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Osmotic Power and Salinity Gradient Energy - REAPower

INES Seminar in Brussels 23 June 2014

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www.reapower.eu

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REAPower: use of desalination brine for power production through reverse electrodialysis

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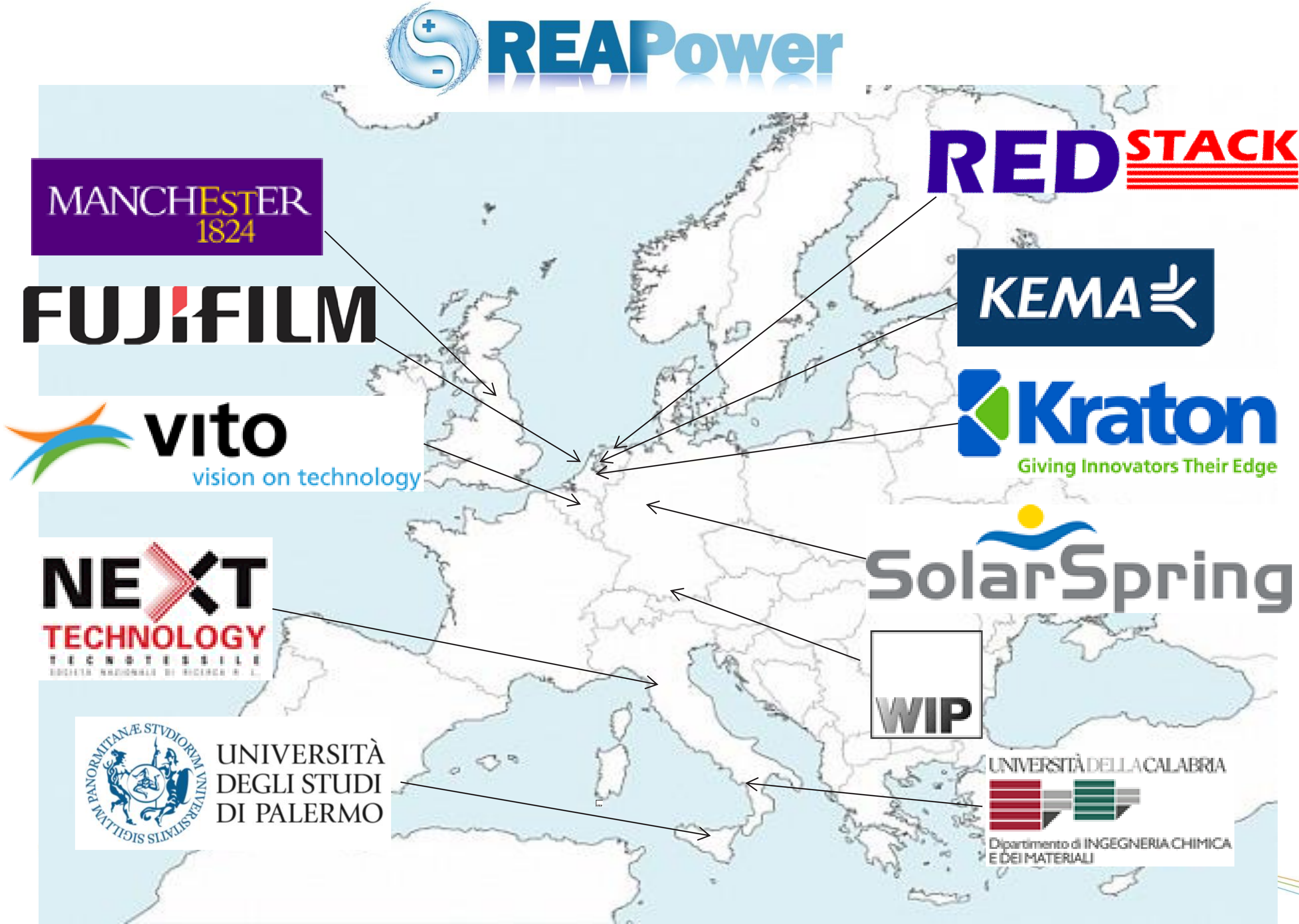
The REAPower Project

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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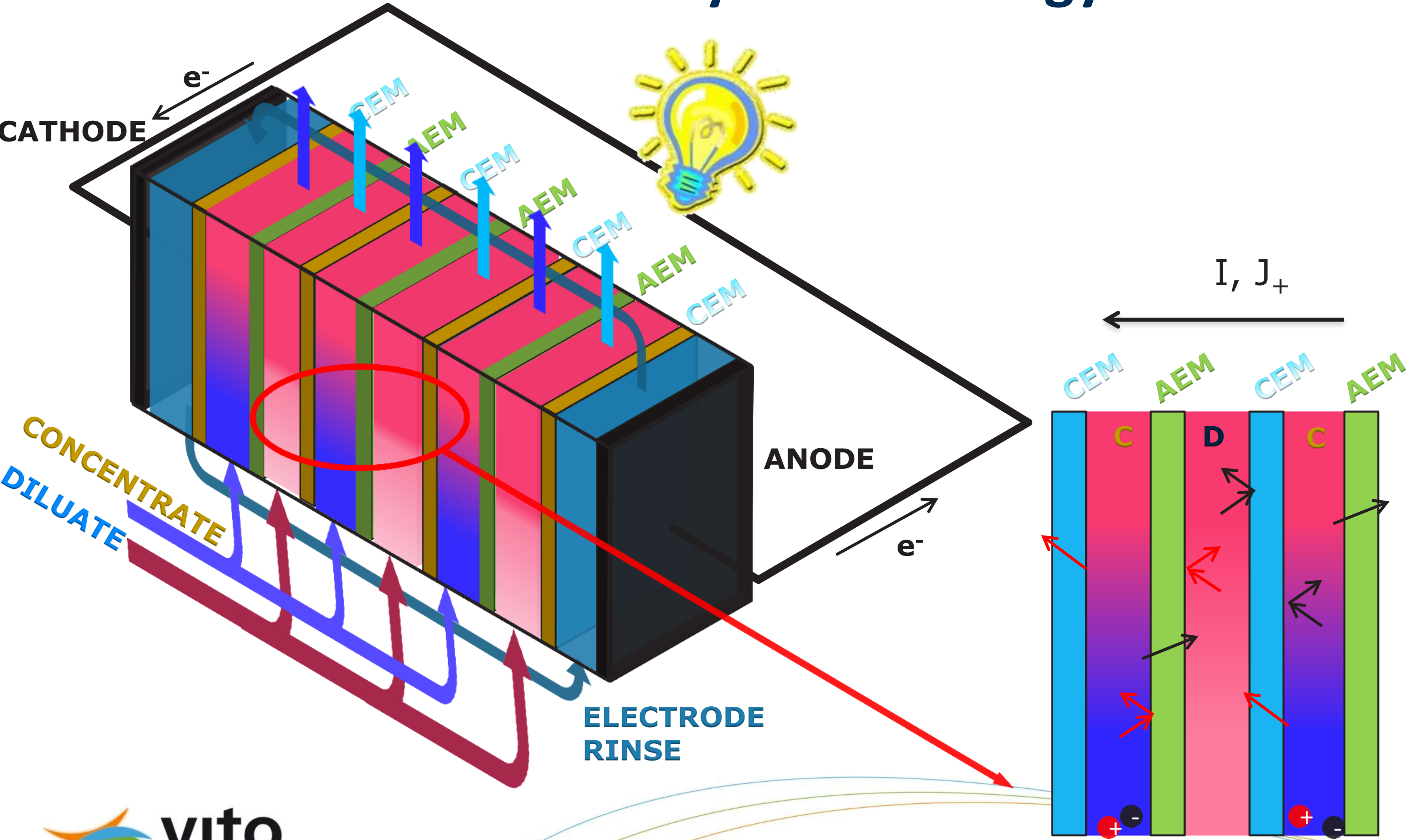
The Reverse Electrodialysis technology



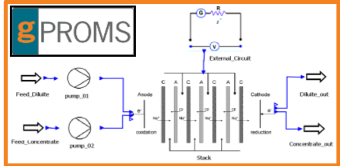
The REAPower Project

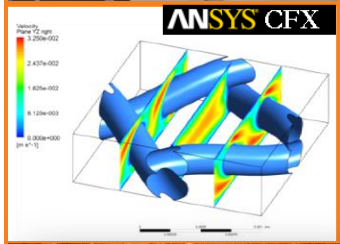
The idea

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** possibly lower in the near future

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

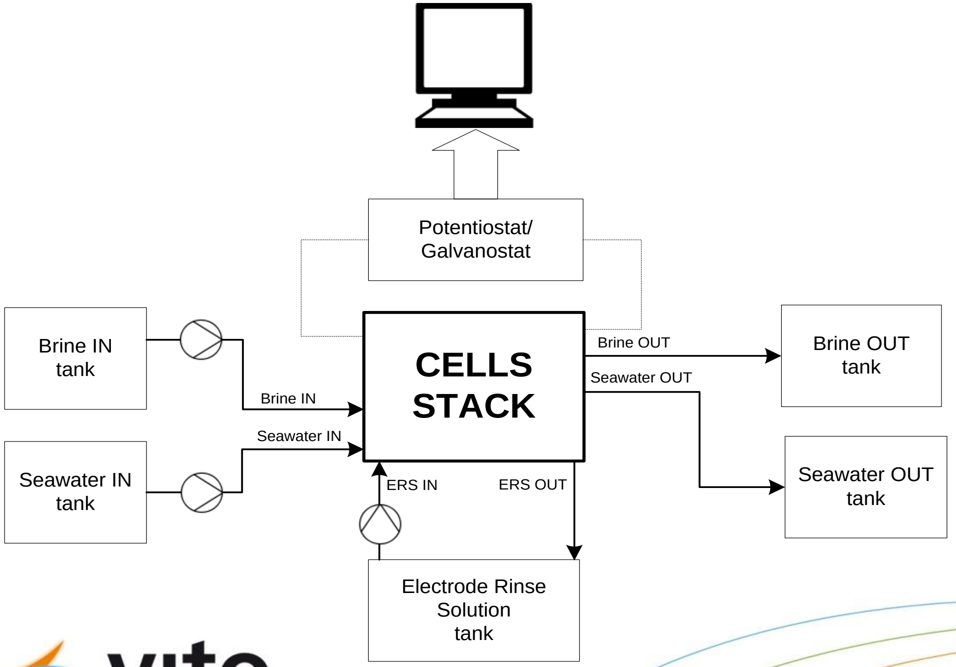
New **stack design**

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

Experimental investigation on a lab-scale unit

Experimental conditions 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.
- ✓ Membrane thickness



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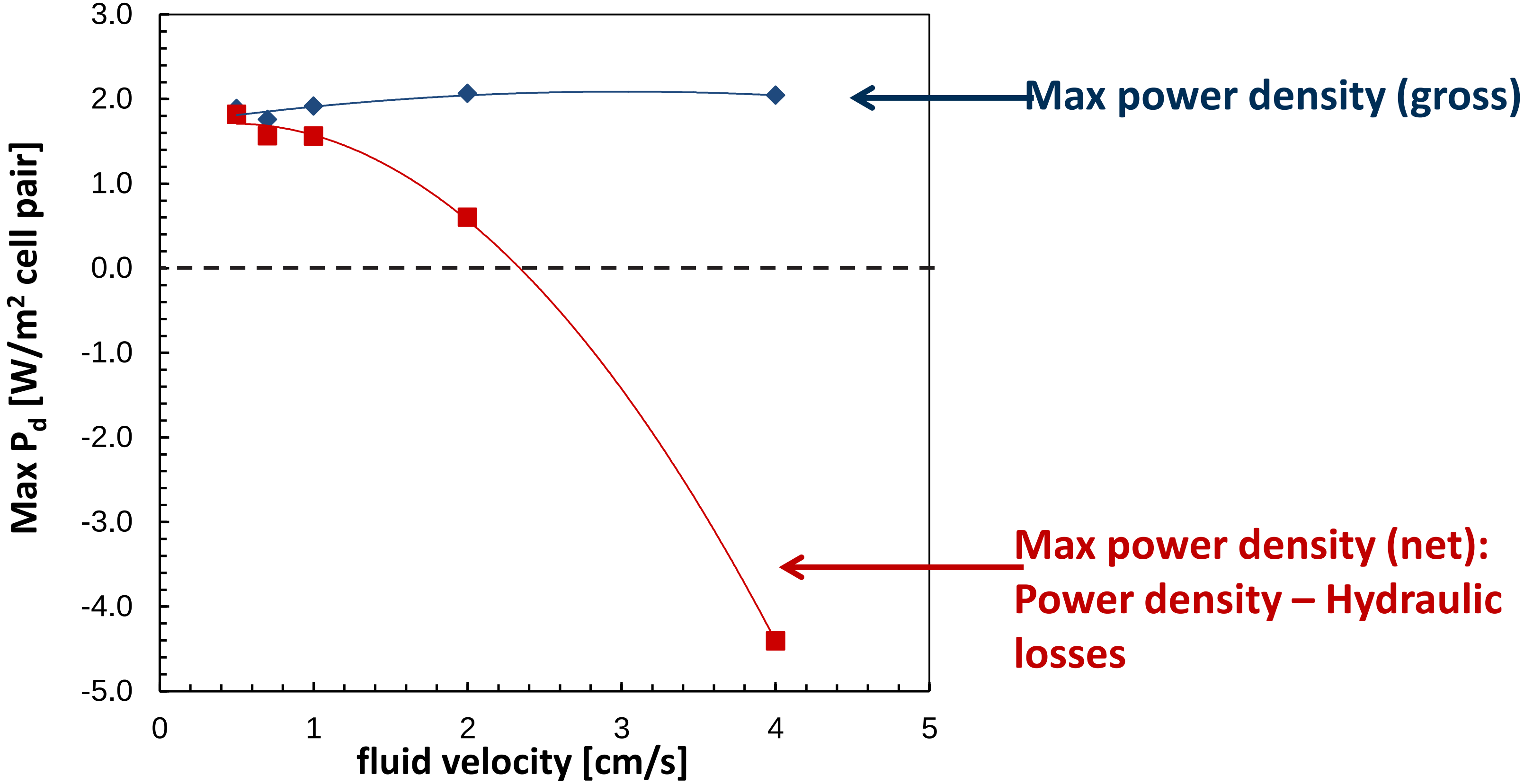
Experimental investigation on a lab-scale unit

Effect of fluid velocity on power output

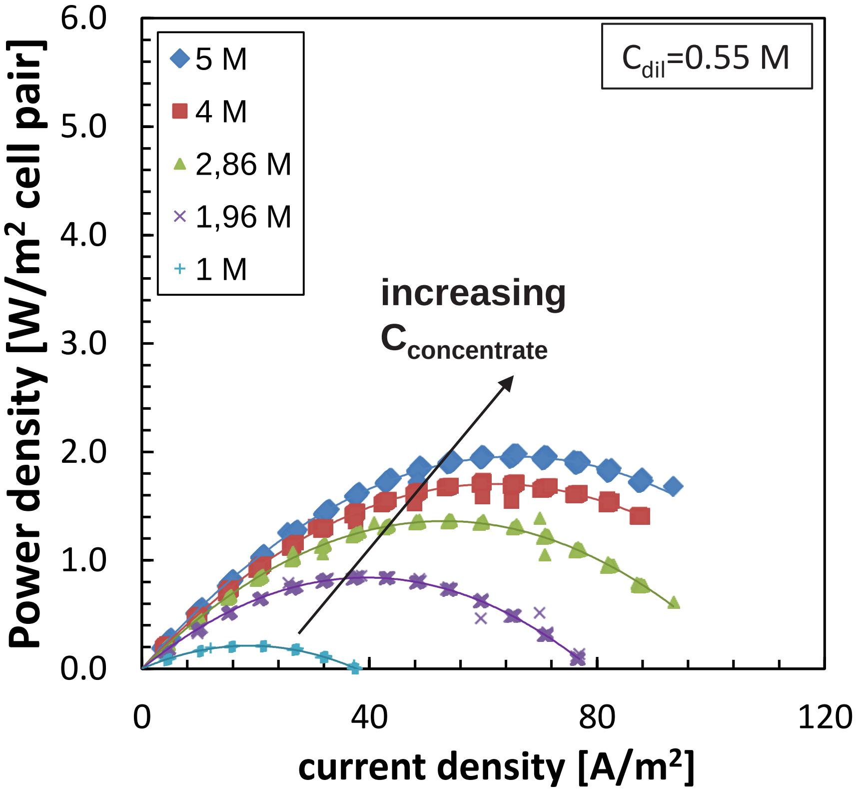


Stack equipped with 50 cell pairs, Fujifilm membranes, Deukum 270 µm spacers .Brine solution: 5 M NaCl, seawater: 0.5 M NaCl. T=20°C. Electrode rinse solution: 0.1 M $K_3Fe(CN)_6$ / $K_4Fe(CN)_6 \cdot 3H_2O$ + 2.5 M NaCl.

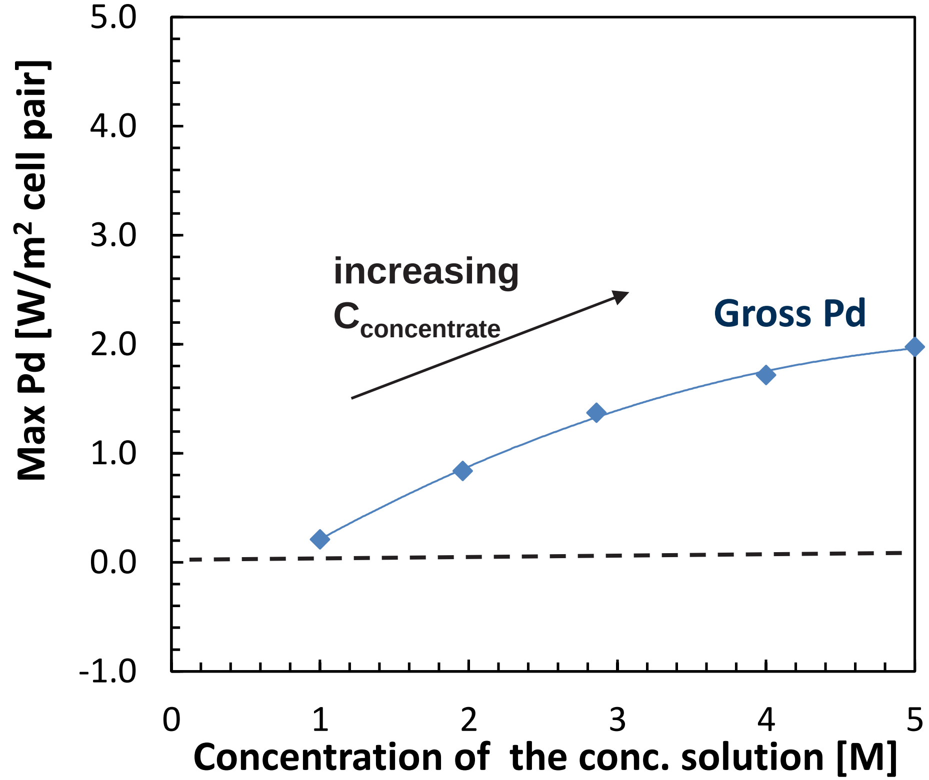
Experimental investigation on a lab-scale unit

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

Power density vs. current density



Maximum power density vs. C_{conc}

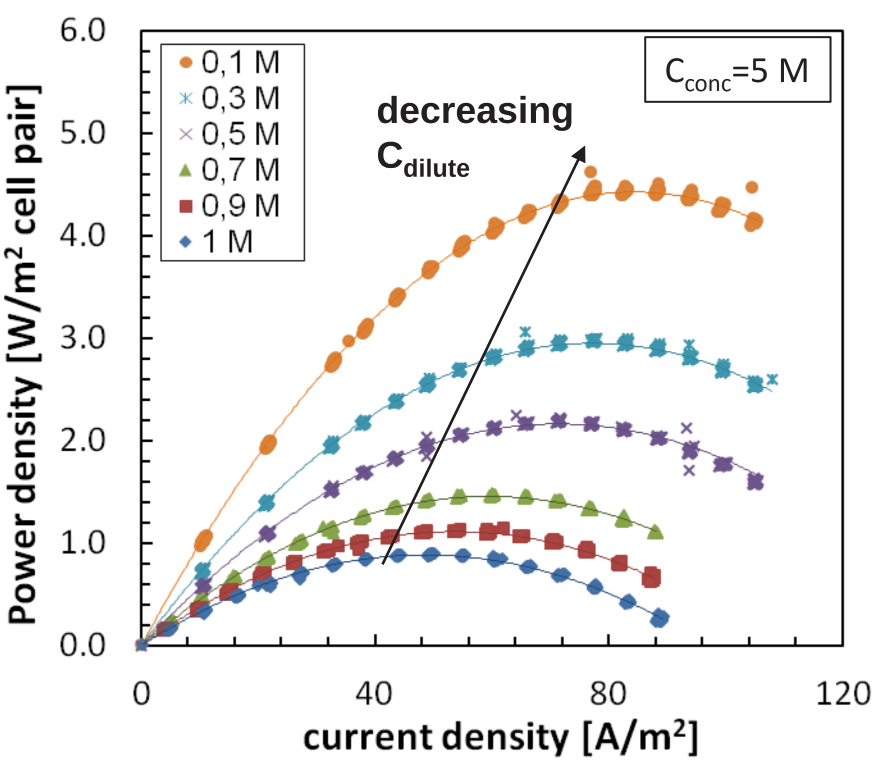


Stack equipped with 50 cell pairs, Fujifilm membranes, Deukum 270 µm spacers . Seawater: 0.55 M NaCl. T=20°C. Fluid velocity: 1 cm/s. Electrode rinse solution: 0.1 M $K_3Fe(CN)_6$ / $K_4Fe(CN)_6 \cdot 3H_2O$ + 2.5 M NaCl.

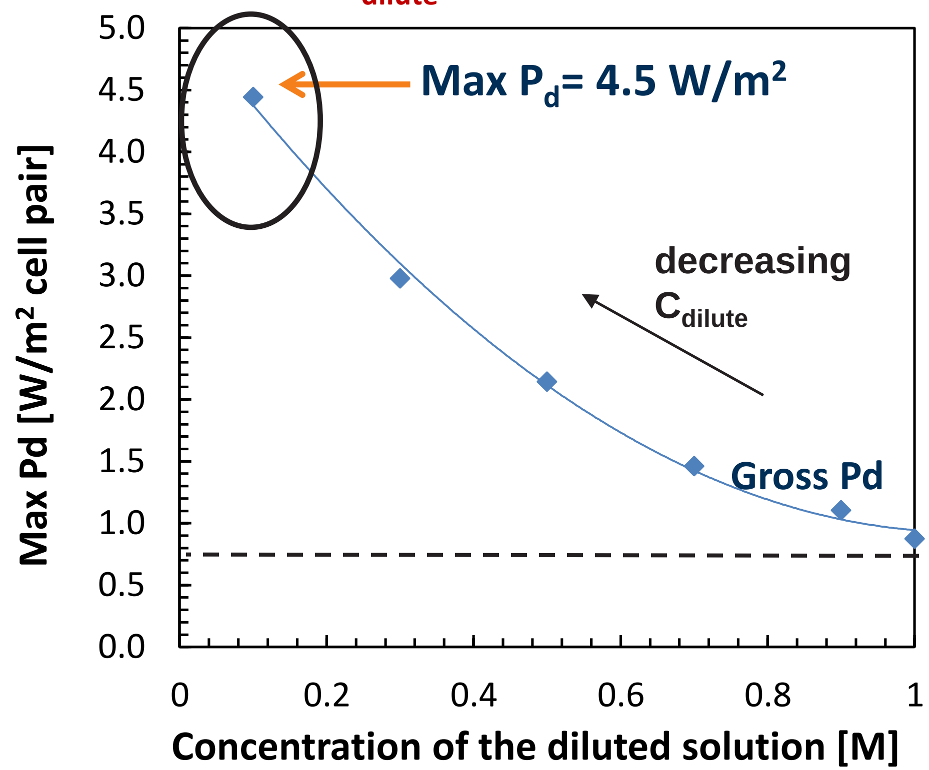
Experimental investigation on a lab-scale unit

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.

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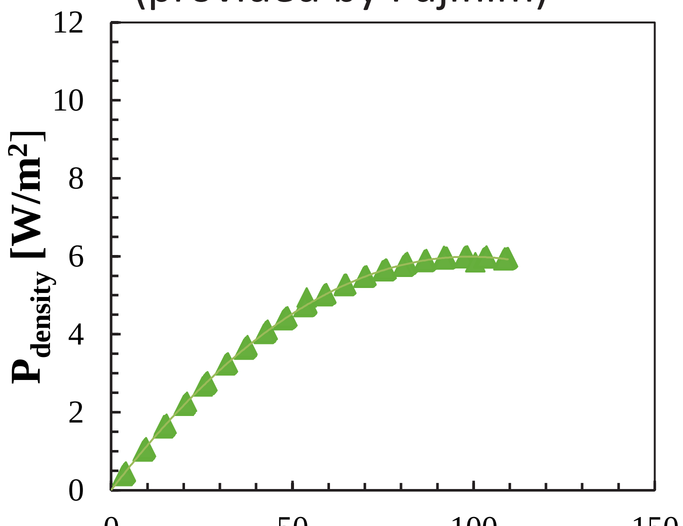
Experimental investigation on a lab-scale unit

MAX power output conditions:

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

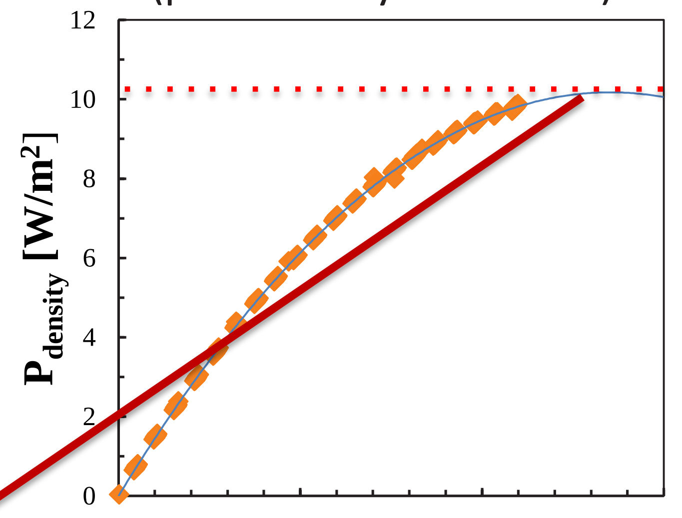
Thick membranes (120µm)

(provided by Fujifilm)



Thin membranes (20µm)

(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**

50 cell pairs; D

CFD modelling and process simulation

Multi-Scale Modelling approach:

Process model implementation

Computational Fluid Dynamics of SGP-RE stack

Lower scale info

Multi scale model implementation

Experimental tests on SGP-RE stacks

validation

Multi scale model validation

Model predictions on process performances & optimisation

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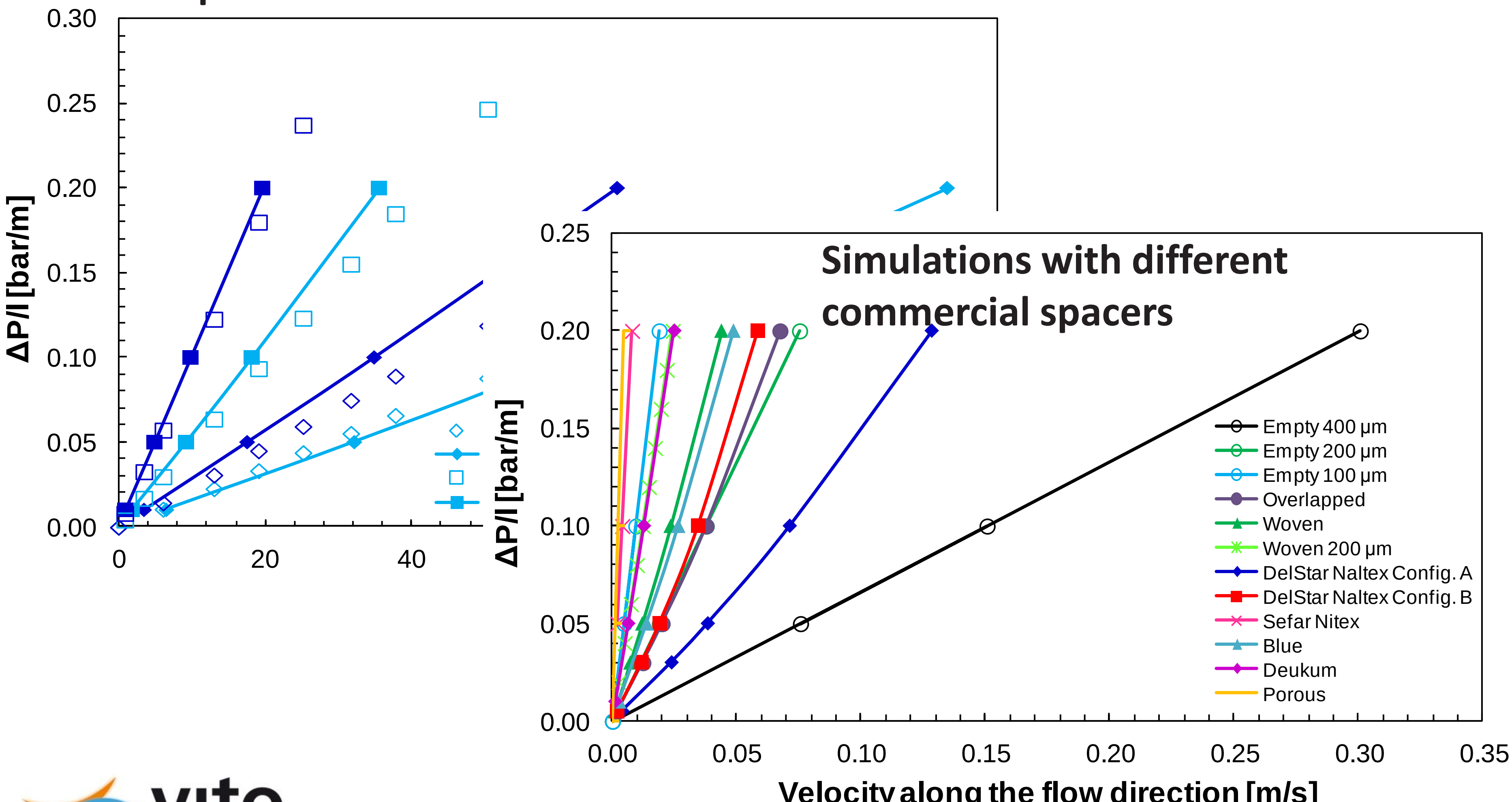
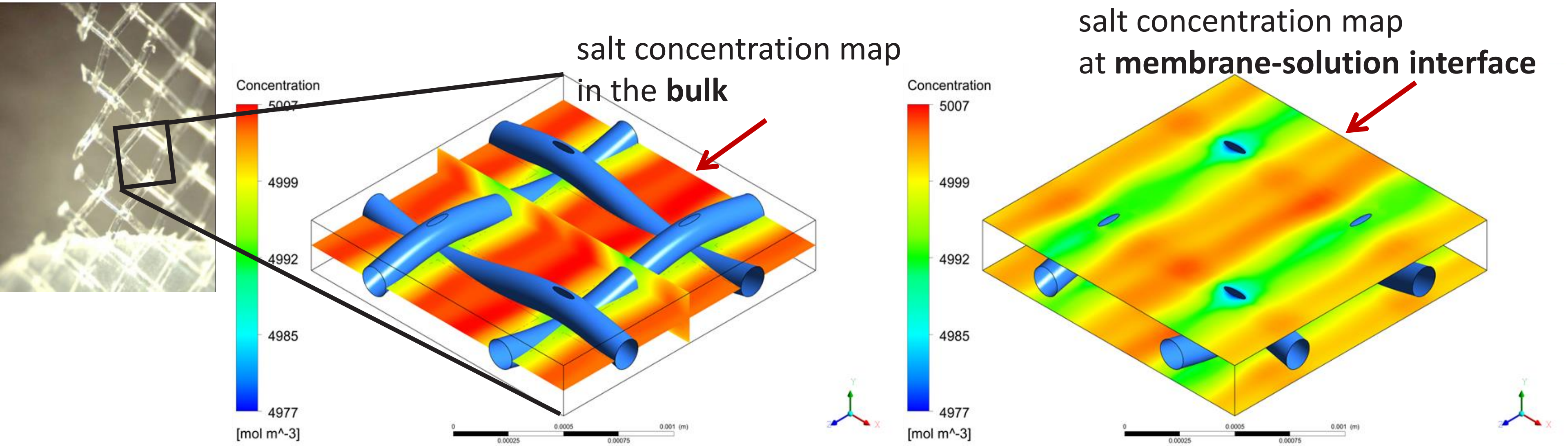
CFD Modelling: prediction of pressure drops

Model validation with experimental results

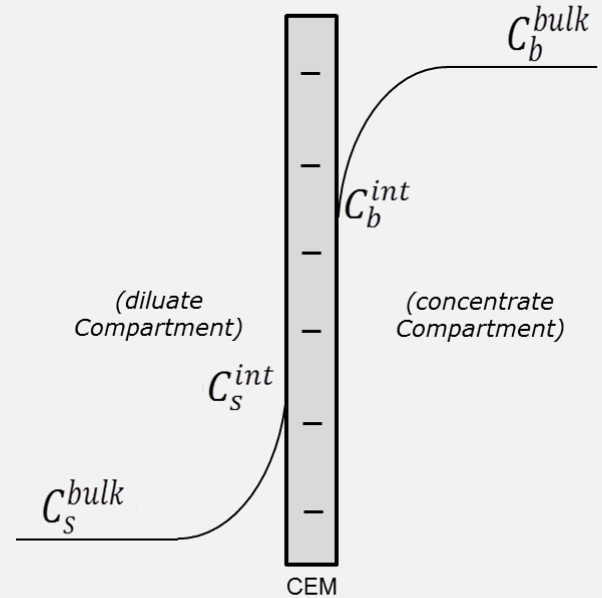


CFD Modelling: prediction of polarisation phenomena



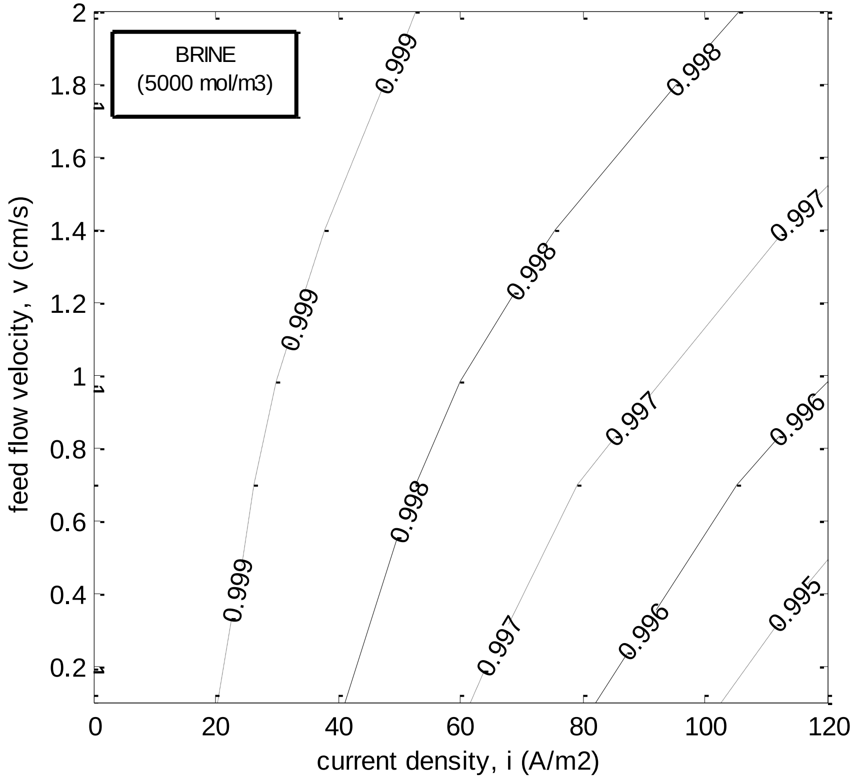
Polarisation Coefficients:

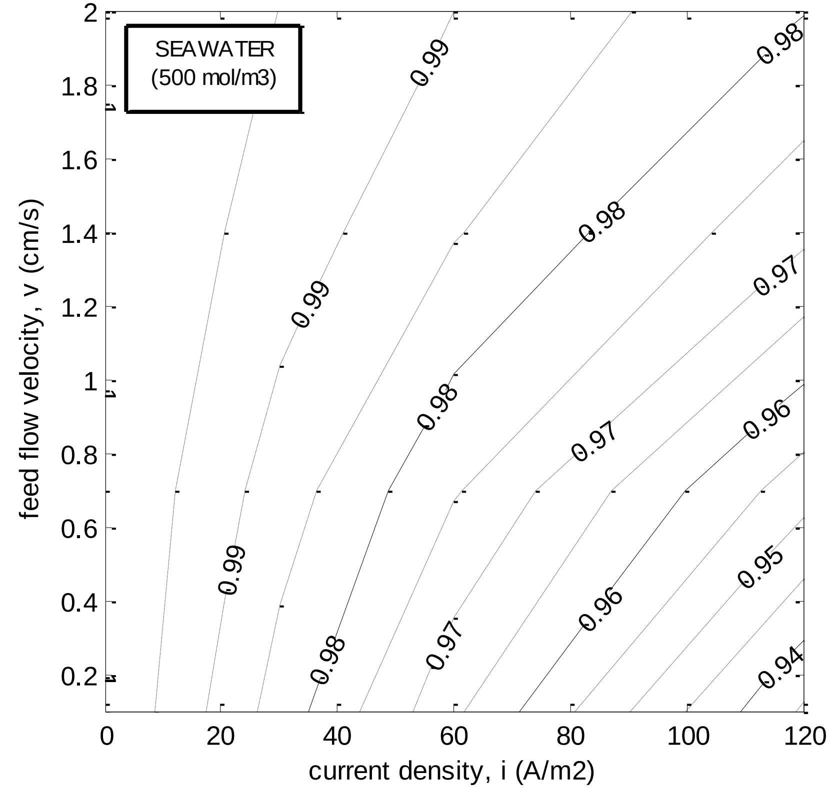
$$
\begin{cases}
\vartheta_b = \dfrac{C_b^{int}}{C_b^{bulk}} \\[2ex]
\vartheta_s = \dfrac{C_s^{bulk}}{C_s^{int}}
\end{cases}
$$



CFD Modelling: prediction of polarisation phenomena

Polarization factor for Deukum spacer-filled channels



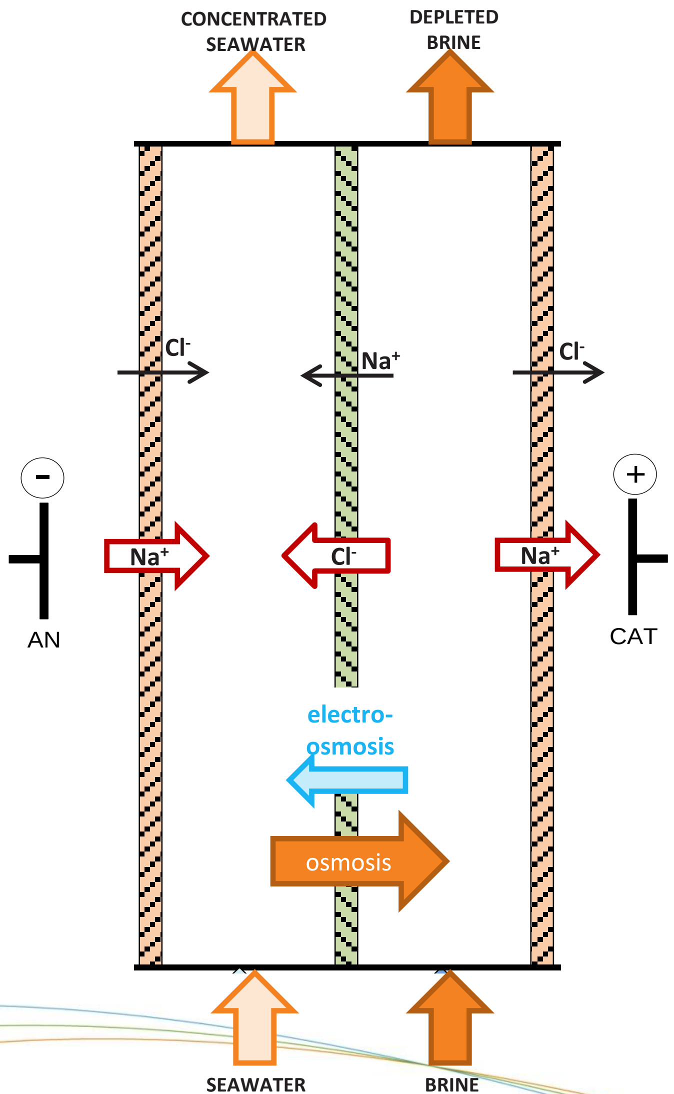


Effect of current density and fluid velocity on polarization coefficients.
CFD Model predictions of a 270 μm polyamide woven spacer (Deukum GmbH, Germany).

Development/validation of process simulator

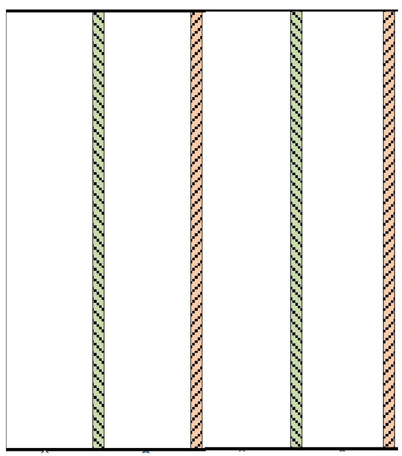
Low-hierarchy model (*cell pair*):

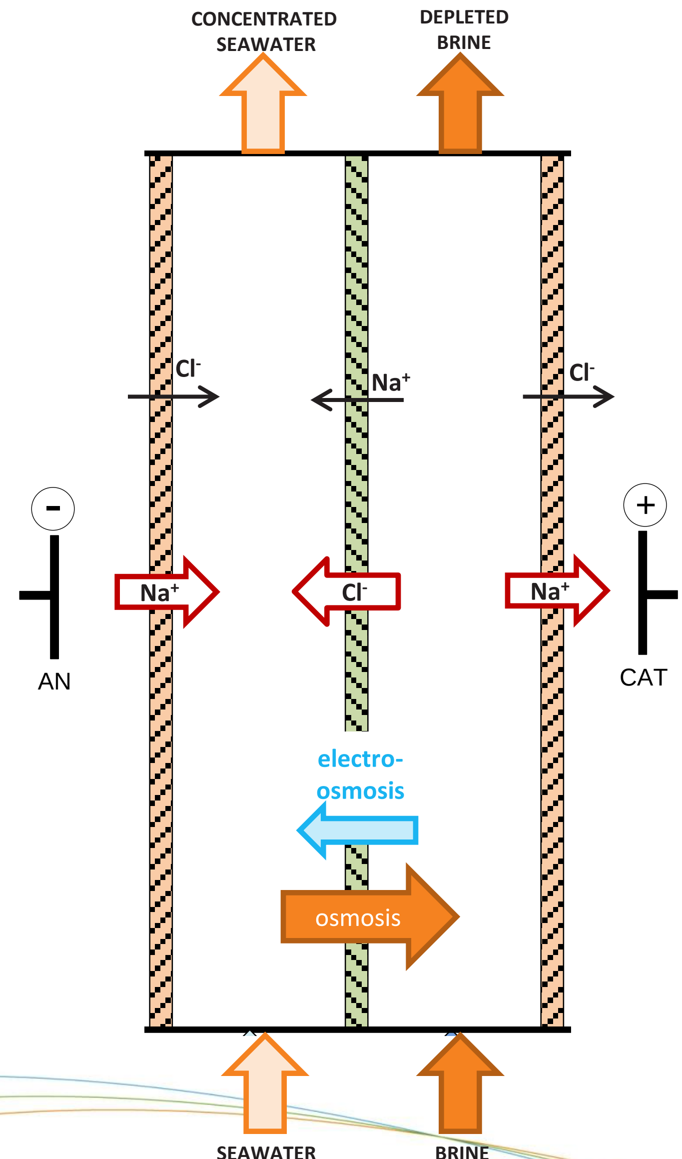
- thermodynamic properties of solutions
- electric variables
- salt transport (counter/co-ions)
- solvent transport (osmosis/electro-osmosis)
- polarization phenomena
- mass balance



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

Process Modelling Approach





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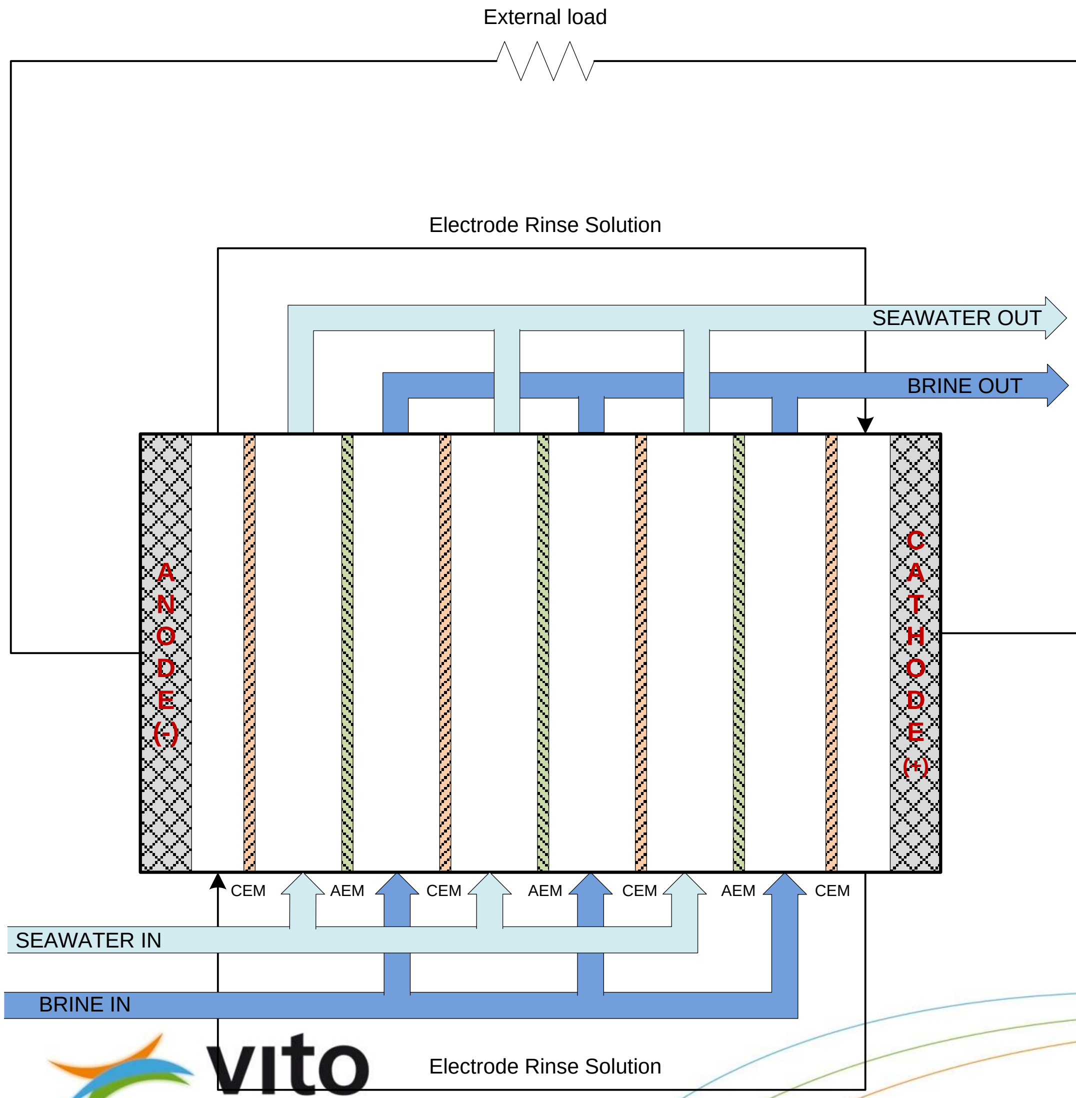
19

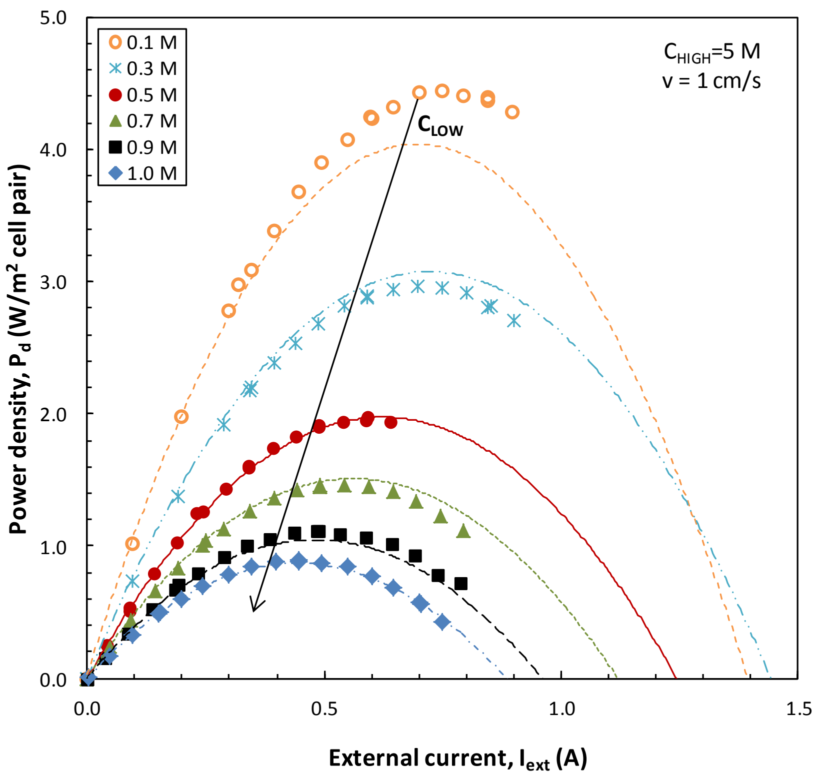
Process Modelling Approach

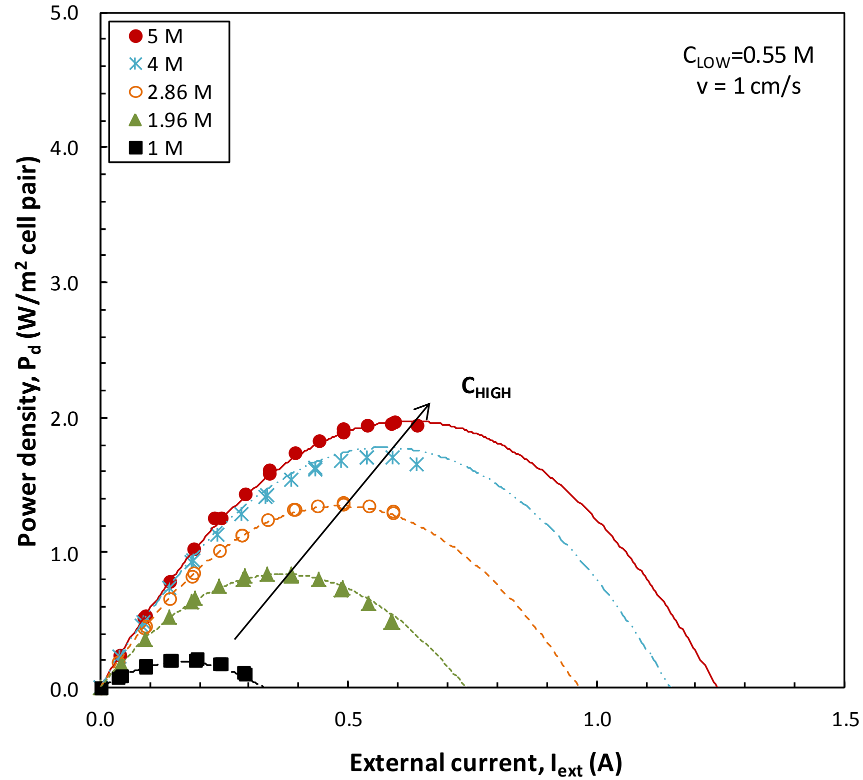


High-hierarchy model (*stack*):

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

Process Modelling validation
Model calibration with variable feed concentration

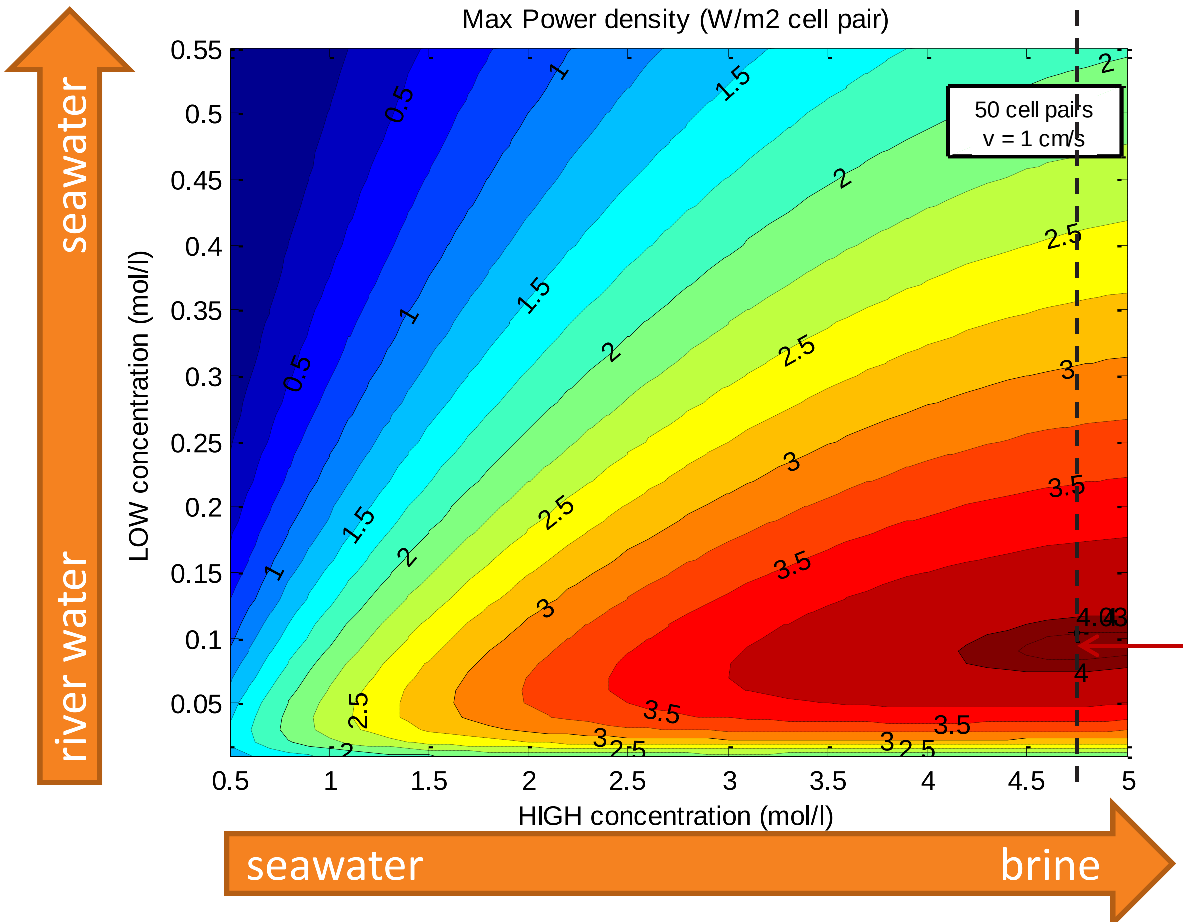




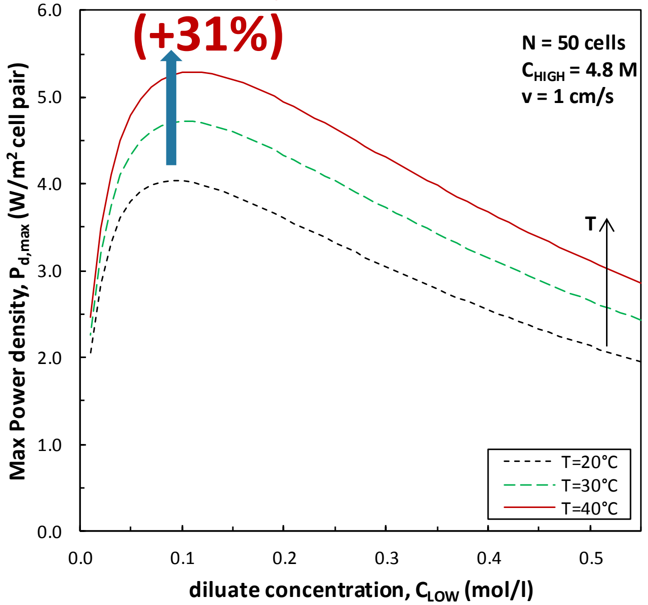
Experimental (points) and simulated (lines) data for a 50-cells stack equipped with Fujifilm membranes, Deukum 270 µm spacers; feed flow velocity: 1 cm/s; T=20°C. Blank resistance: 0.4 Ω.

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.

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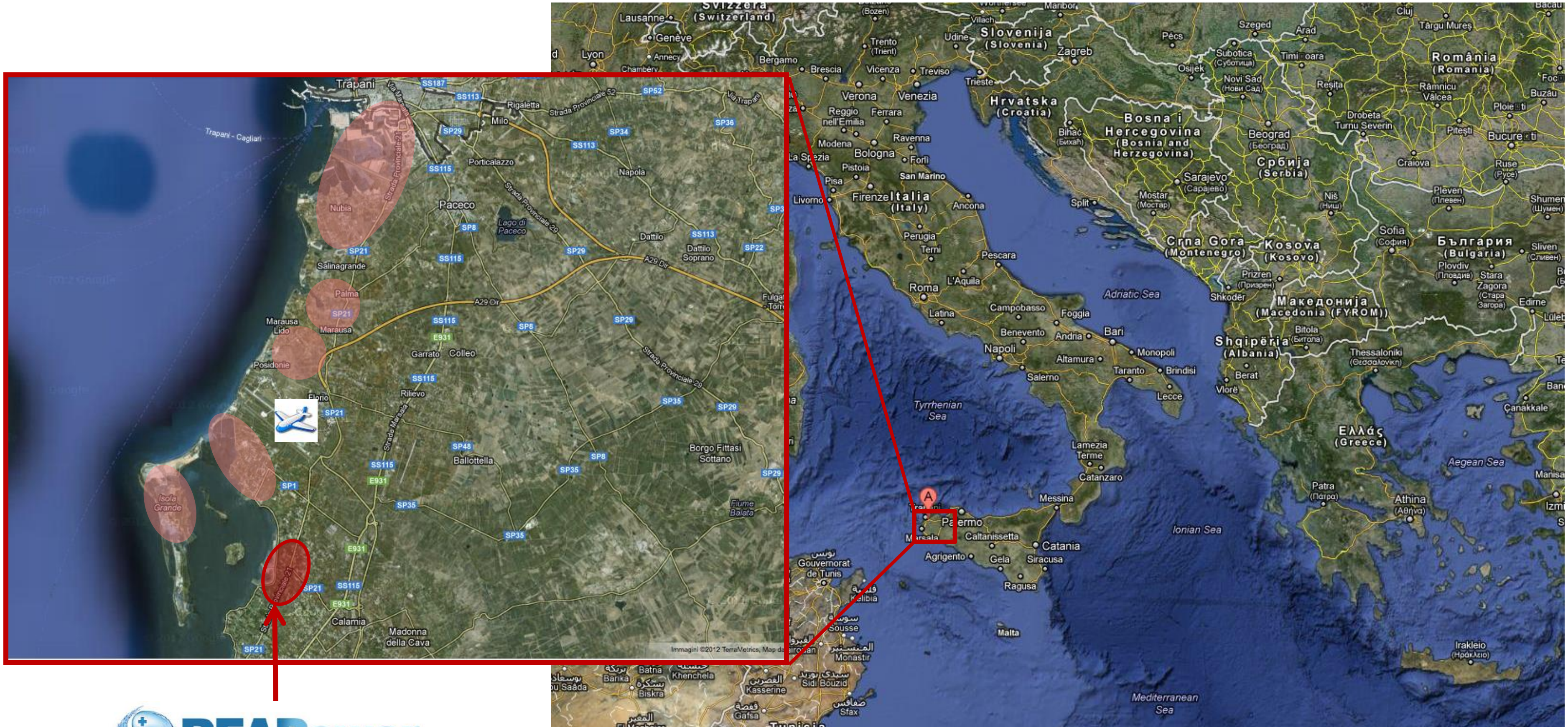
The REAPower prototype installation site

The singular framework of Trapani saltworks



Prototype installation site

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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

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The REAPower website

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