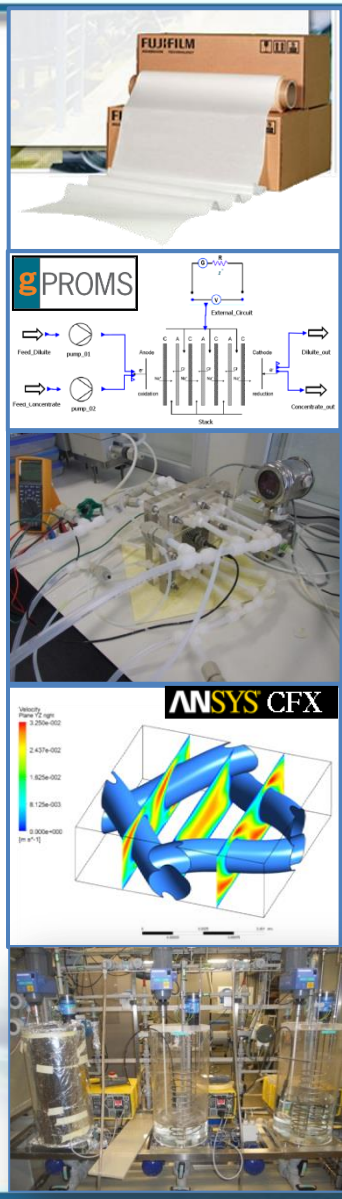
The REAPower Project

The idea

to produce energy from salinity gradients generated by sea/brackish water and ultra-concentrated brines

R&D strategy

- ✓ Development of new **Ion Exchange Membranes** for highly concentrated solutions
- ✓ Selection of best conditions for **redox couple/stack design**
- ✓ Wide **experimental investigation** on lab-scale stack
- ✓ Development/validation of a **predictive modelling tool**
- ✓ **Economic analysis** and process sustainability on large scale



Improvements in membranes development

Increased **permselectivity**

✓ Permselectivity has achieved values of **65% for AEM** and **up to 90% for CEM** when **in contact with** almost saturated **brine**

Reduced **membrane resistance**

✓ Membrane specific resistance reduced to **1.5-2.5 Ω·cm²** aiming at a 3-5 folds reduction in the next months

Electrochemical aspects and stack design

Redox couples selection

Investigated redox couples under different conditions:

- ✓ **$FeCl_3/FeCl_2$**
- ✓ **$K_3Fe(CN)_6/K_4Fe(CN)_6$**
- ✓ Fe(III)-EDTA/Fe(II)-EDTA

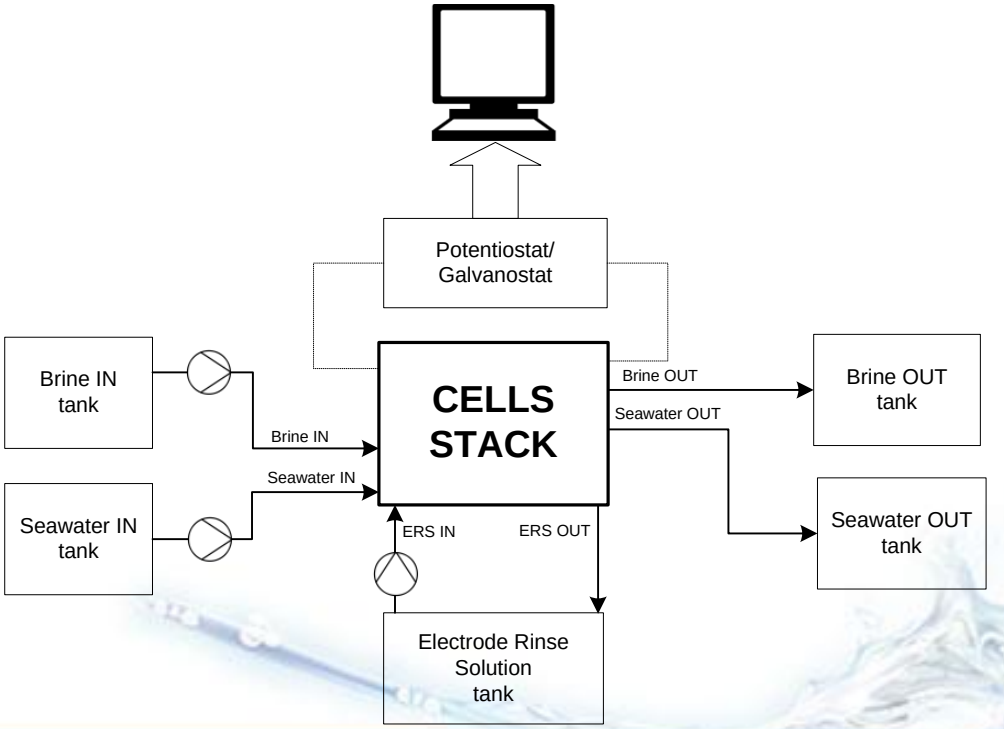
New **stack design**

- ✓ Two different **stack geometries** already designed, constructed and tested
- ✓ Currently available for the consortium

Experimental investigation on a lab-scale unit

Experimental conditions already investigated:

- ✓ fluid velocity (0.1 – 4 cm/s)
- ✓ feed temperature (20 – 40 °C)
- ✓ number of cell pairs (5 – 50)
- ✓ concentration of redox couple (0.1 – 0.3 M of $K_3Fe(CN)_6/K_4Fe(CN)_6$)
- ✓ salt concentration of both solutions.



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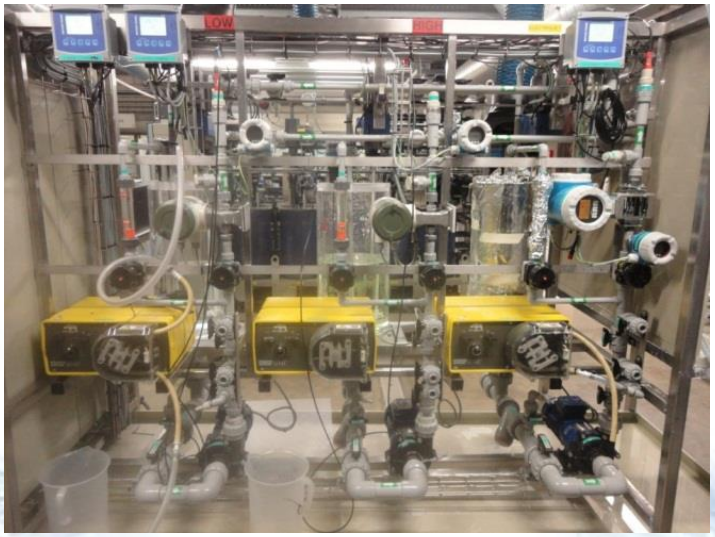
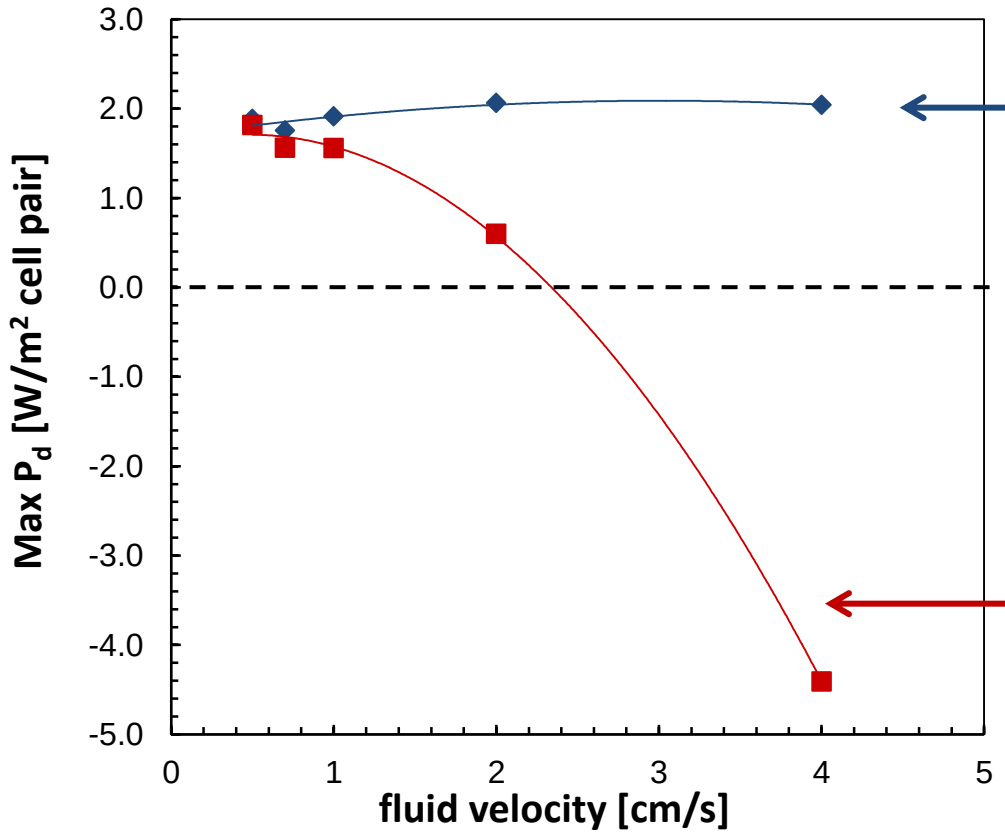
vision on technology



Experimental investigation on a lab-scale unit

Effect of fluid velocity on power output



Max power density (gross)

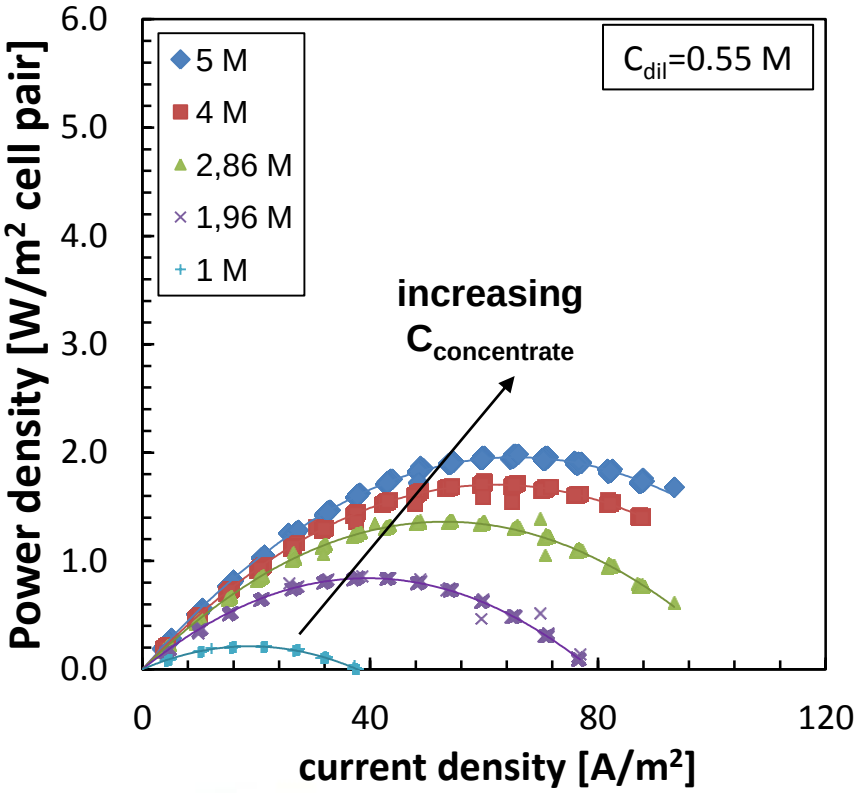
Max power density (net): Power density – Hydraulic losses

Stack equipped with 50 cell pairs, Fujifilm membranes, Deukum 270 µm spacers .Brine solution: 5 M NaCl, seawater: 0.5 M NaCl. T=20° C. Electrode rinse solution: 0.1 M $K_3Fe(CN)_6$ / $K_4Fe(CN)_6 \cdot 3H_2O$ + 2.5 M NaCl.

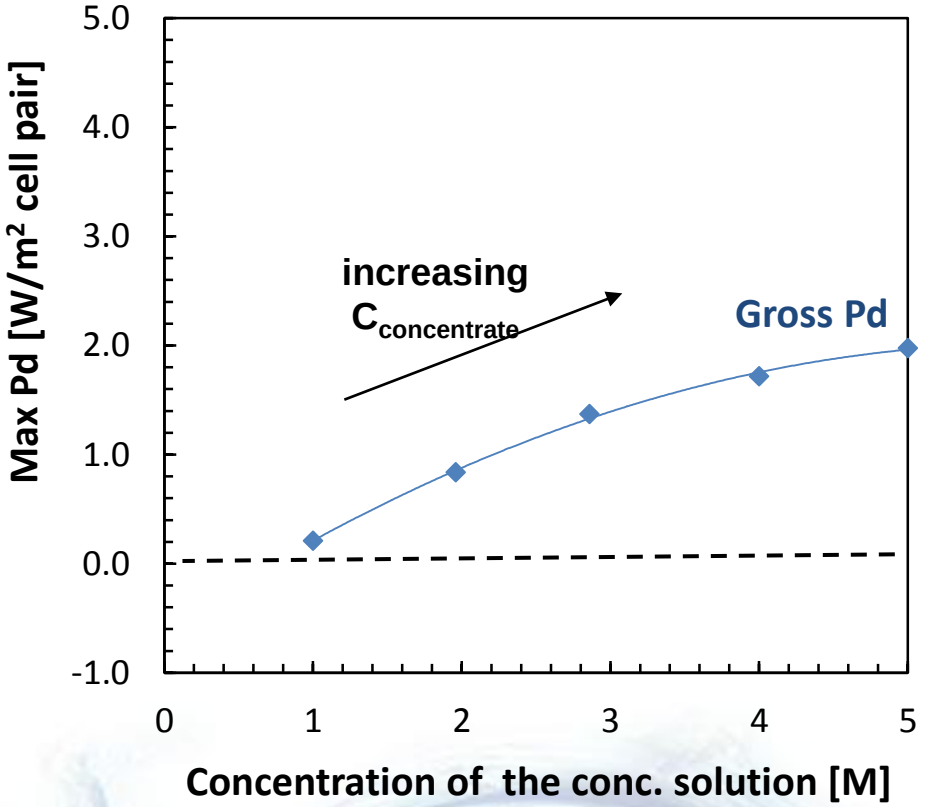
Experimental investigation on a lab-scale unit

Effect of the concentration of the concentrated solution (1 ÷ 5 M)

Power density vs. current density



Maximum power density vs. C_{conc}

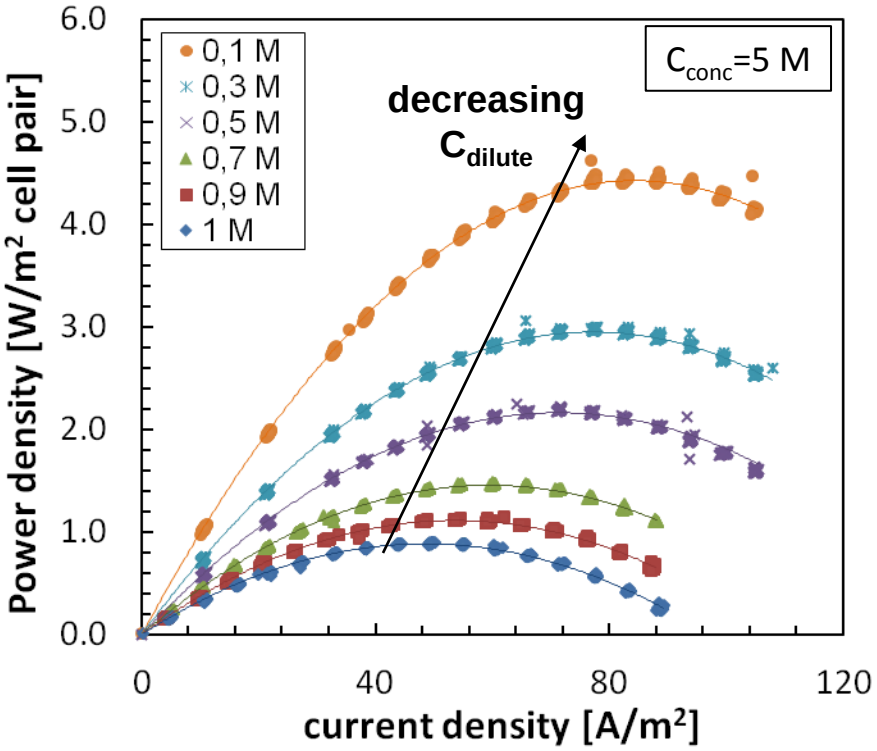


Stack equipped with 50 cell pairs, Fujifilm membranes, Deukum 270 µm spacers . Seawater: 0.55 M NaCl. T=20° C. Fluid velocity: 1 cm/s. Electrode rinse solution: 0.1 M $K_3Fe(CN)_6$ / $K_4Fe(CN)_6 \cdot 3H_2O$ + 2.5 M NaCl.

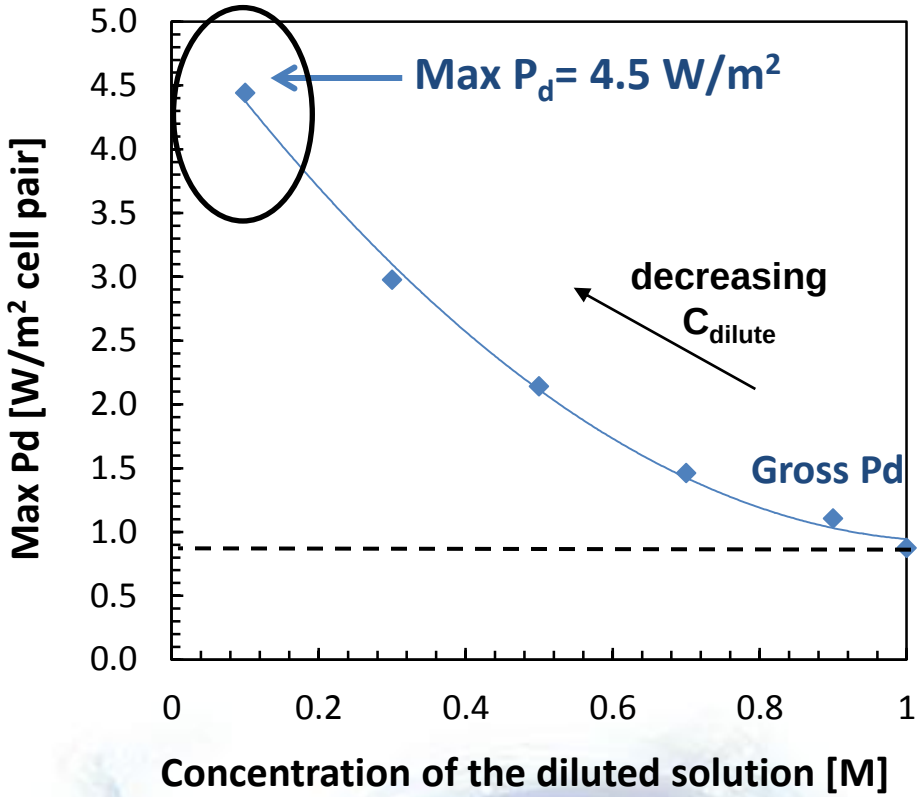
Experimental investigation on a lab-scale unit

Effect of the concentration of the diluted solution (0.1 ÷ 1 M)

Power density vs. current density



Maximum power density vs. C_{dilute}



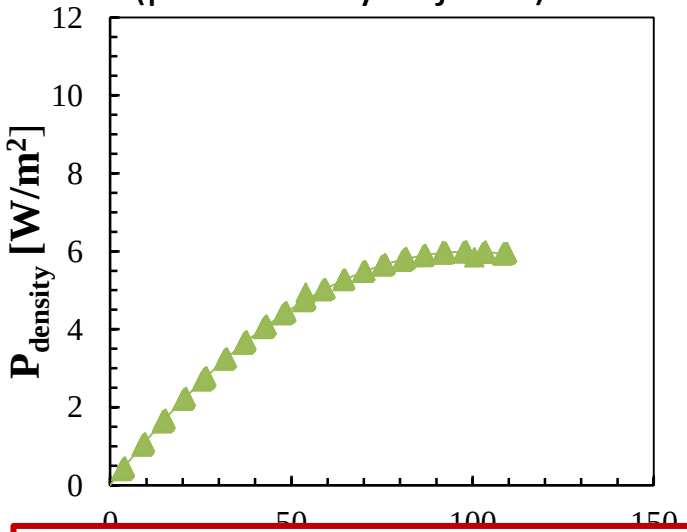
Stack equipped with 50 cell pairs, Fujifilm membranes, Deukum 270 µm spacers . Brine: 5 M NaCl. T=20° C. Fluid velocity: 1 cm/s. Electrode rinse solution: 0.1 M $K_3Fe(CN)_6$ / $K_4Fe(CN)_6 \cdot 3H_2O$ + 2.5 M NaCl.

Experimental investigation on a lab-scale unit

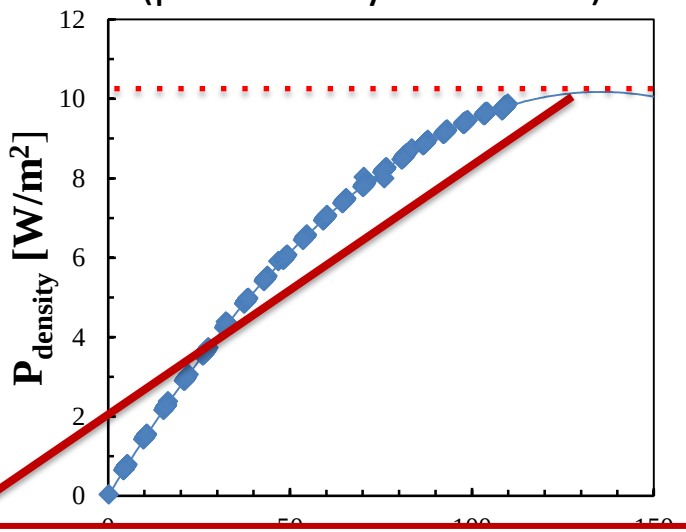
MAX power output conditions:

4cm/s, T = 40°C & brackish water diluate (0.1M)

Thick membranes (120 µm)
(provided by Fujifilm)



Thin membranes (20-30mm)
(provided by Fumatech)



Power density between **15 and 20 W/m²** can be expected with larger number of cell pairs, i.e. reducing the effect of **blank resistance**

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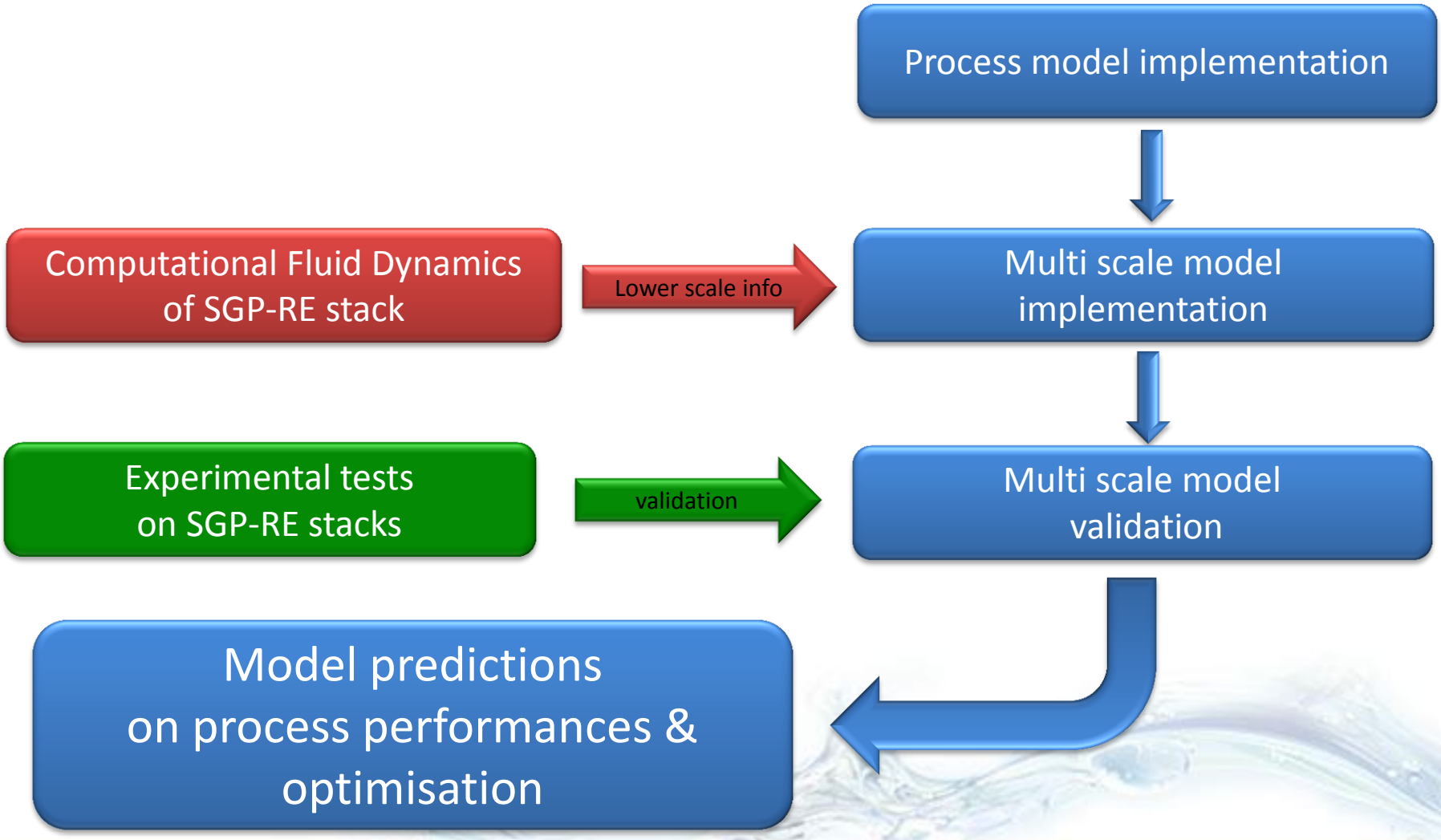
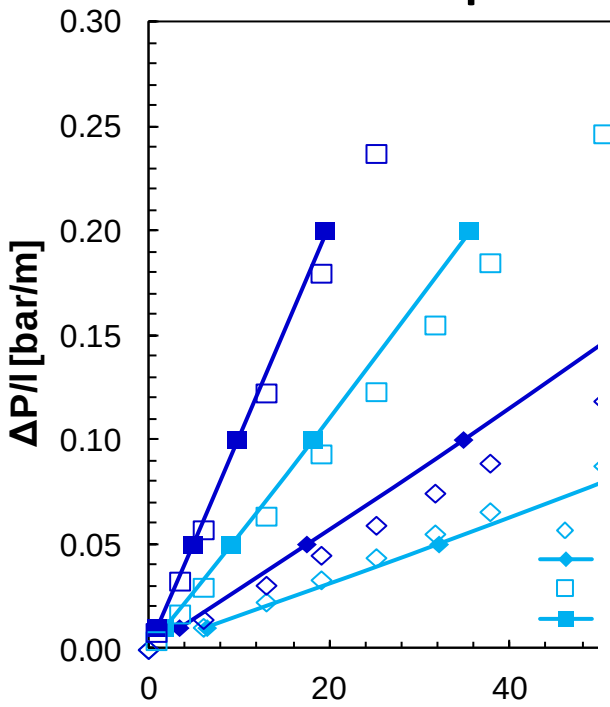
CFD modelling and process simulation

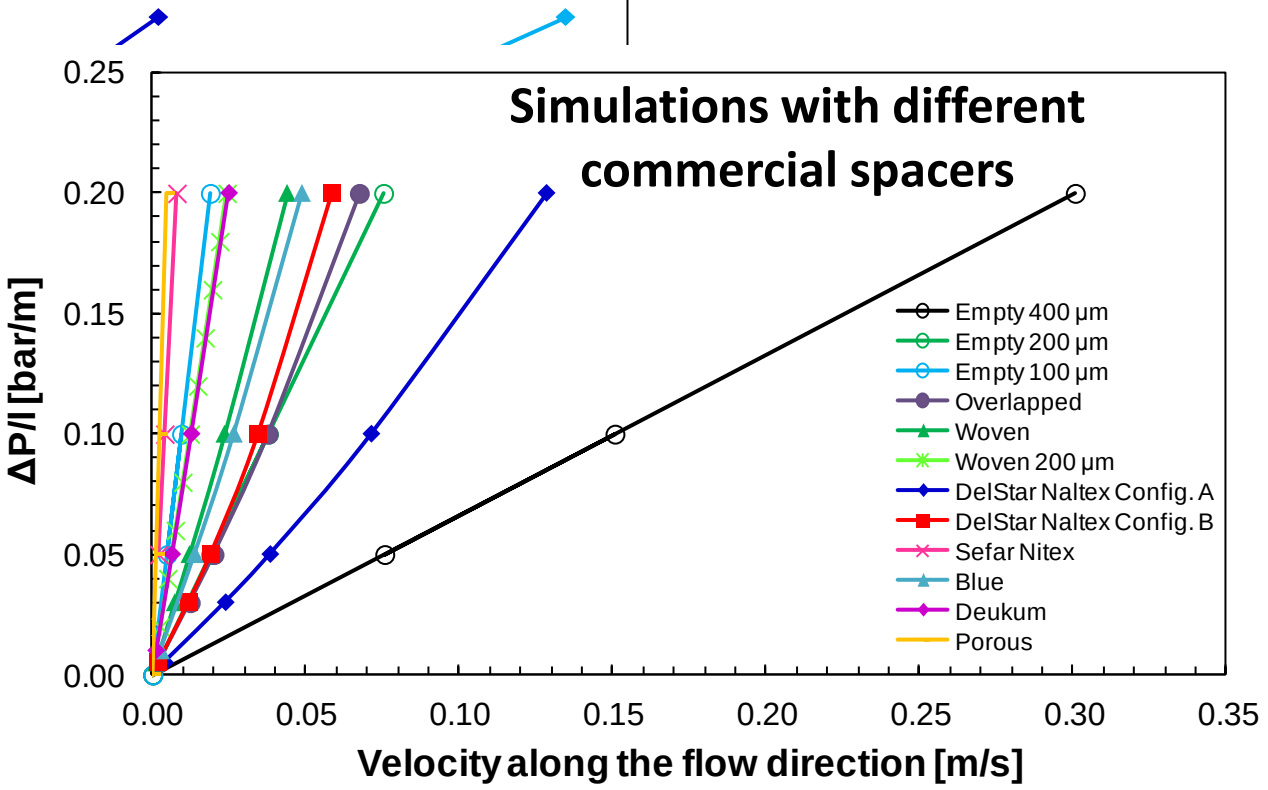
Multi-Scale Modelling approach:



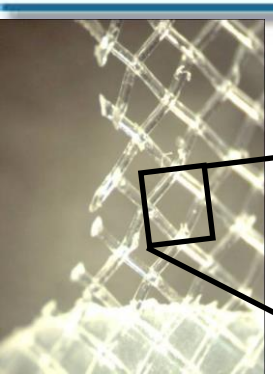
CFD Modelling: prediction of pressure drops

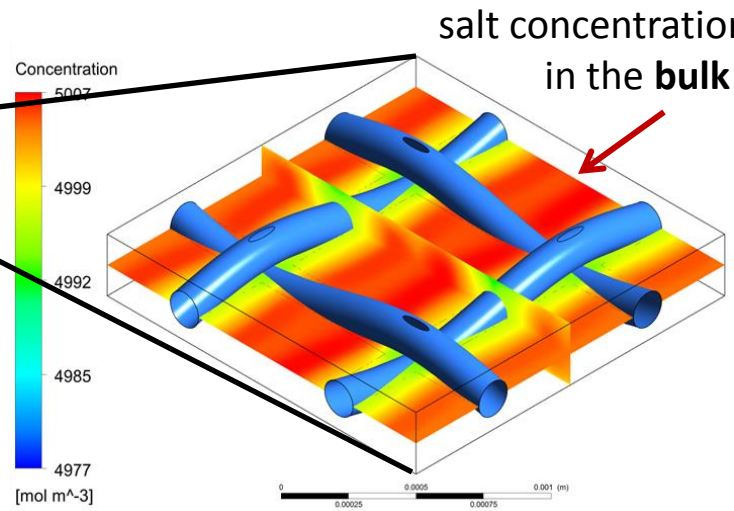
Model validation with experimental results

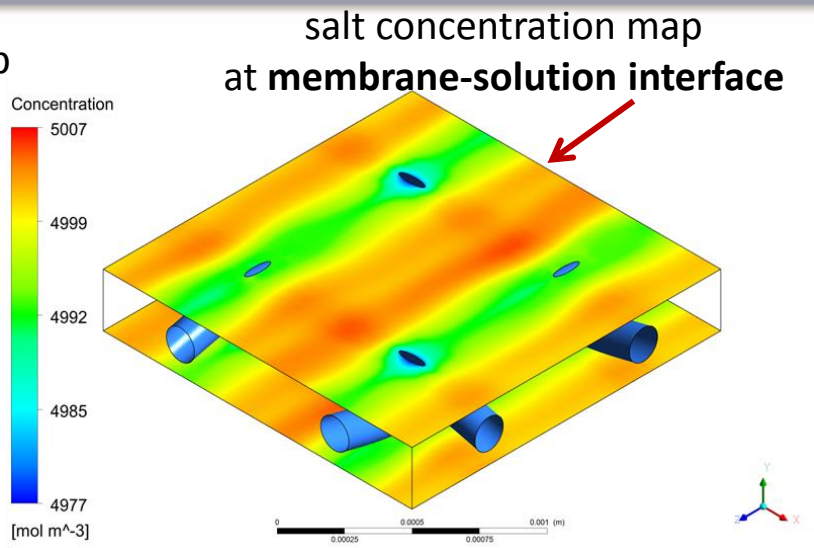




CFD Modelling: prediction of polarisation phenomena

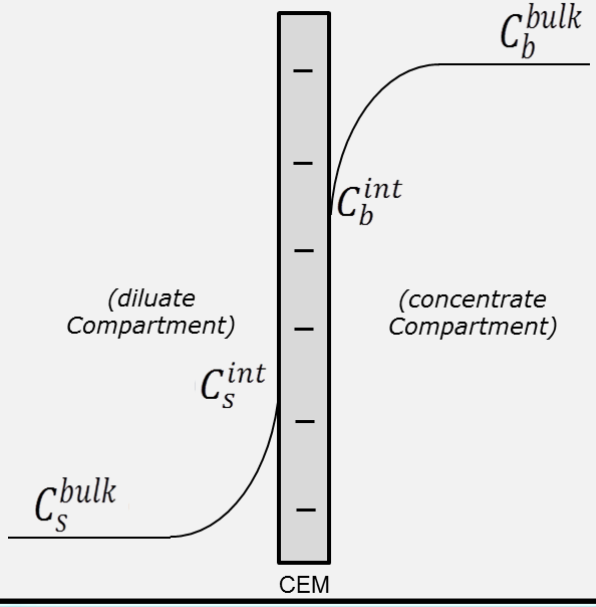






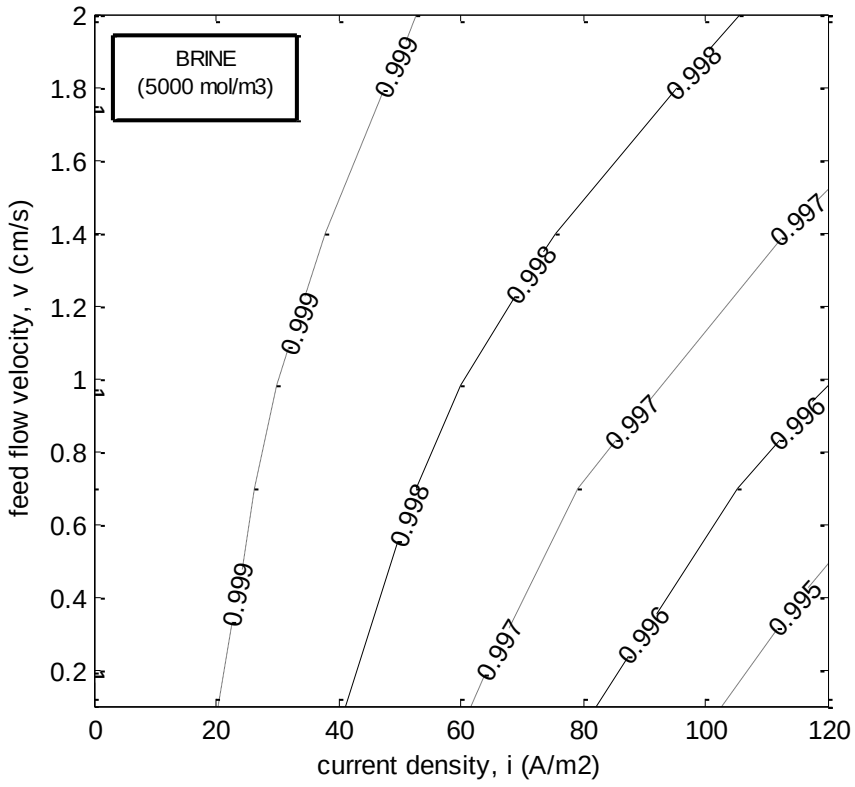
Polarisation Coefficients:

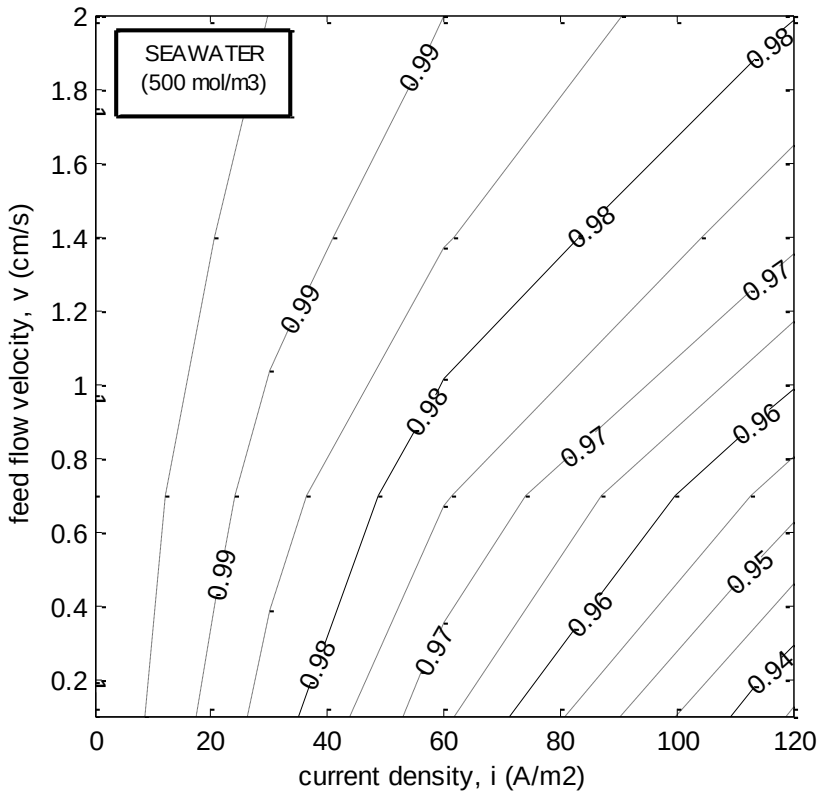
$$\begin{cases} \vartheta_b = \dfrac{C_b^{int}}{C_b^{bulk}} \\ \vartheta_s = \dfrac{C_s^{bulk}}{C_s^{int}} \end{cases}$$



CFD Modelling: prediction of polarisation phenomena

Polarization factor for Deukum spacer-filled channels



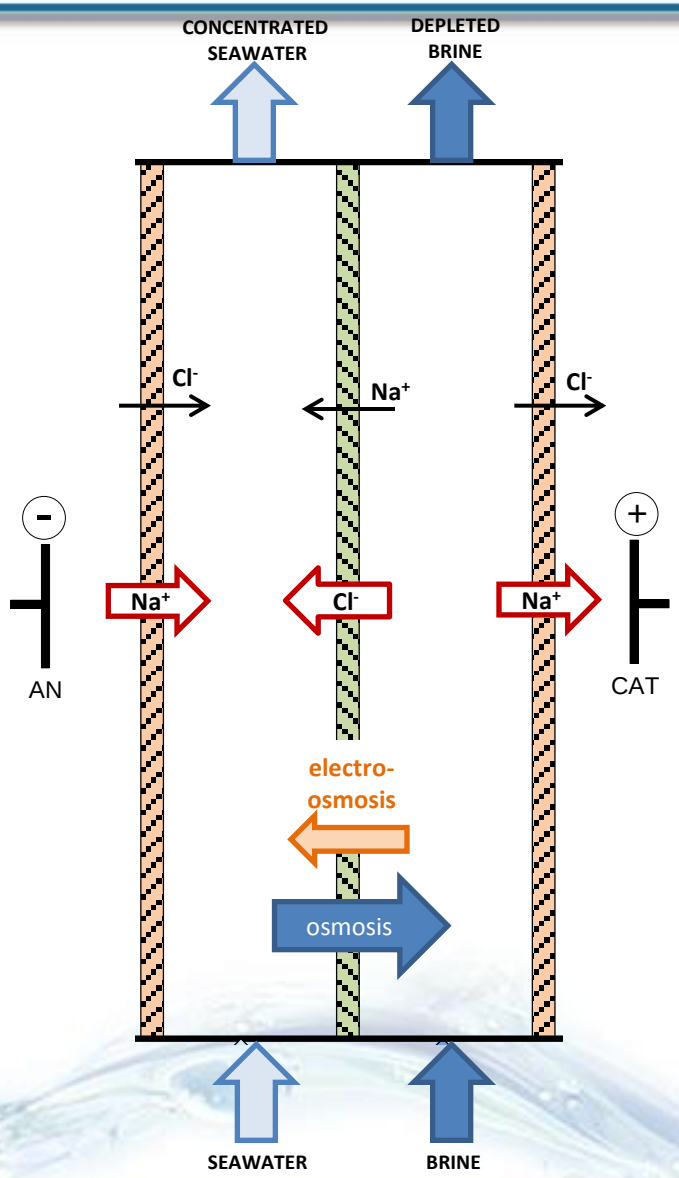


Effect of current density and fluid velocity on polarization coefficients.
CFD Model predictions of a 270 µm polyamide woven spacer (Deukum GmbH, Germany).

Development/validation of process simulator

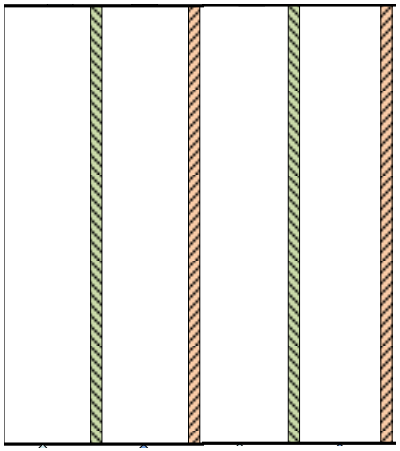
Low-hierarchy model (*cell pair*):

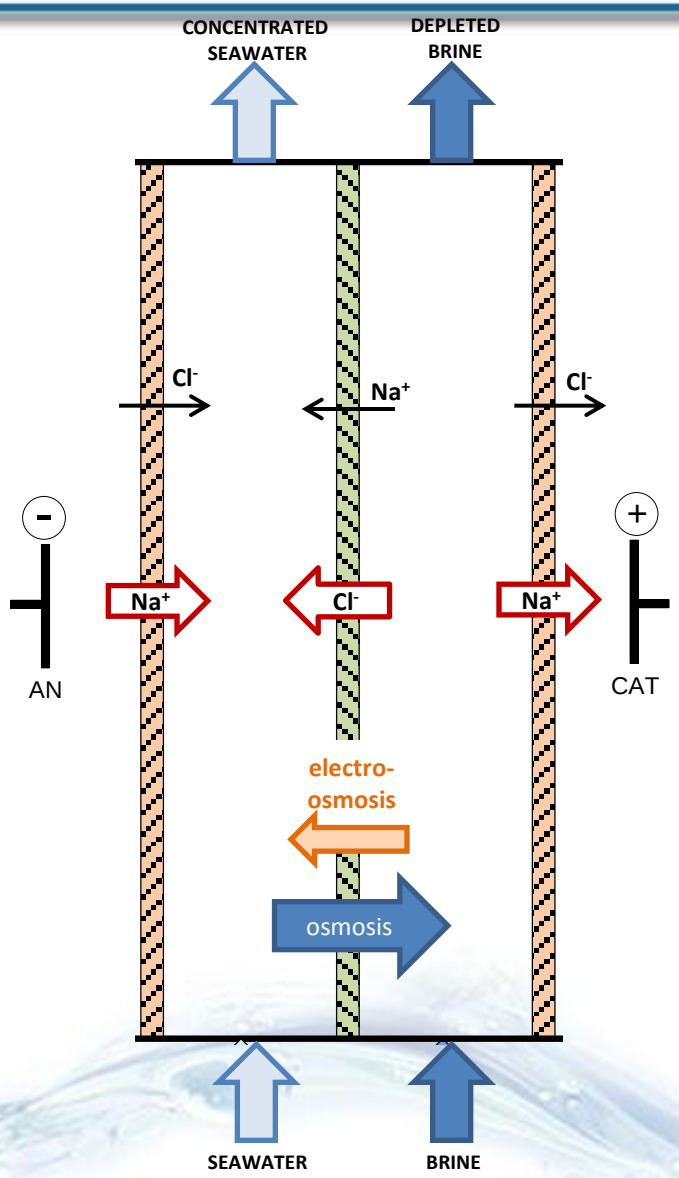
- thermodynamic properties of solutions
- electric variables
- salt transport (counter/co-ions)
- solvent transport (osmosis/electro-osmosis)
- polarization phenomena
- mass balance



Source: M. Tedesco *et al.*, *Desalination and Water Treatment*, vol. 49, pp. 404-424, 2012

Process Modelling Approach





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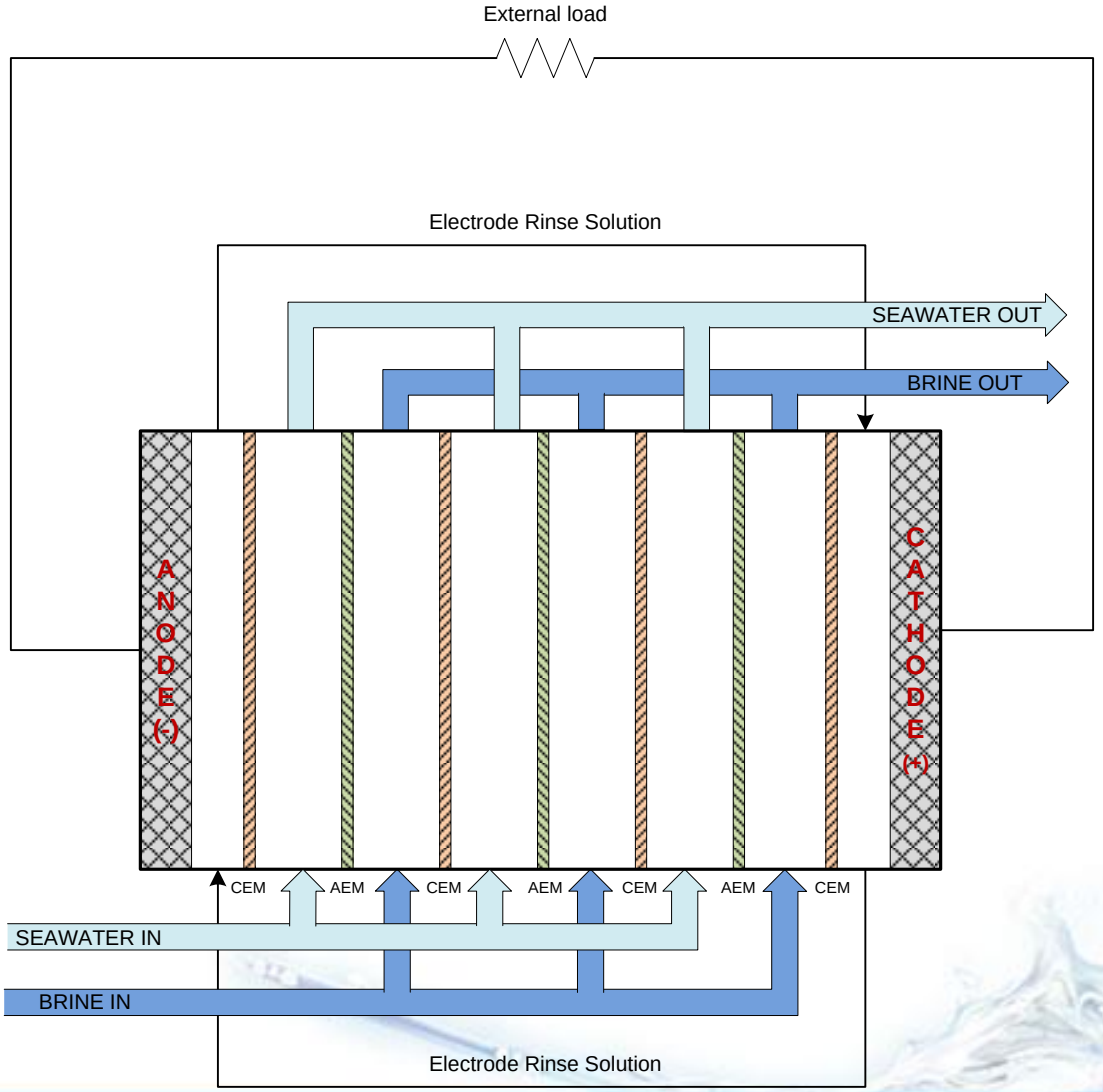
Process Modelling Approach

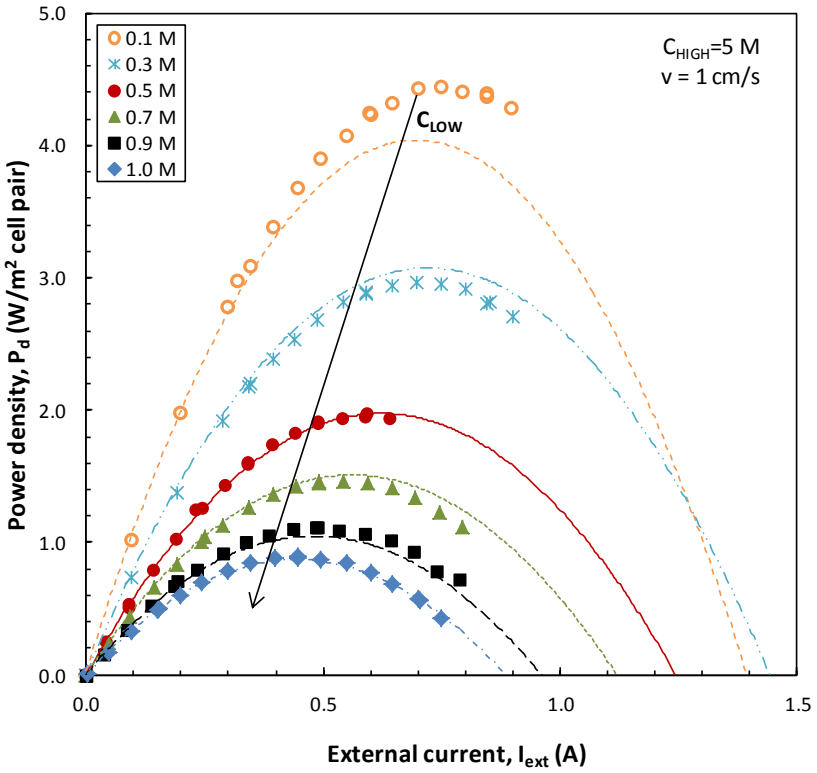


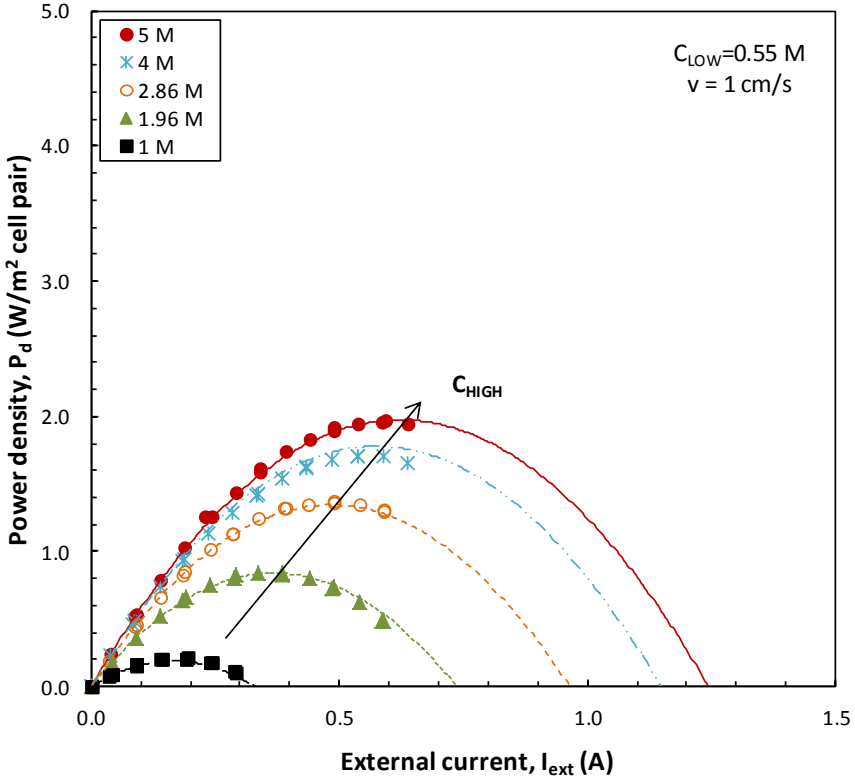
High-hierarchy model (*stack*):

- parasitic currents through manifolds
- stack resistance
- stack voltage
- Pressure drops
- power density (gross/net)

Process Modelling validation

Model calibration with variable feed concentration

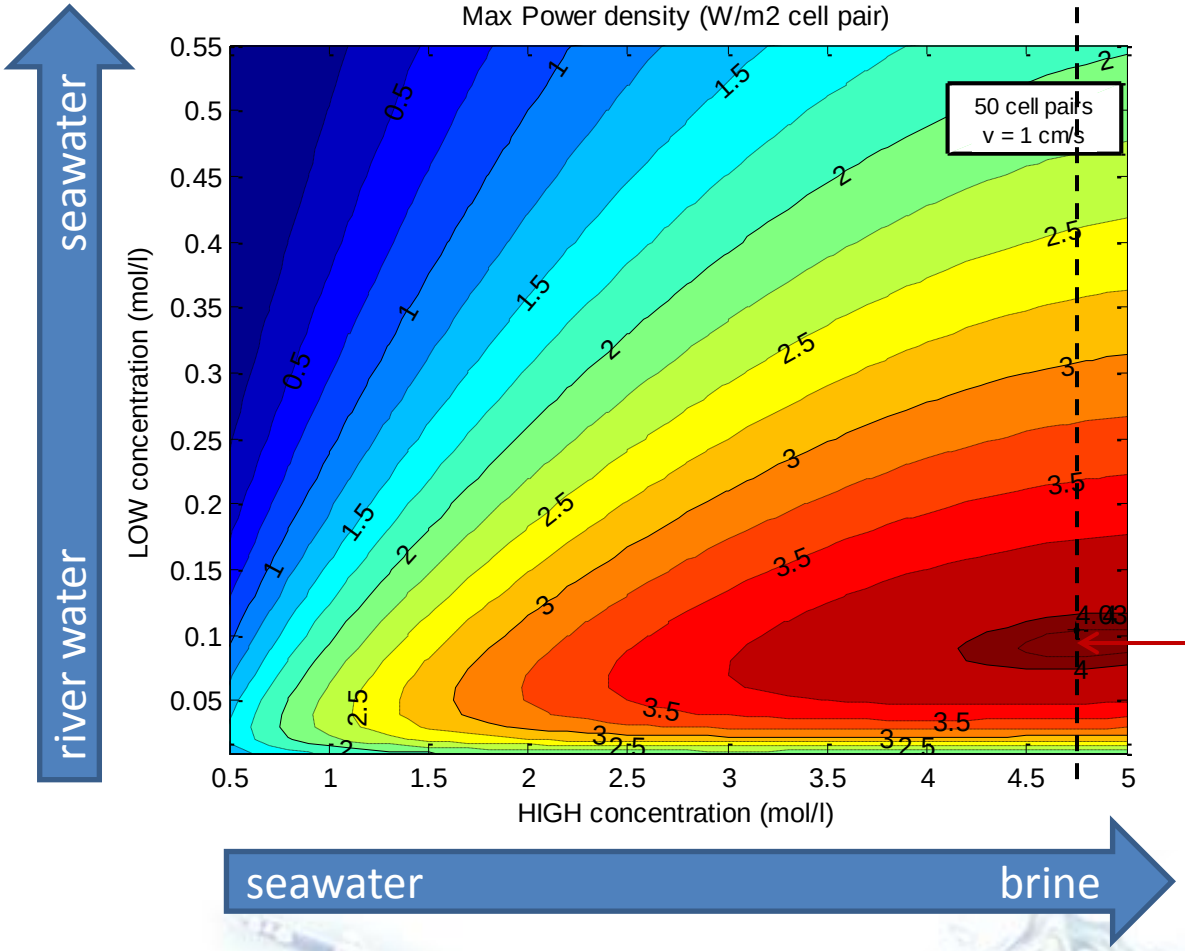




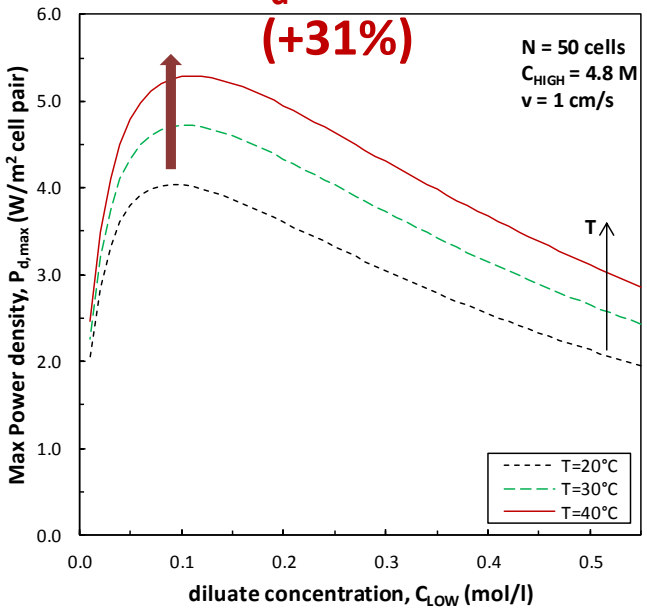
Experimental (points) and simulated (lines) data for a 50-cells stack equipped with Fujifilm membranes, Deukum 270 µm spacers; feed flow velocity: 1 cm/s; T=20° C. Blank resistance: 0.4 Ω.

Prediction of dependences

Influence of feed T & concentration



Max P_d= 5.3 W/m²
(+31%)

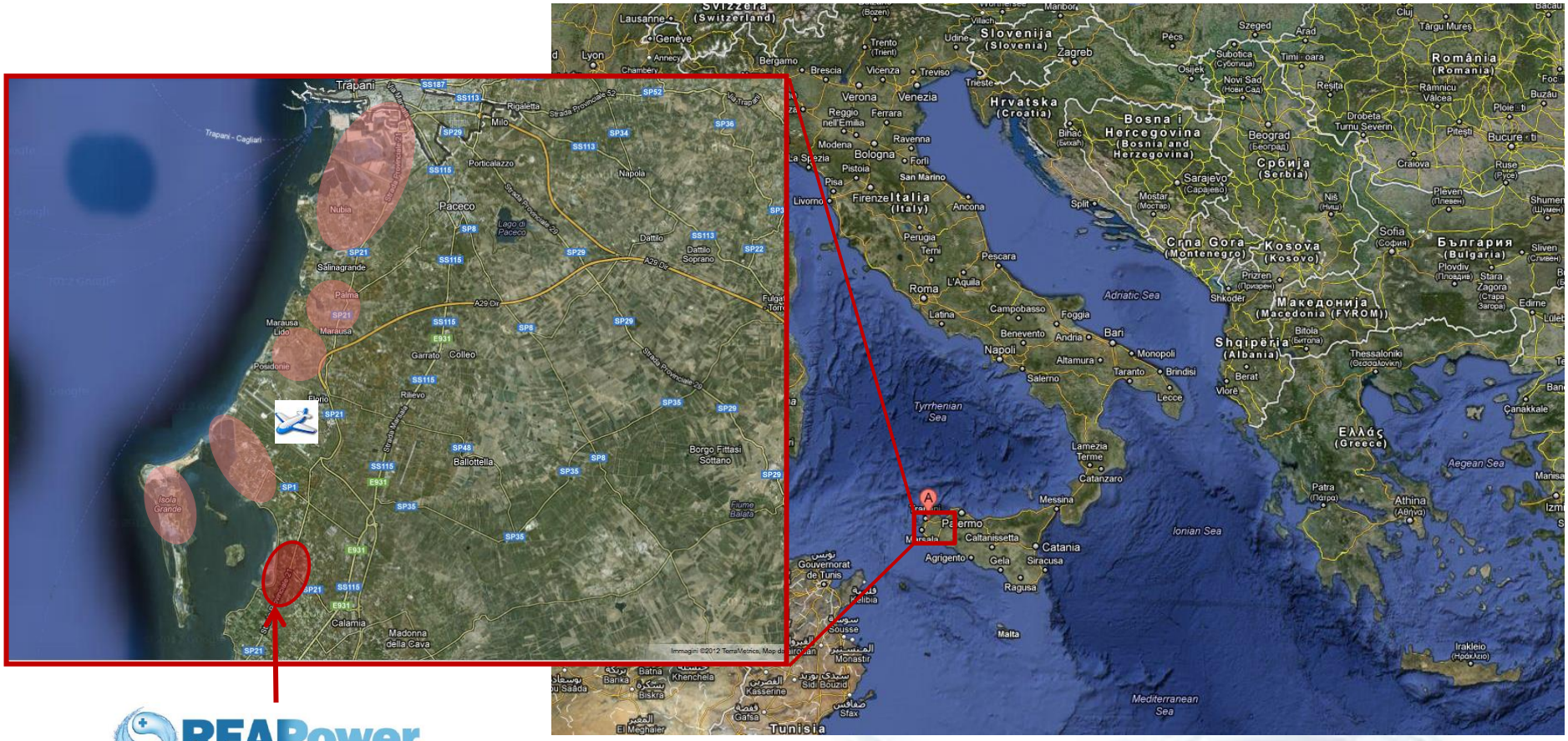


BEST conditions:
brackish water (0.05 – 0.1 M)
+ brine (4.5 – 5 M)

Simulations of a 50-cells stack equipped with Fujifilm membranes, Deukum spacers; fluid velocity inside channels: 1 cm/s; T=20° C. Blank resistance: 0.4 Ω.

The REAPower prototype installation site

The singular framework of Trapani saltworks



REAPower

Prototype installation site

The REAPower prototype installation site

The "*Ettore-Infersa*" saltworks

Direct access to both saturated brine and seawater from open channels

Installation place within an old, restructured WINDMILL

Prototype installation: plant specifications

Site features

- Seawater availability: unlimited;
- Brine availability: 10-15 m^3/h (much larger with feed-recycle);
- Brine concentration: variable between 250 and 320 gr/lt.

Provisional Prototype features

- Total cell pair surface: from 4 to 125m^2 (2 stacks will be tested);
- Expected power density: > 5 W/m^2;
- Expected power output: from 20 to 600W

The REAPower website

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EDS
European Desalination Society

EUROMED 2014
PALERMO, October 2014

Thank you

for your attention

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