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

REAPower

SGP-RE Energy Production from Seawater and Brines: the *REAPower* Project. Achievements and Perspectives

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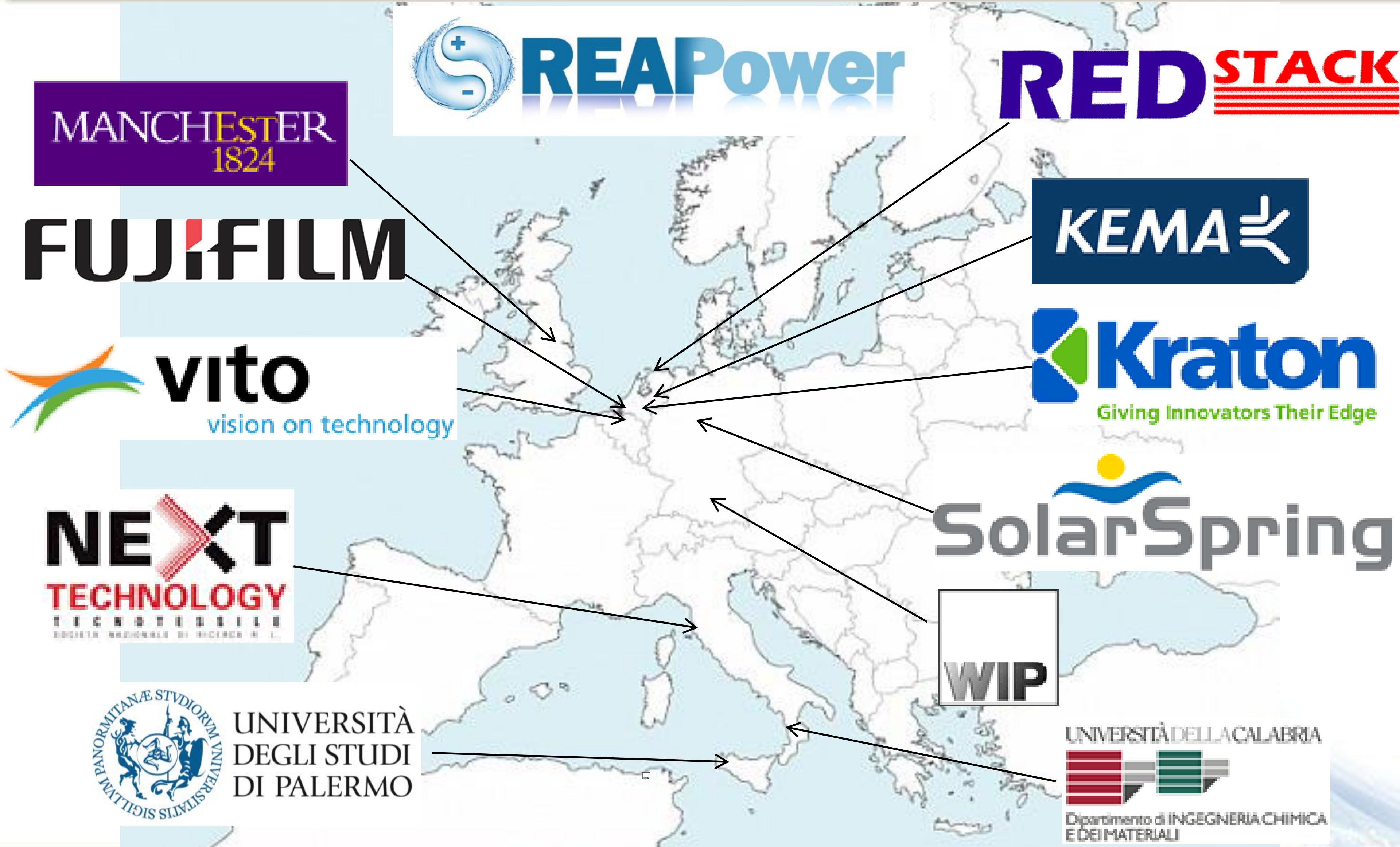
INES seminar
21-22 May 2013, Palermo (Italy)

The REAPower Project

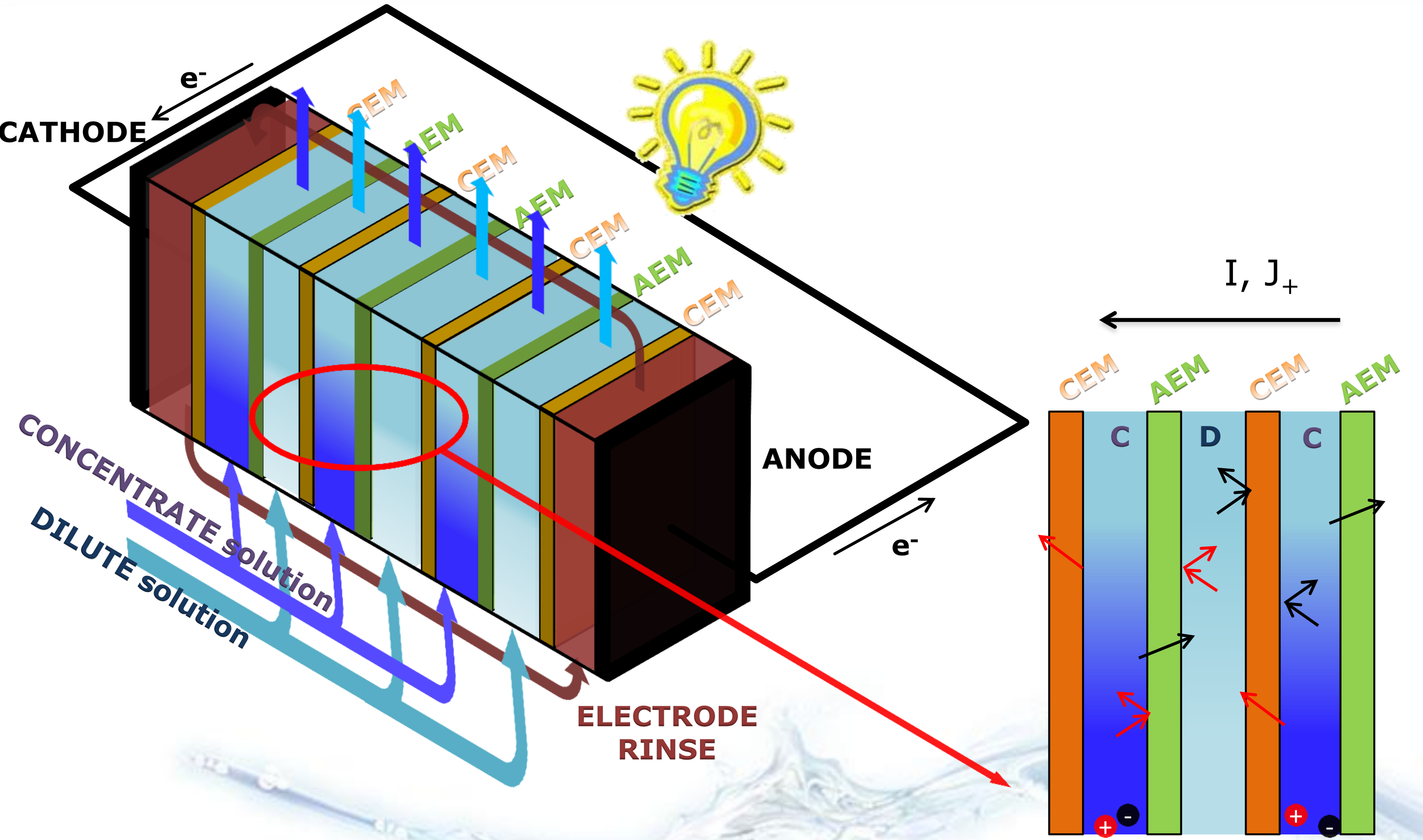
Main facts:

- Project acronym: “Reverse Electrodialysis for Alternative Power production”
- Cooperative project financed through the FP7 programme
- 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

Technological benefits for the SGP-RE process

new potentials for the exploitation of brines

The REAPower Project

Technological basic concepts . . .

i) Seawater (≈30-35 g/lt) in the LOW conc. compartment and concentrated brine (≈ 300 g/lt) in the HIGH conc. compartment dramatically reduce the electrical resistance in all battery compartments

ii) As a result: an ultra-low overall internal resistance within the SGP-RE battery cell-pairs can be achieved . . . especially with the introduction of thinner membranes

iii) Thus, the ultra-low internal resistance will significantly promote a higher power density of the SGP-RE battery.

The REAPower Project

Technological barriers. . .

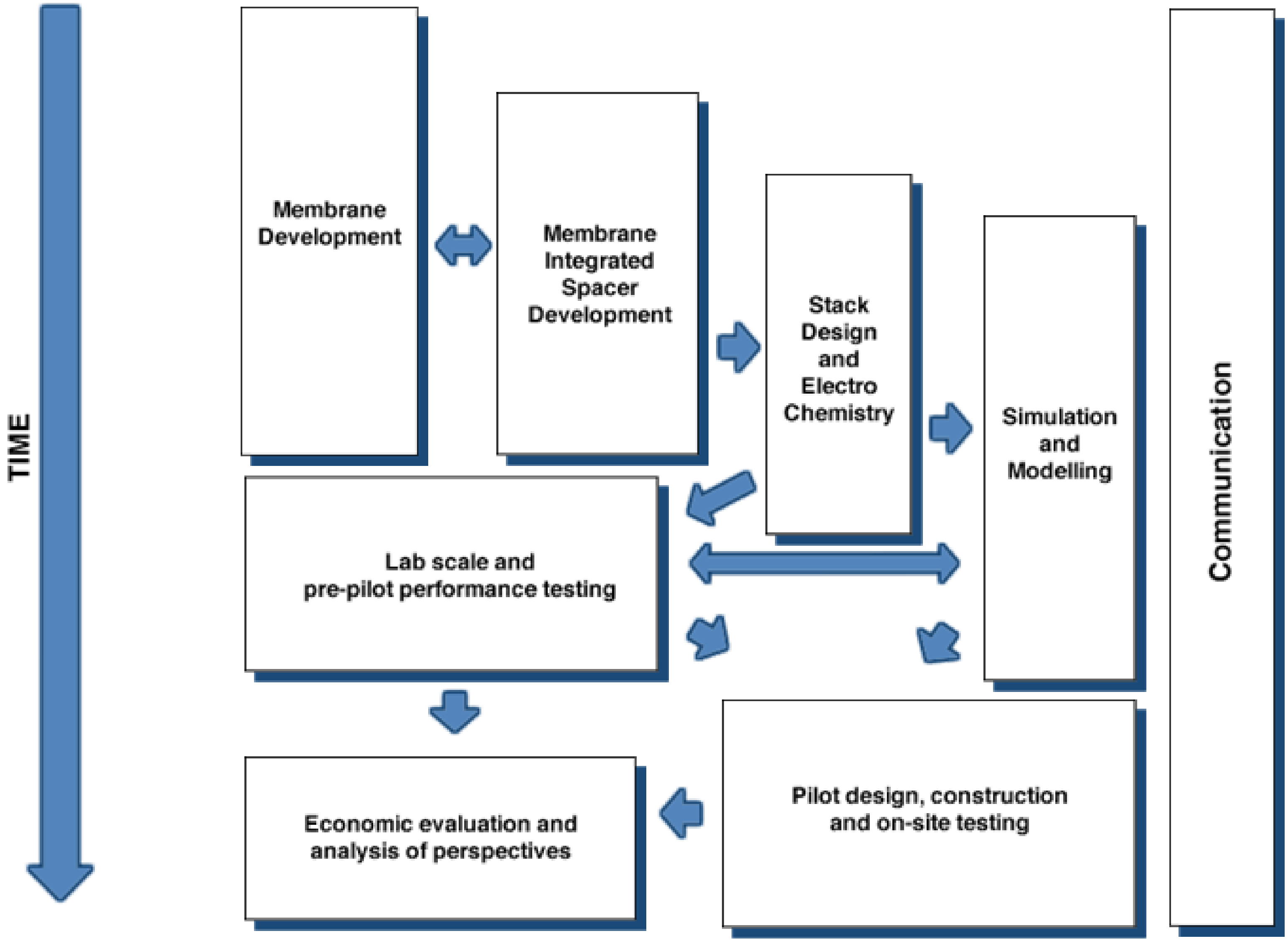
Effect of salinity on permselectivity	Solution strategy →	Improve IEMs formulation/preparation
High fouling and scaling potentials	Solution strategy →	Adequate pre-treatments for seawater and brine
Still low power density	Solution strategy →	Thin IEMs & optimised spacer geometry
Limited quantity of brine	Solution strategy →	Increase “fuel efficiency” and regeneration strategies

The REAPower Project

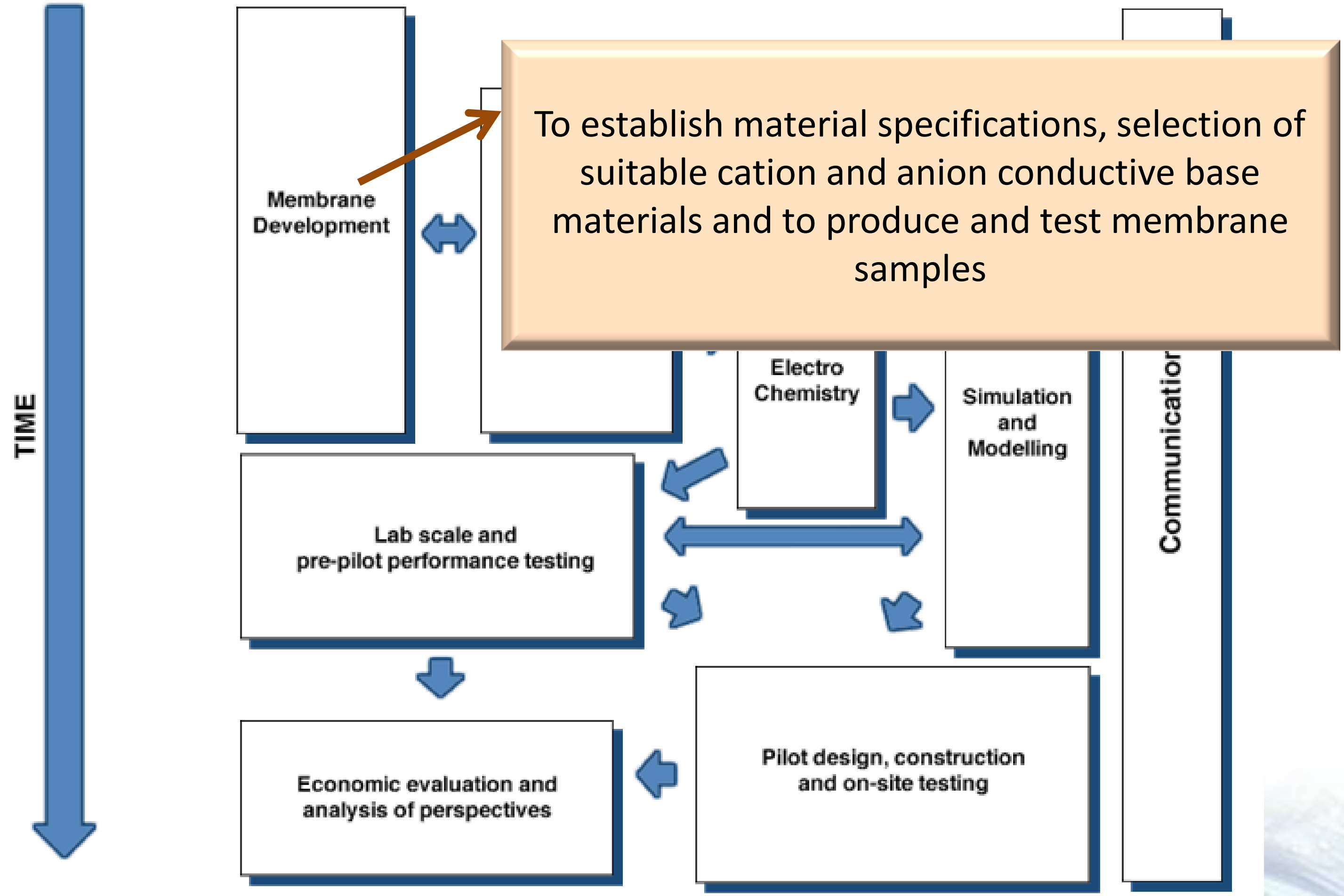
The Objectives. . .

1. Define and optimise materials and components tailored to the requirements of the technology
2. Optimise the design of the SGP-RE cell pairs and stack using computer modelling tools;
3. Validate the model and assess the developed materials, components and design by laboratory stack tests;
4. Evaluate and improve the system performance through tests on a prototype fed with real brine;
5. Analyse the "economics" and assess the perspectives
6. Define the next R&D steps

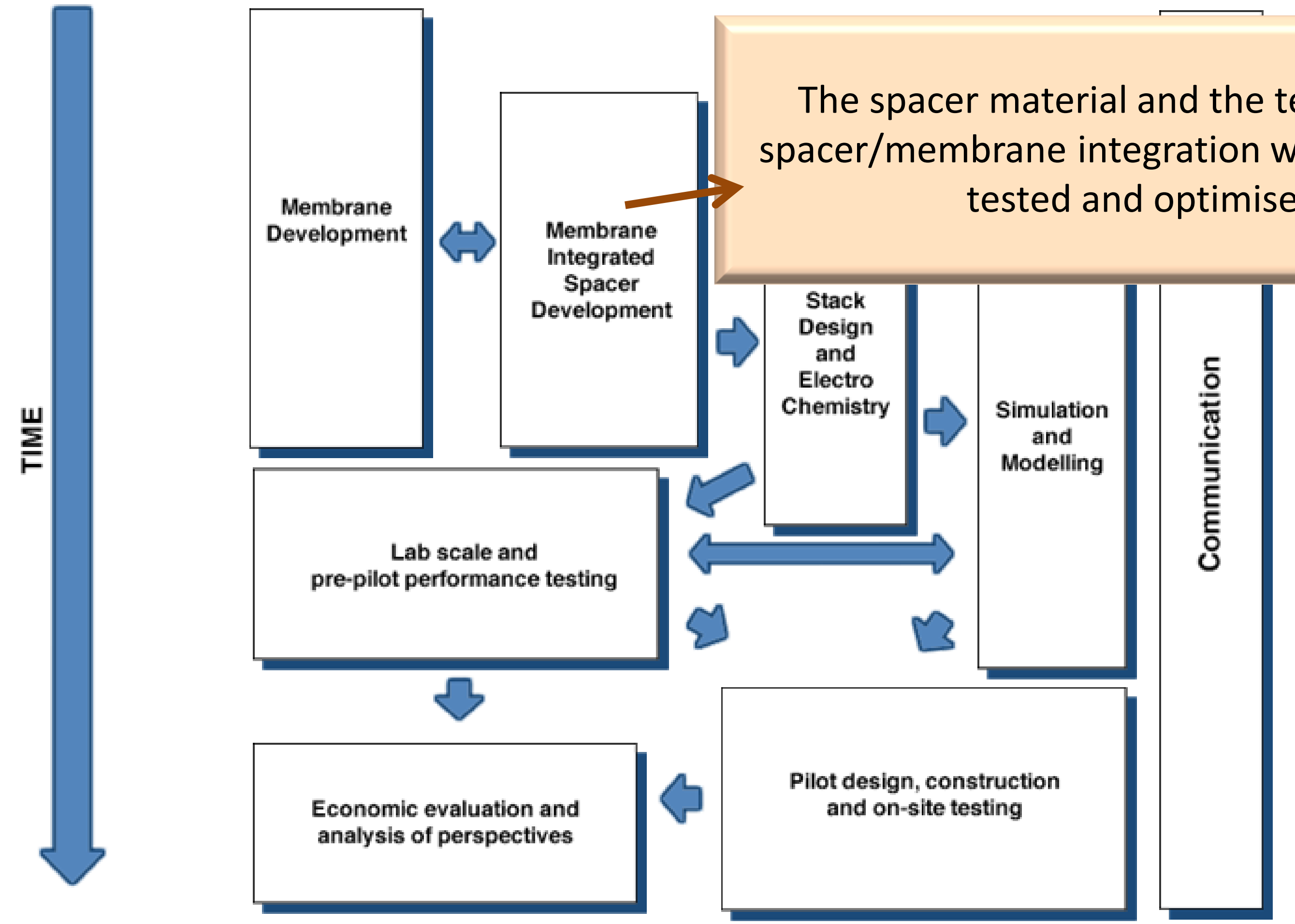
Project workplan



WP2. Membrane Development

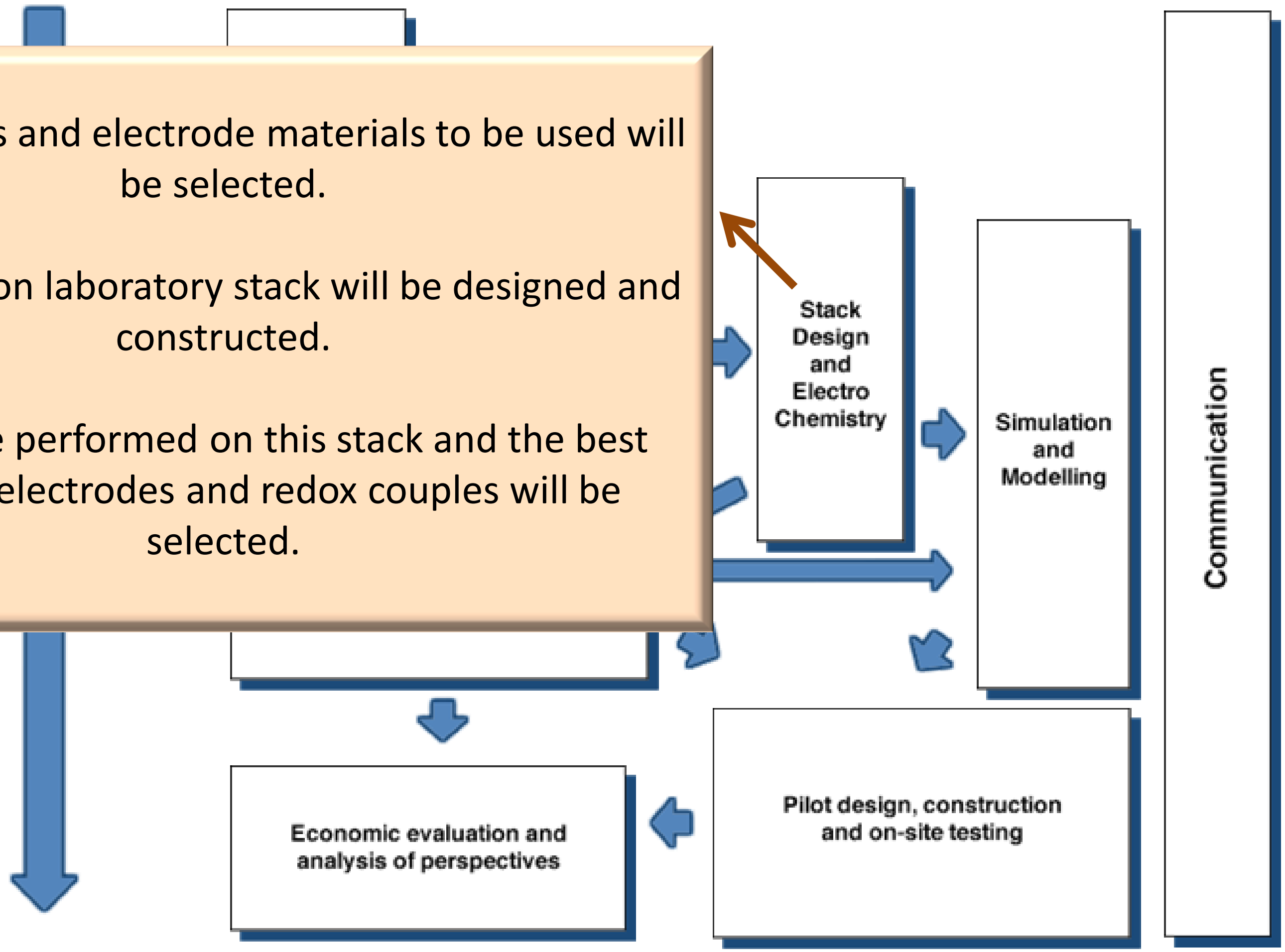


WP3. Membrane Integrated Spacer Development



The spacer material and the technique for spacer/membrane integration will be selected, tested and optimised.

WP4. Electrochemical engineering/stack design



Redox couples and electrode materials to be used will be selected.

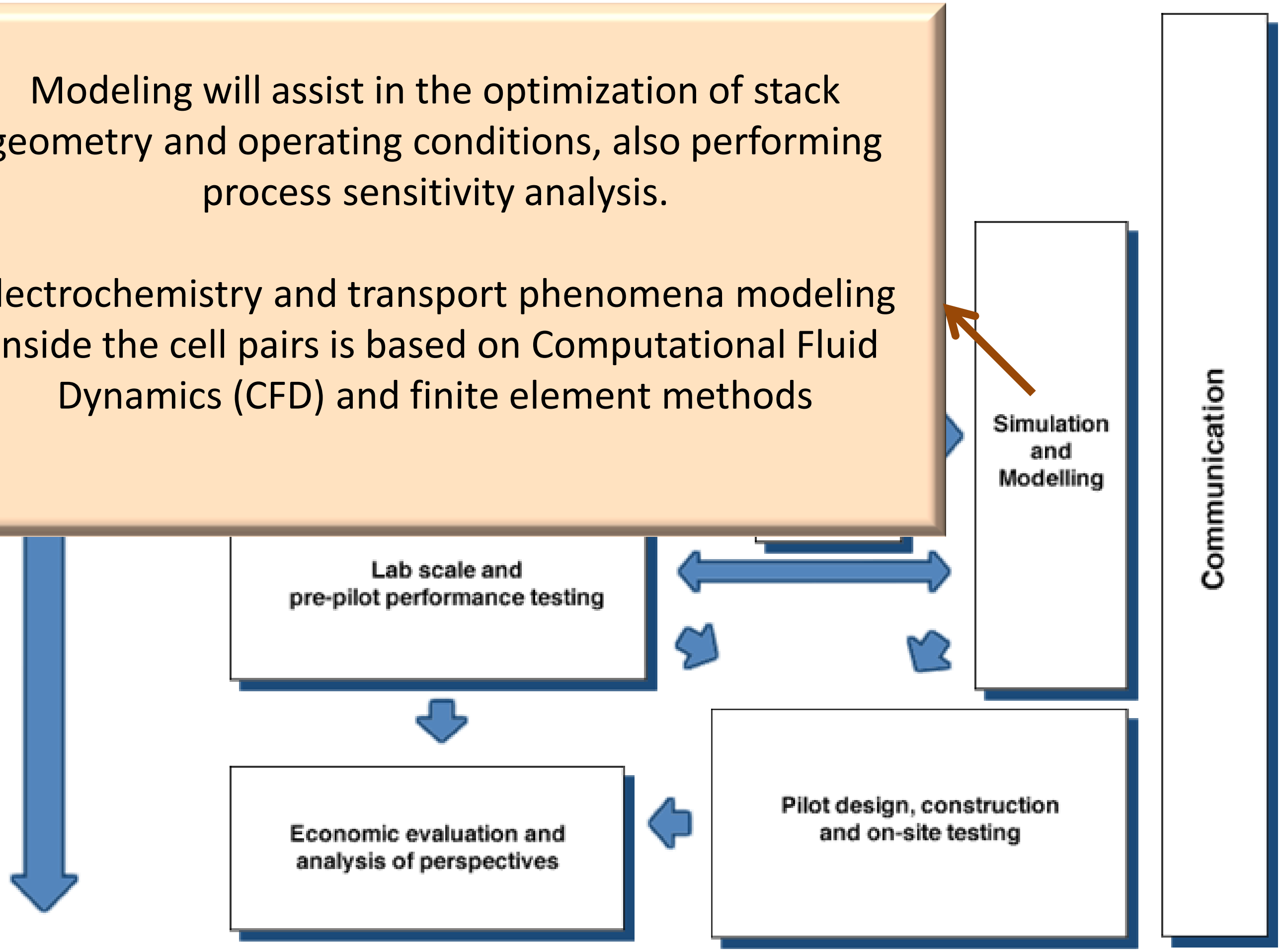
First generation laboratory stack will be designed and constructed.

Tests will be performed on this stack and the best couple of electrodes and redox couples will be selected.

WP5. Process simulation

Modeling will assist in the optimization of stack geometry and operating conditions, also performing process sensitivity analysis.

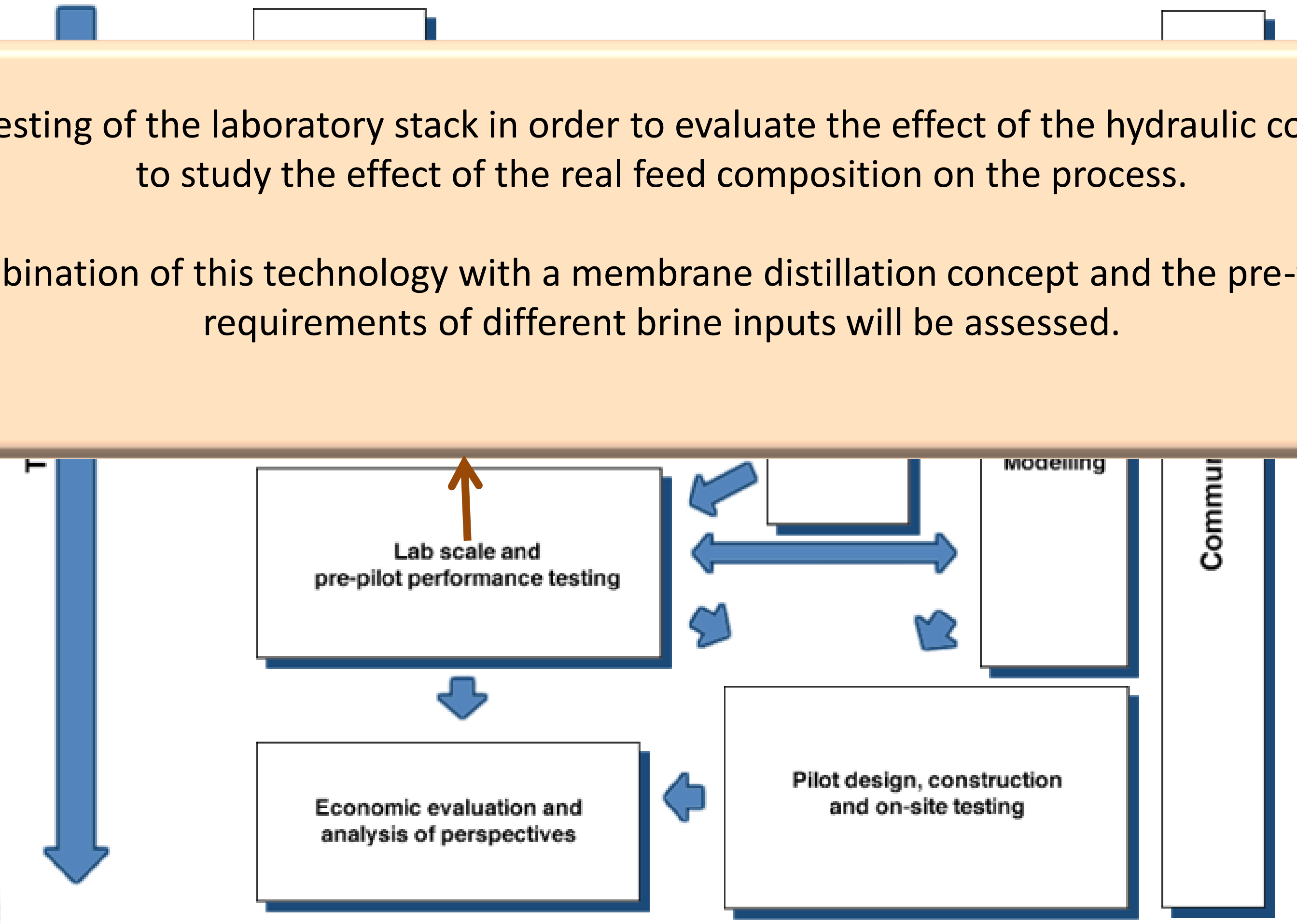
Electrochemistry and transport phenomena modeling inside the cell pairs is based on Computational Fluid Dynamics (CFD) and finite element methods



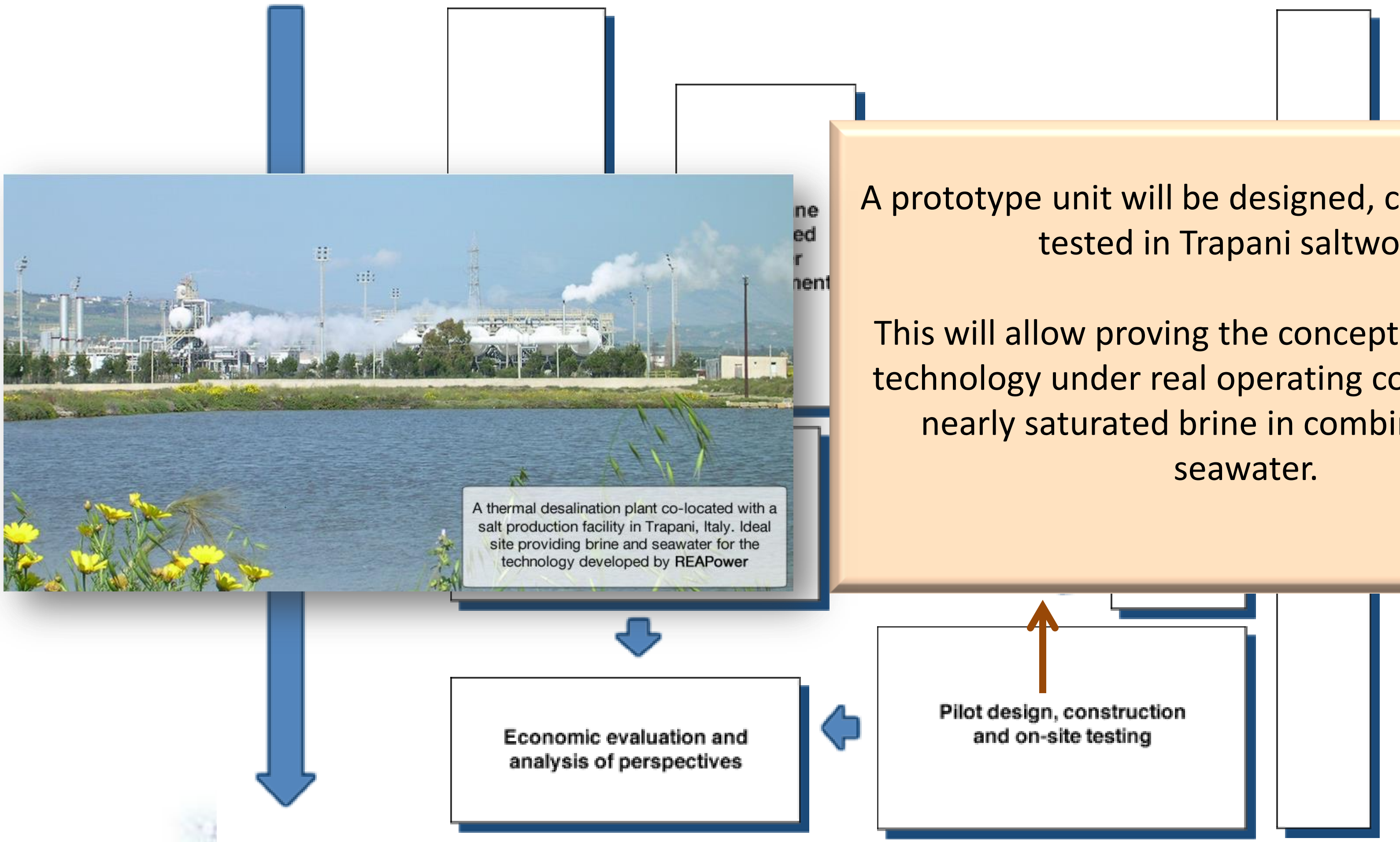
WP6. Lab-scale performance testing

Extensive testing of the laboratory stack in order to evaluate the effect of the hydraulic conditions and to study the effect of the real feed composition on the process.

The combination of this technology with a membrane distillation concept and the pre-treatment requirements of different brine inputs will be assessed.



WP7. Design, construction, testing of the prototype

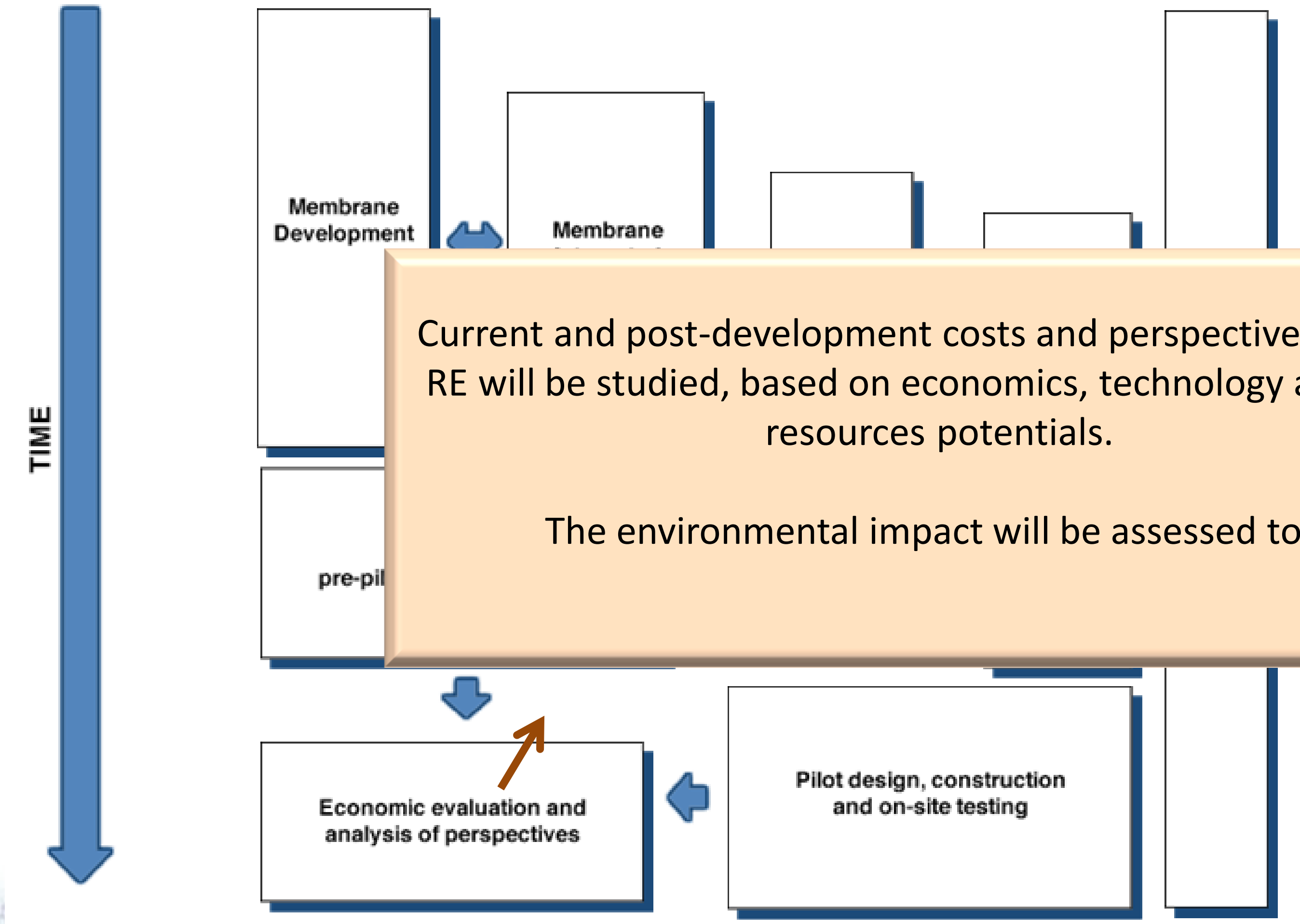


A thermal desalination plant co-located with a salt production facility in Trapani, Italy. Ideal site providing brine and seawater for the technology developed by REAPower

A prototype unit will be designed, constructed and tested in Trapani saltworks.

This will allow proving the concept of the SGP-RE technology under real operating conditions using nearly saturated brine in combination with seawater.

WP8. Economic evaluation/analysis of perspectives



Current and post-development costs and perspectives for SGP-RE will be studied, based on economics, technology and brine resources potentials.

The environmental impact will be assessed too.

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The *REAPower* Project: Achievements and Perspectives

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Membranes performance enhancements

Increased permselectivity → Permselectivity has achieved values between **65 and 90%** when **in contact with** almost saturated **brine**

Reduced membrane resistance → Membrane specific resistance has been reduced to values around 1.5-2.5 $\Omega \cdot cm^2$ aiming at a 5-folds reduction in the next months

Redox couples and stack design

Redox couples selection → Several redox couples have been tested under different conditions, finding the most promising for the SGP-RE prototype: $FeCl_3/FeCl_2$; Water/Na_2SO_4; $[Fe(CN)_6]^{3-}/[Fe(CN)_6]^{4-}$

2 stack generations already designed and tested → Two different stack geometries have been already designed, constructed and tested and are now available for the consortium

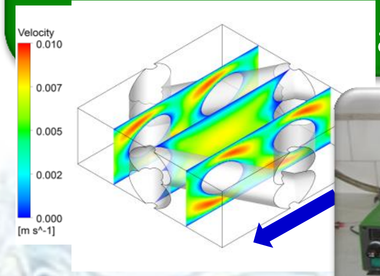
IEM-integrated Spacer & Fluid Dynamics optimisation

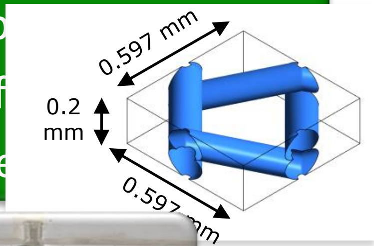
Membrane Integrated Spacer

Tests are being performed for the preparation of **Membrane Integrated Spacers**, aiming at membrane thickness in the range **10-20 μm**

Choice of spacer thickness and geometry

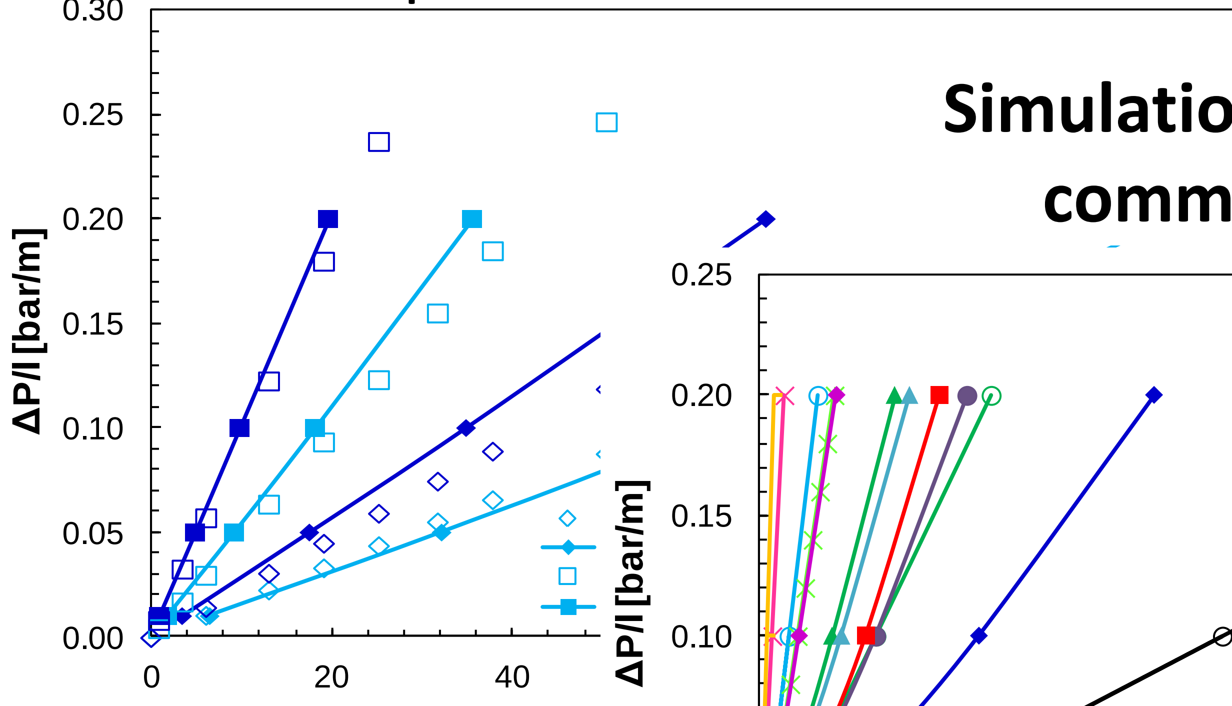
CFD simulations have been carried out along with exp characterisation of dif and ge



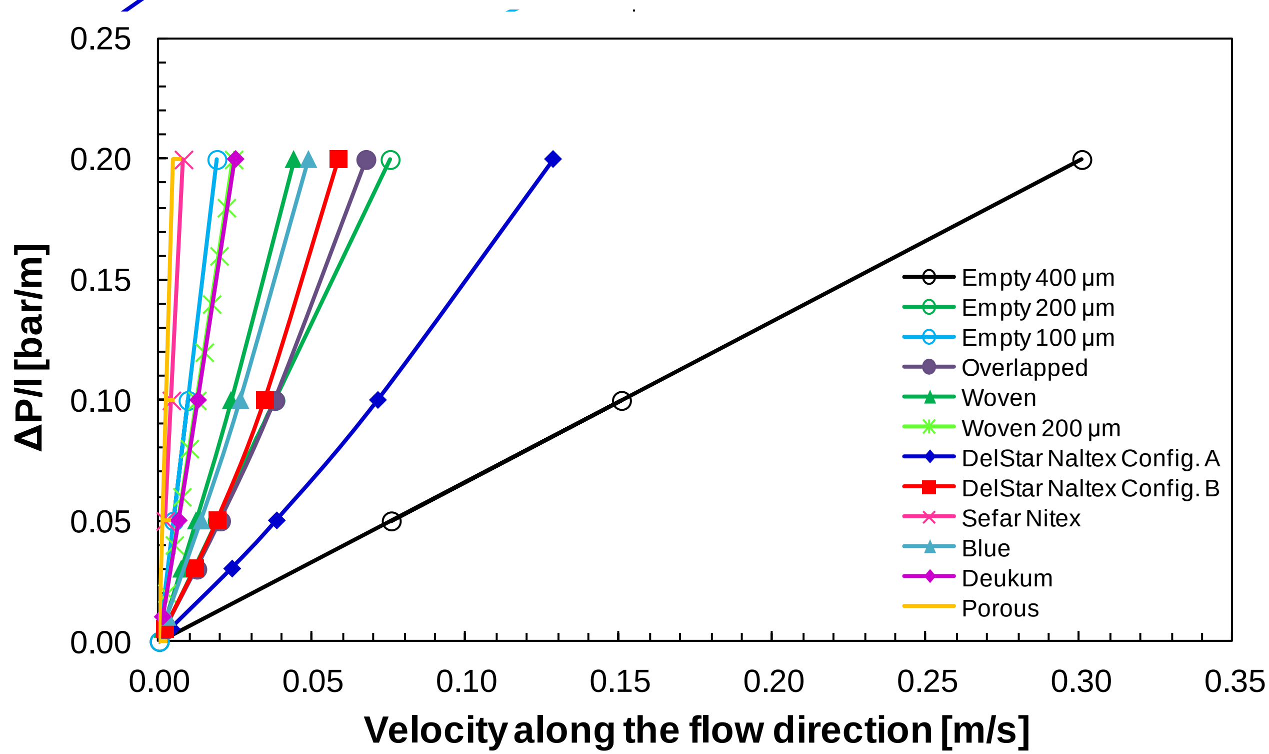


CFD Modelling: prediction of pressure drops

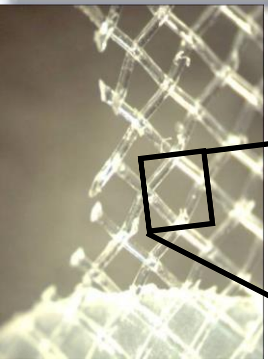
Model validation with experimental results



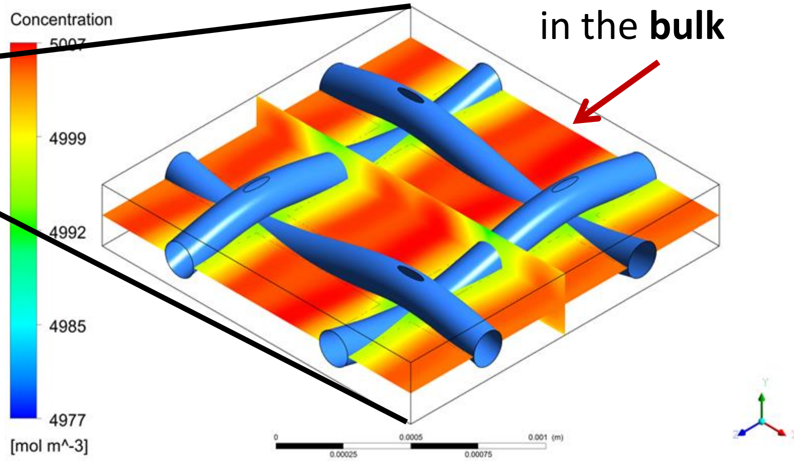
Simulations with different commercial spacers



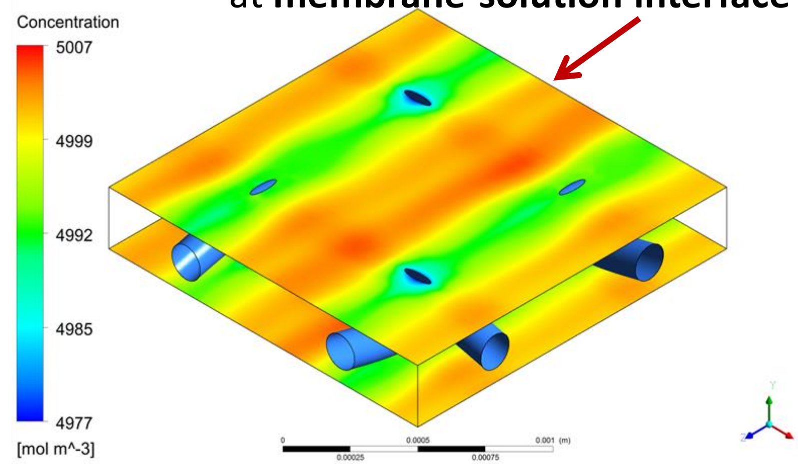
CFD Modelling: prediction of polarisation phenomena



salt concentration map in the **bulk**

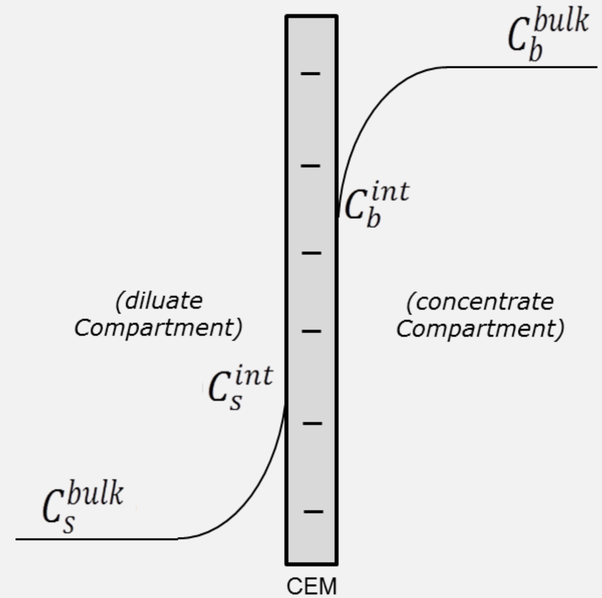


salt concentration map at **membrane-solution interface**



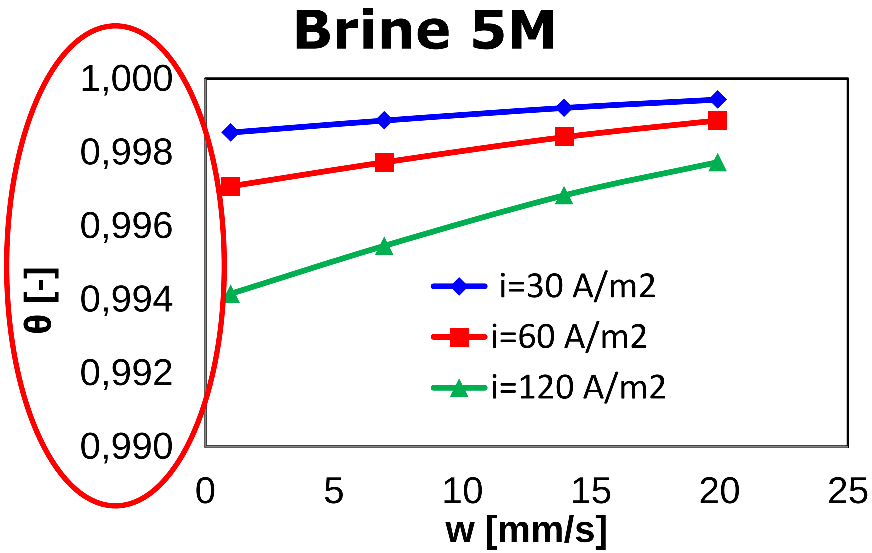
Polarisation Coefficients:

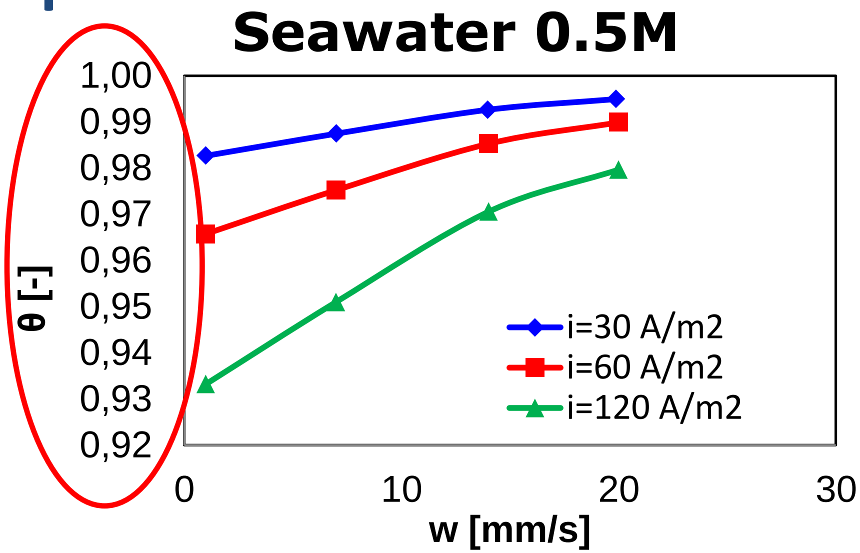
$$\begin{cases} \vartheta_b = \dfrac{C_b^{int}}{C_b^{bulk}} \\ \vartheta_s = \dfrac{C_s^{bulk}}{C_s^{int}} \end{cases}$$

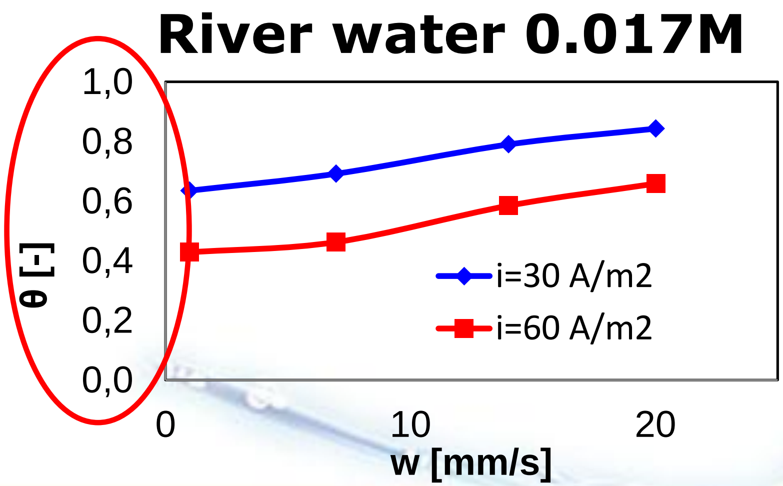


CFD Modelling: prediction of polarisation phenomena

Polarization factor for Deukum spacer-filled channels



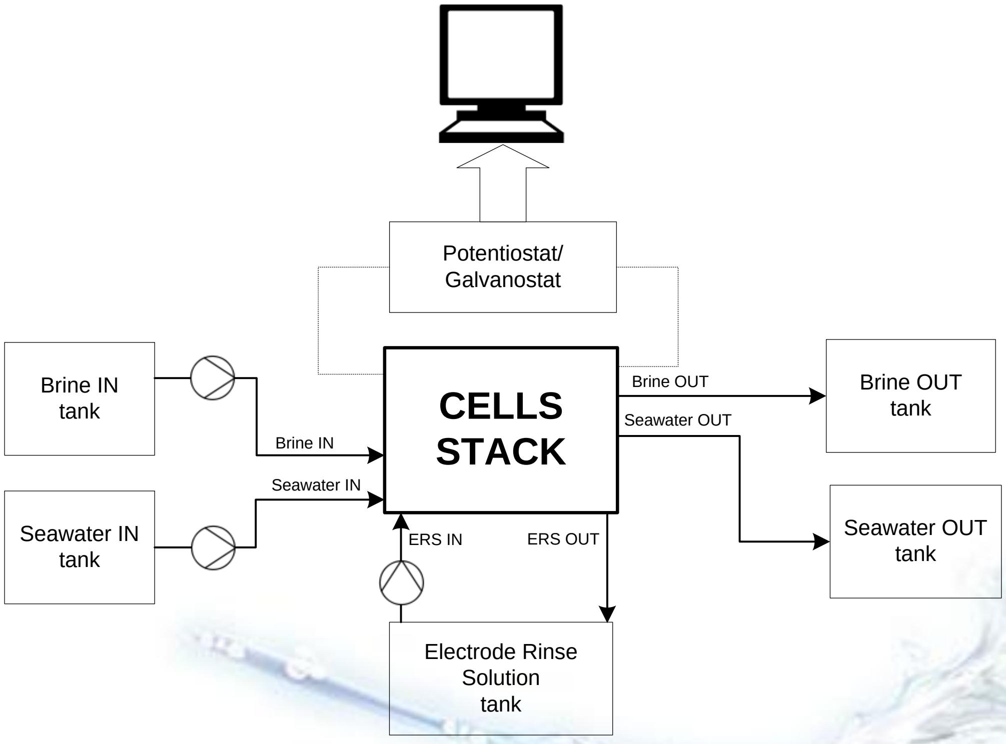




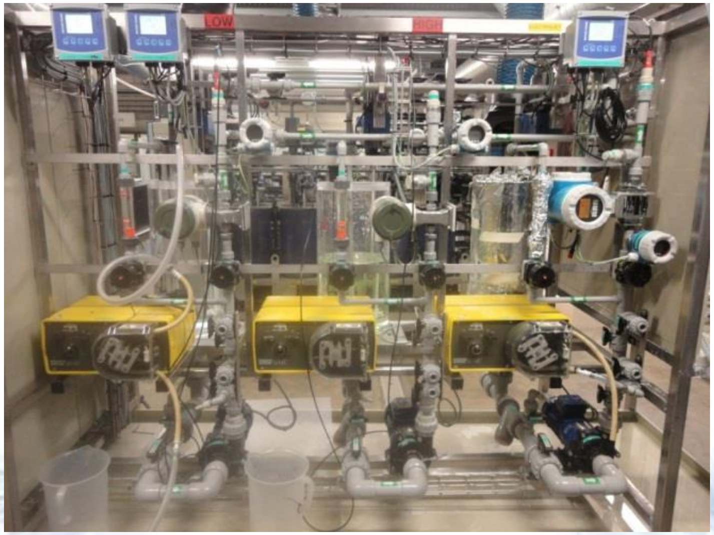
- Very high *θ* values predicted for brine and seawater, lower for river water. If C↑, θ↑
- The higher *i*, the lower the *θ* value, but this dependence is crucial only for river water
- Higher *w* corresponds to an enhanced mixing. If *w*↑, *θ*↑

Experiments on the "second generation" stack

An extended experimental campaign has been (and is currently being) carried out at VITO laboratories to investigate the performance of a novel design SGP-RE stack under REAPower conditions

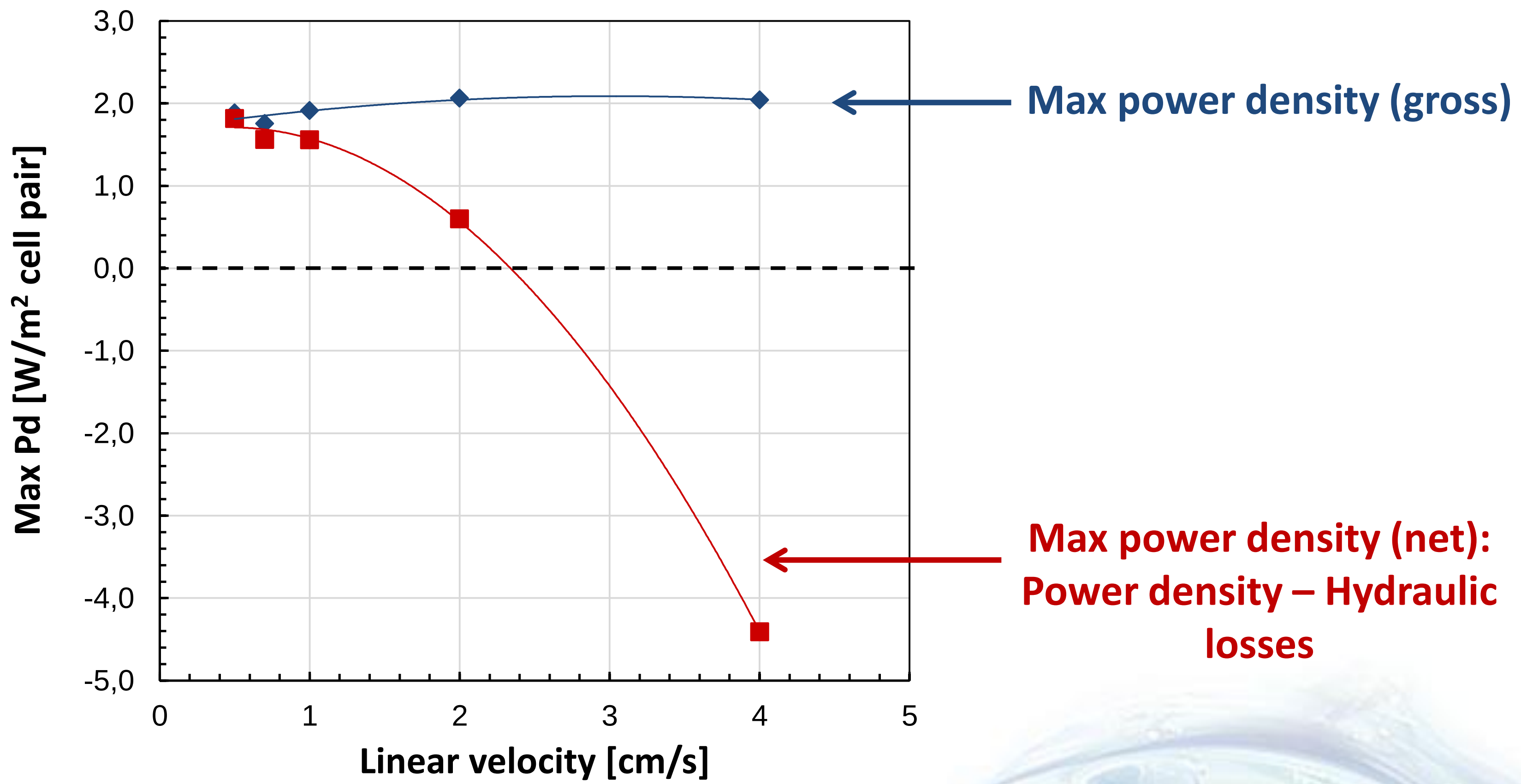


vito
vision on technology



Experiments on the “second generation” stack

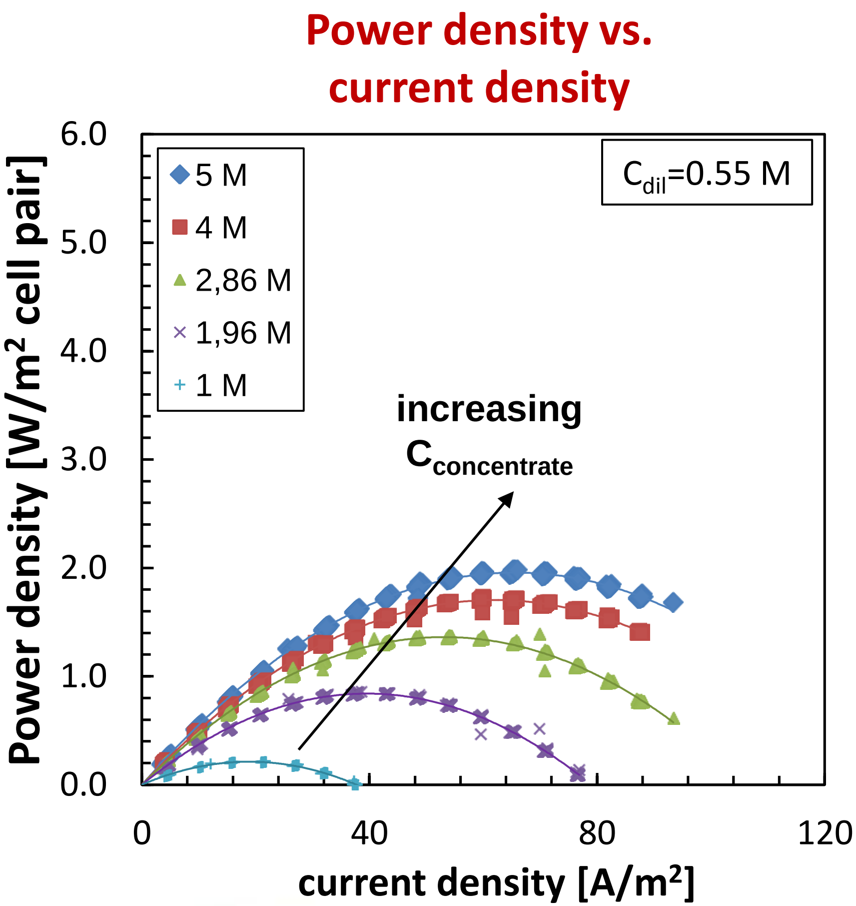
Effect of feed flow linear velocity

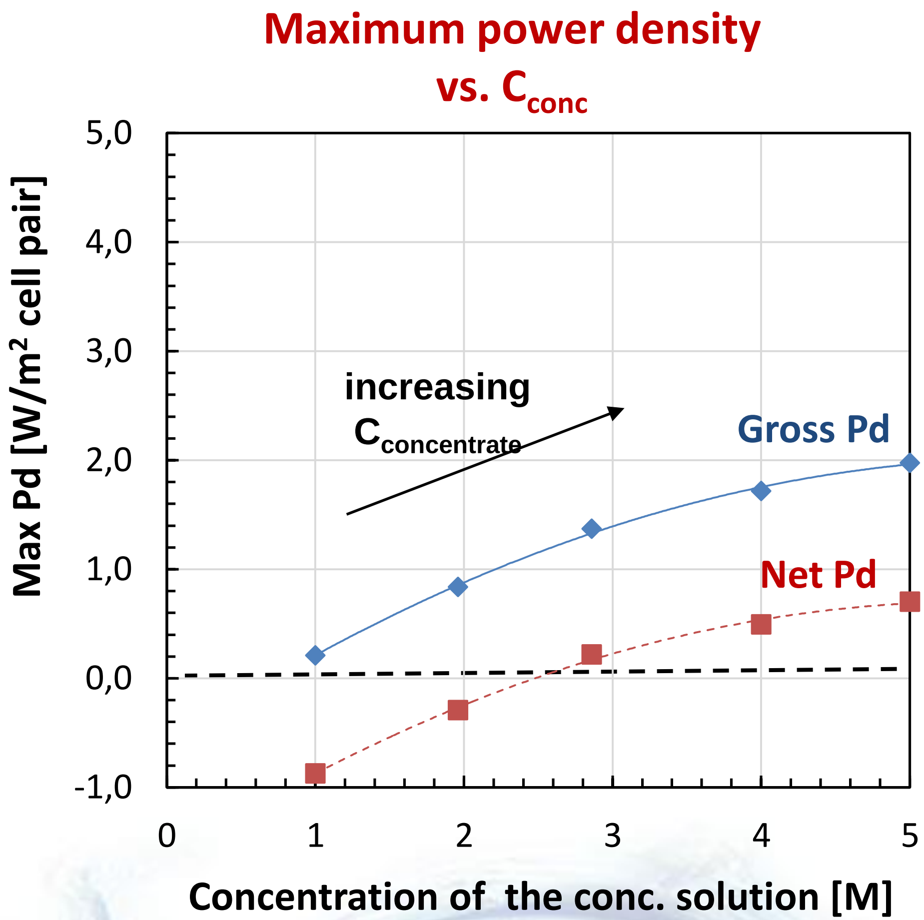


50 cell pairs - 80050 (CEM) and 80045 (AEM) membranes [thickness 120µm] - Deukum spacers [thickness 270 µm] - Brine 5 M, seawater 0,5 M - Electrode rinse solution [($K_3Fe(CN)_6$ 0,1 M, $K_4Fe(CN)_6 \cdot 3H_2O$ 0,1M; NaCl 2,5M) –conductivity 204 mS/cm – flow rate 30l/h].

Experiments on the "second generation" stack

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



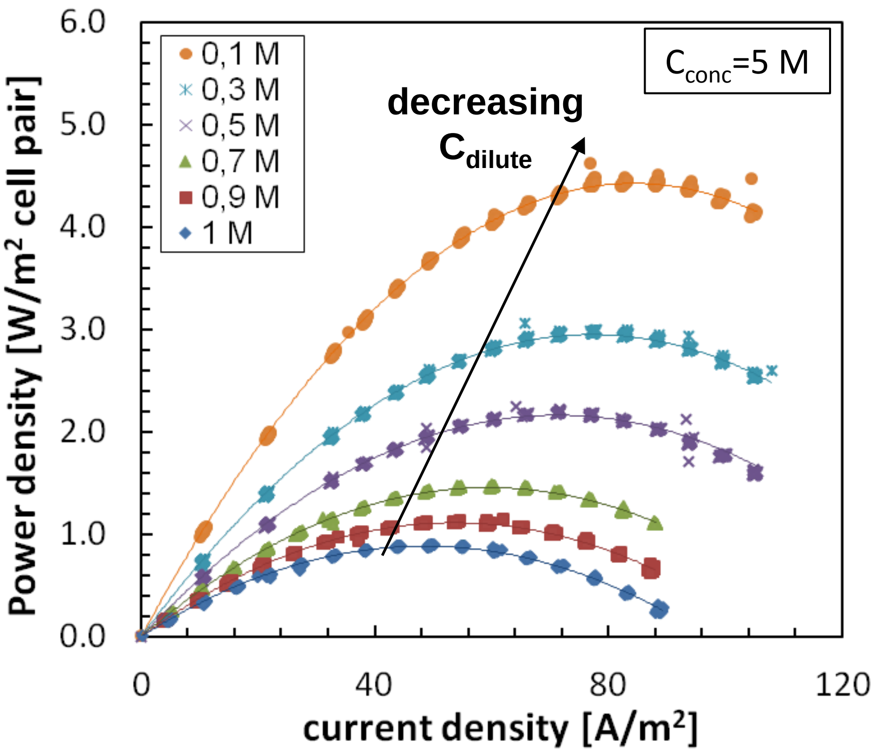


50 cell pairs - 80050 (CEM) and 80045 (AEM) membranes [thickness 120μm] - Deukum spacers [thickness 270 μm] - Brine 5 M [conductivity: 230 mS/cm – linear speed 1cm/s], seawater 0,1÷0,5 M [conductivity: 10,46÷84,4 mS/cm – linear speed 1cm/s] - Electrode rinse solution [($K_3Fe(CN)_6$ 0,1 M, $K_4Fe(CN)_6 \cdot 3H_2O$ 0,1M; NaCl 2,5M) –conductivity 204 mS/cm – flow rate 30l/h].

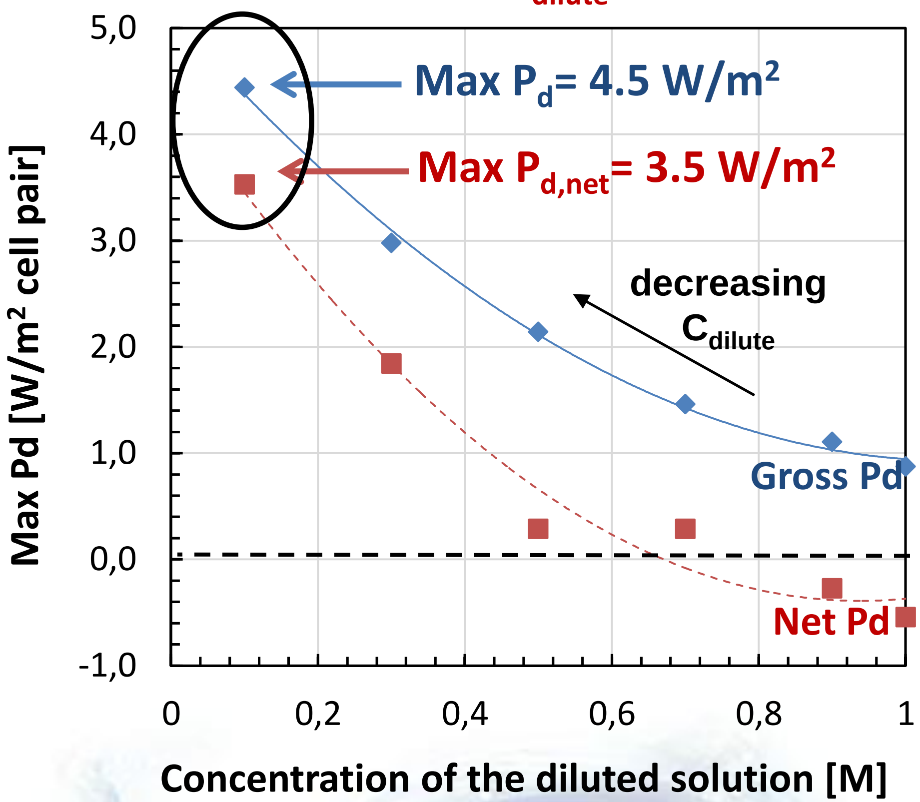
Experiments on the “second generation” stack

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

Power density vs. current density



Maximum power density vs. C_{dilute}



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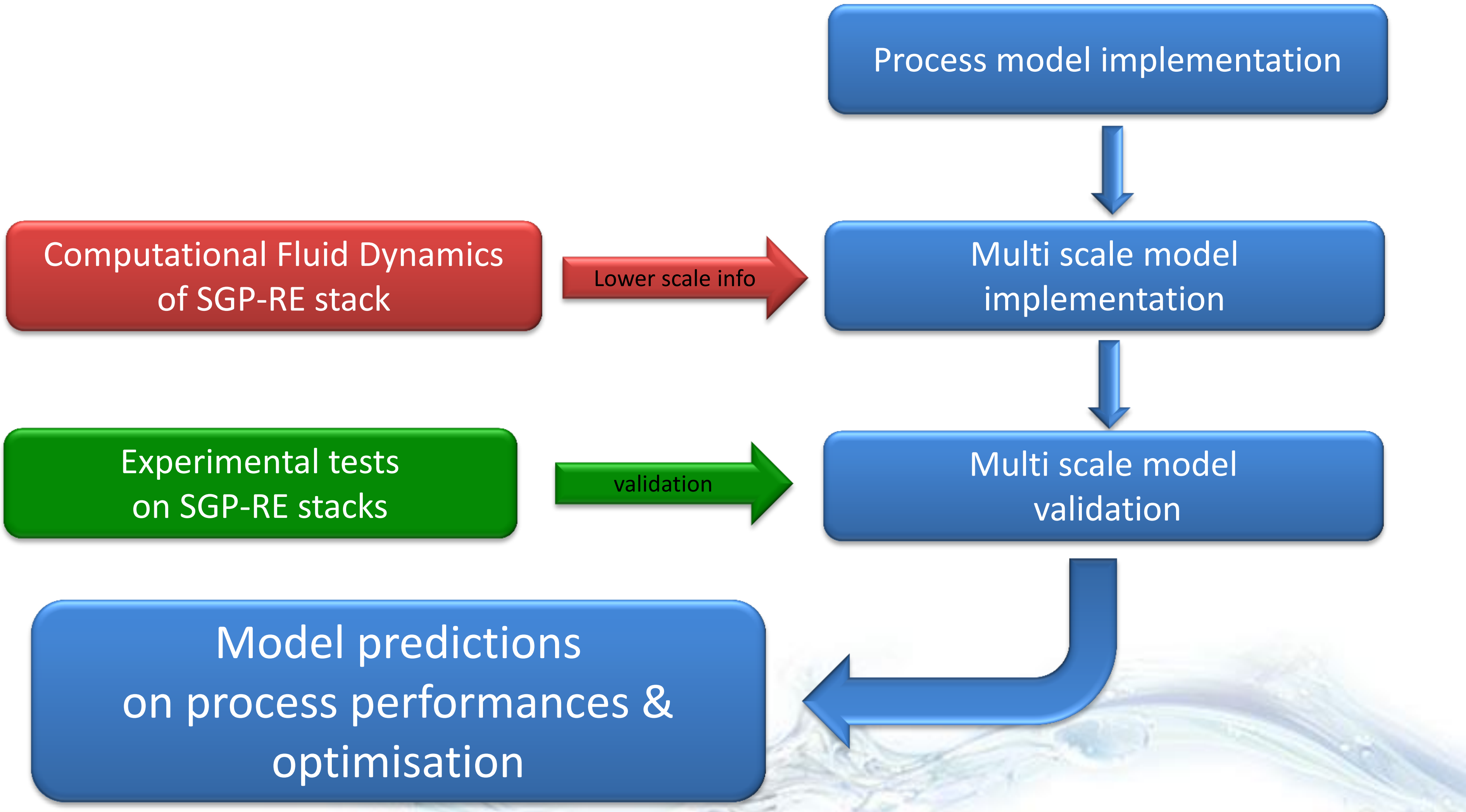
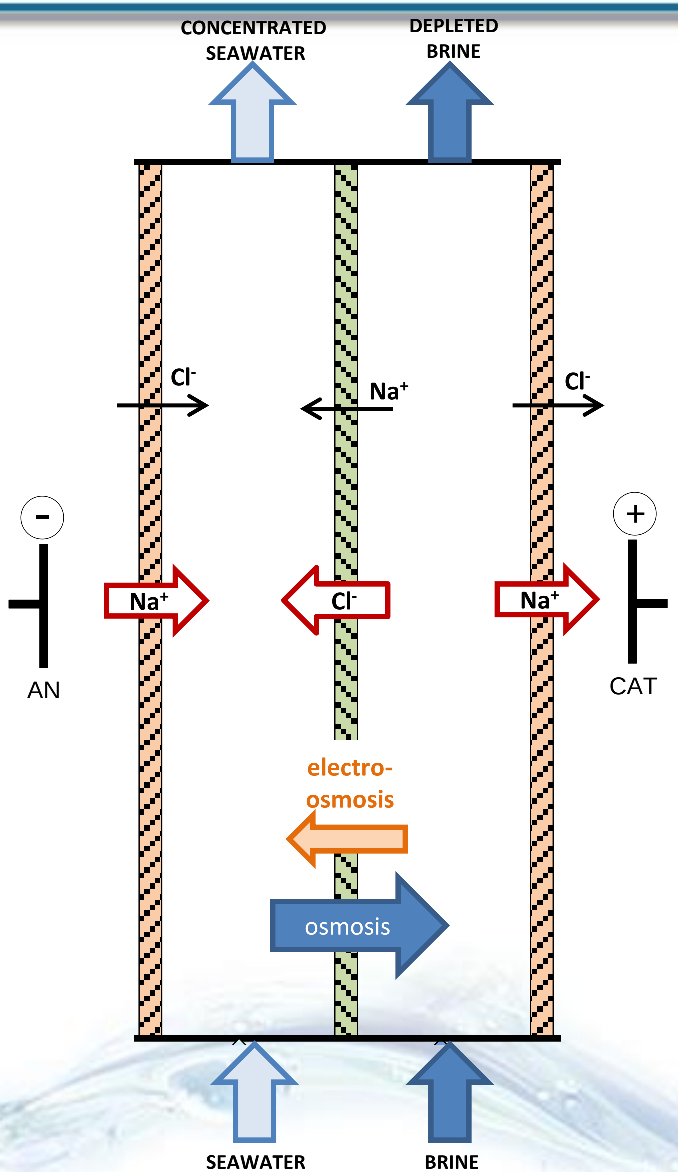
Multi-scale model implementation



Process Modelling Approach

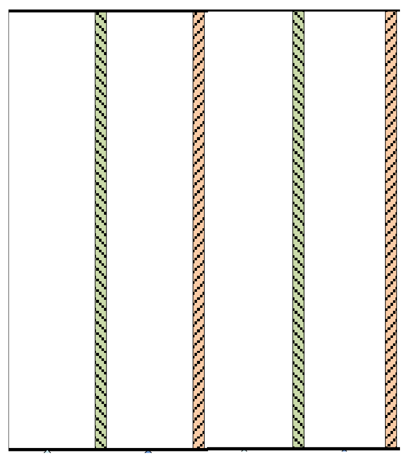


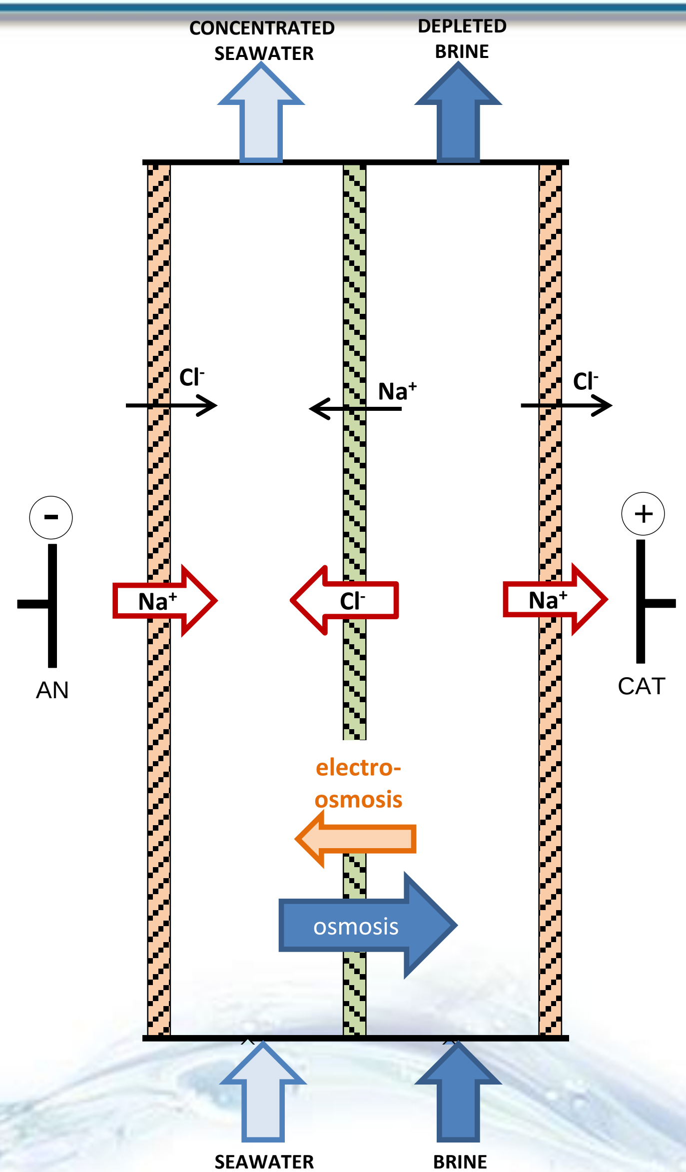
Low-hierarchy model (*cell pair*):

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

Tedesco, M.; Cipollina, A; Tamburini, A.; van Baak, W.; Micale, G.; "Modelling the Reverse ElectroDialysis process with seawater and concentrated brines", *Desalination and Water Treatment*, vol. 49, pp. 404-424, 2012.

Process Modelling Approach





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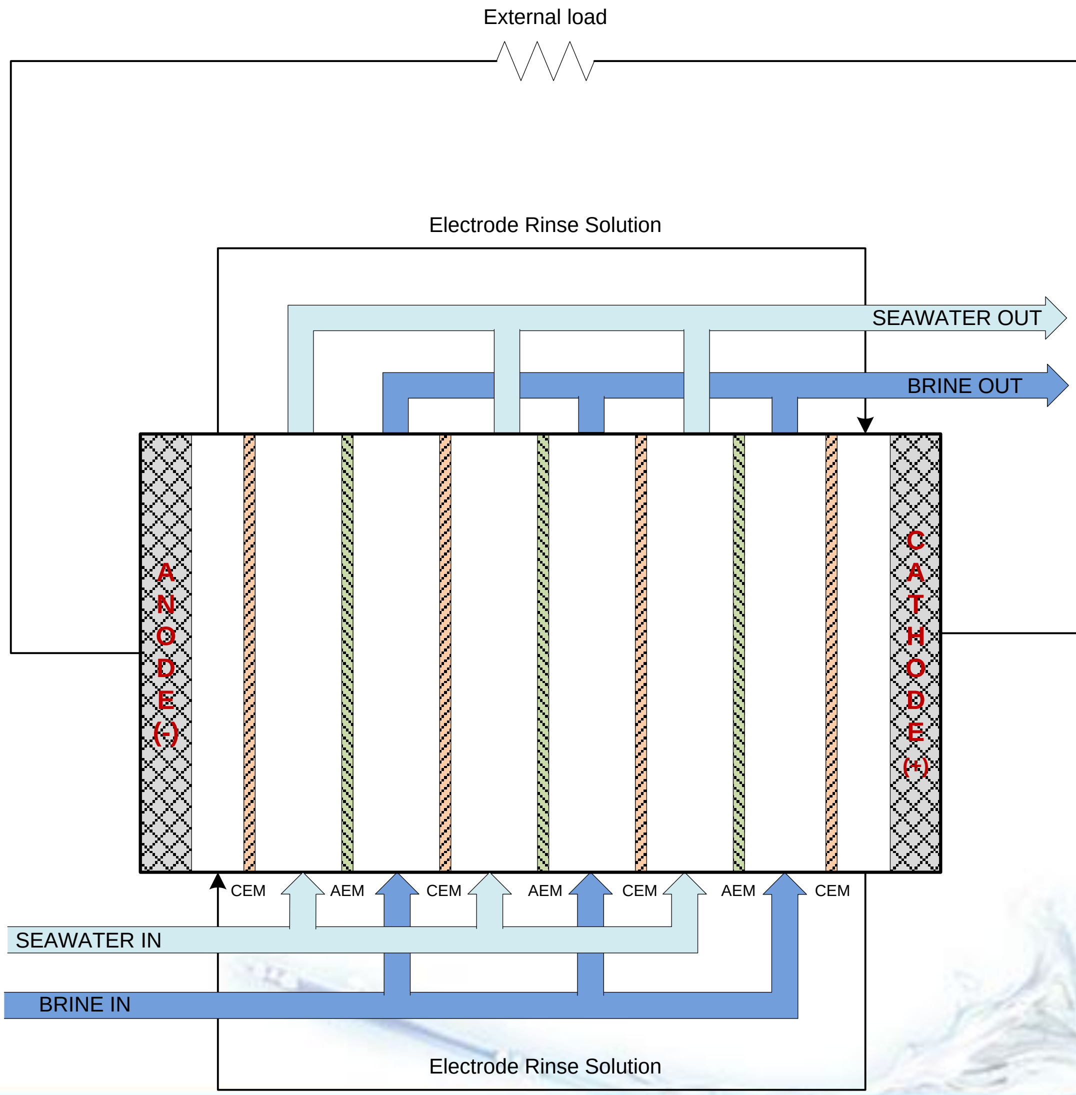
Process Modelling Approach

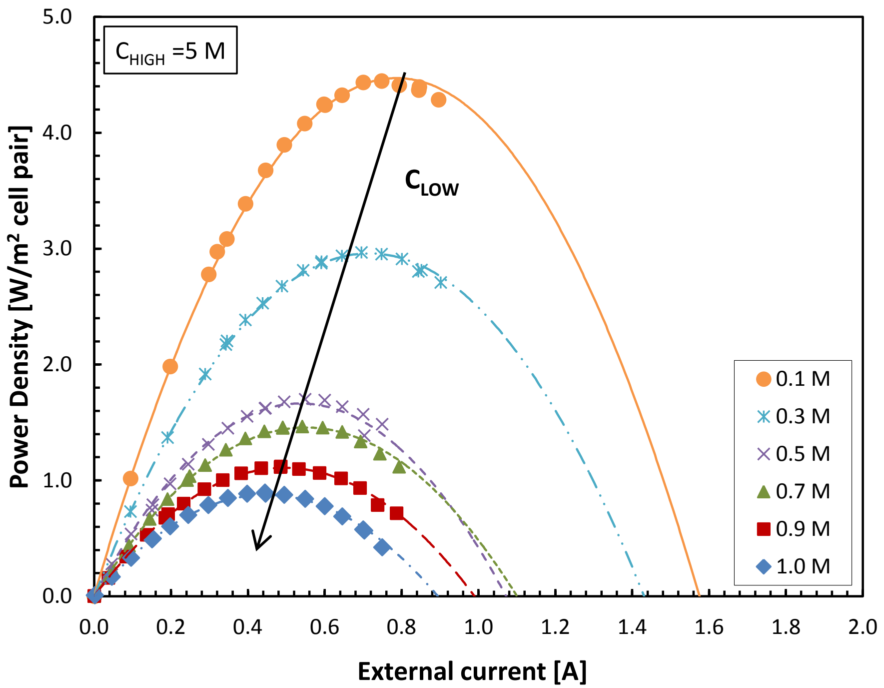


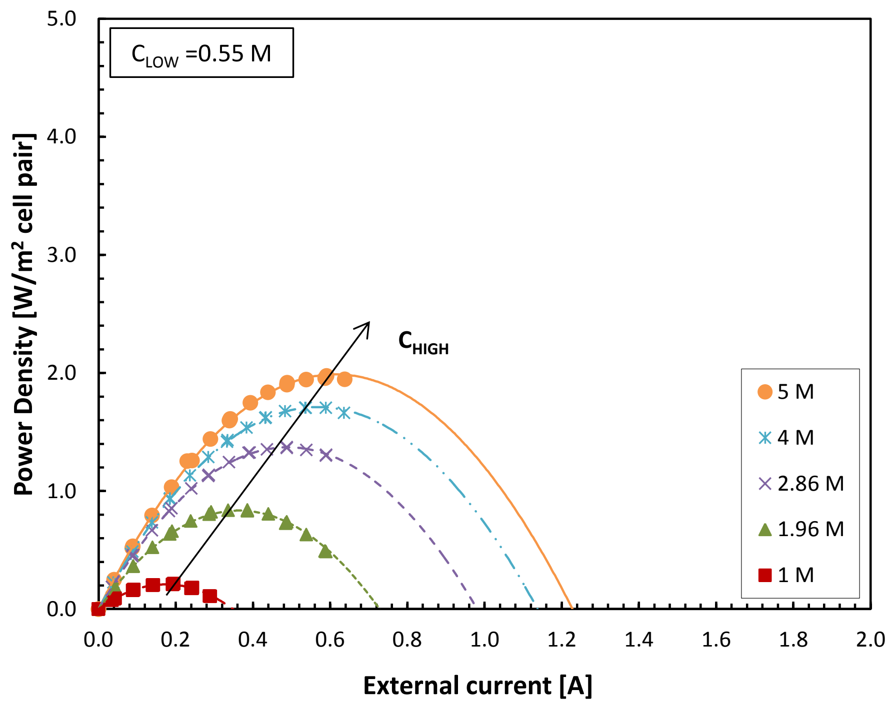
High-hierarchy model (*stack*):

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

Process Modelling validation

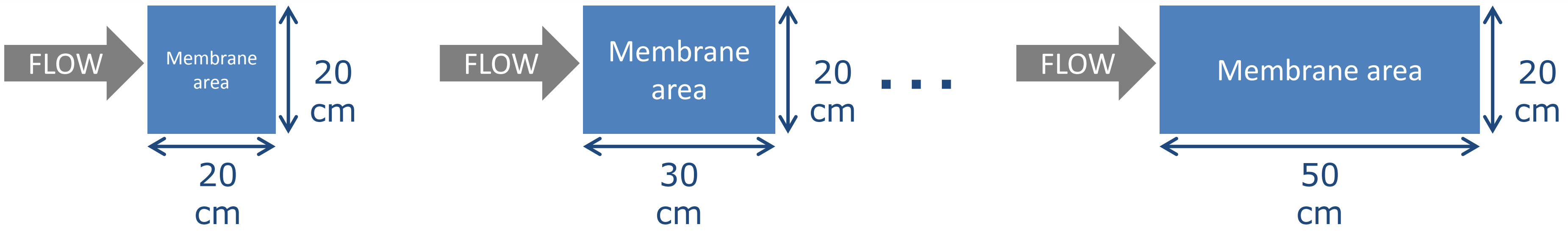
Model validation has been performed with the experimental results collected at VITO

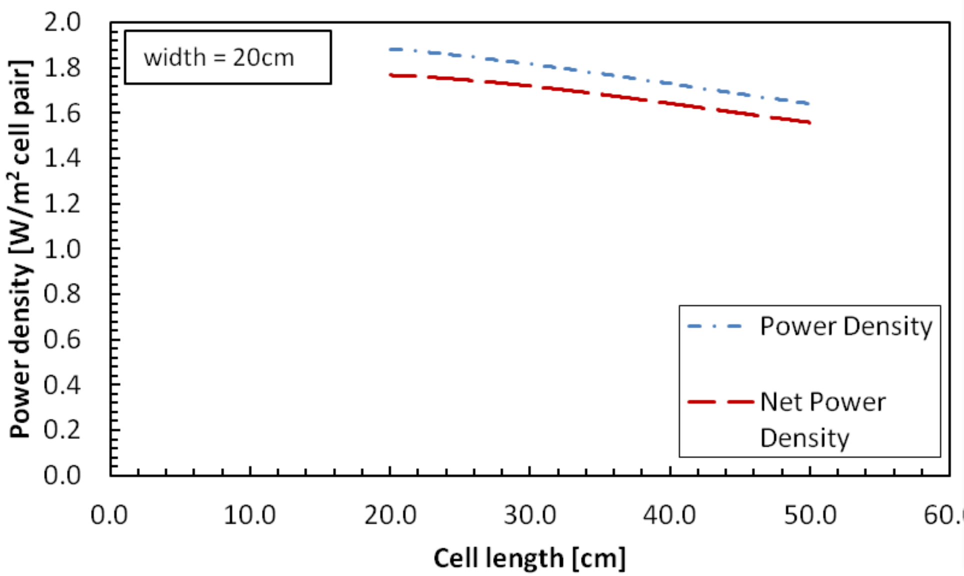


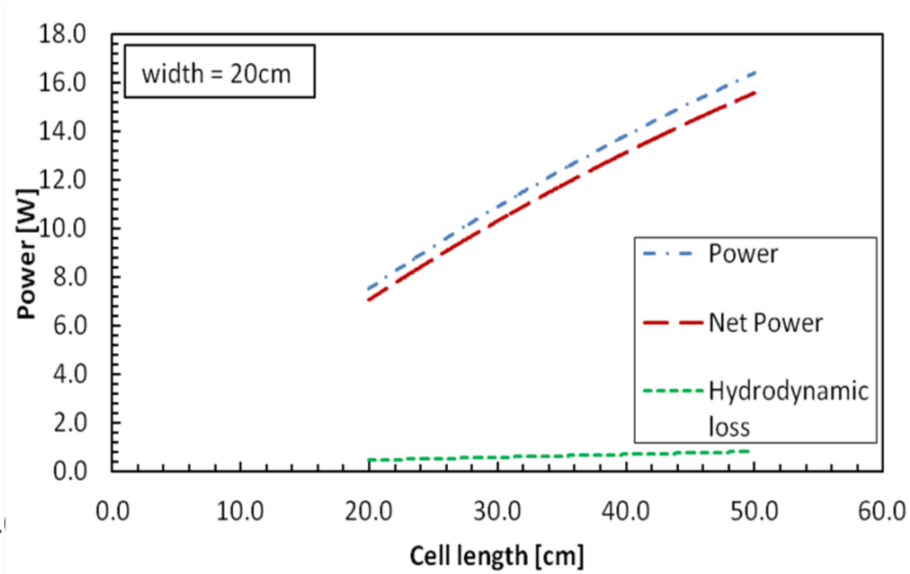


Effect of the **LOW/HIGH inlet concentration** on Power density.
Experimental (points) and simulated (lines) data for a 50-cells stack equipped with Fujifilm membranes - Deukum spacers; spacer thick: 270 micron; linear velocity: 1 cm/s.

Effect of stack size on power output



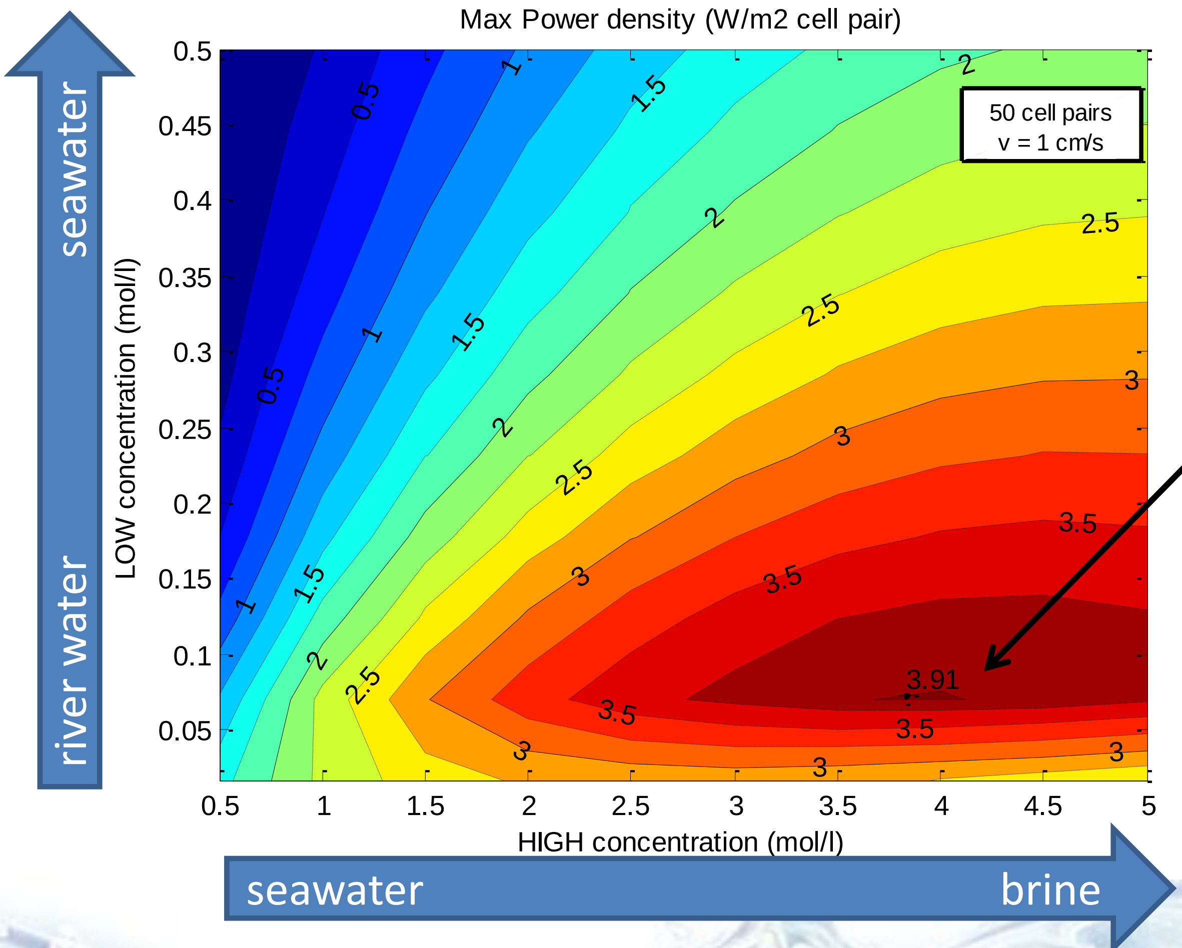




Simulations of a 100-cells stack equipped with Fujifilm membranes, Deukum spacers; linear velocity inside channels: 1 cm/s. Power density defined with respect to the cell pair area (N*A).

Which salt solutions for the SGP-RE Process?

Effect of inlet solutions concentration on Power Density

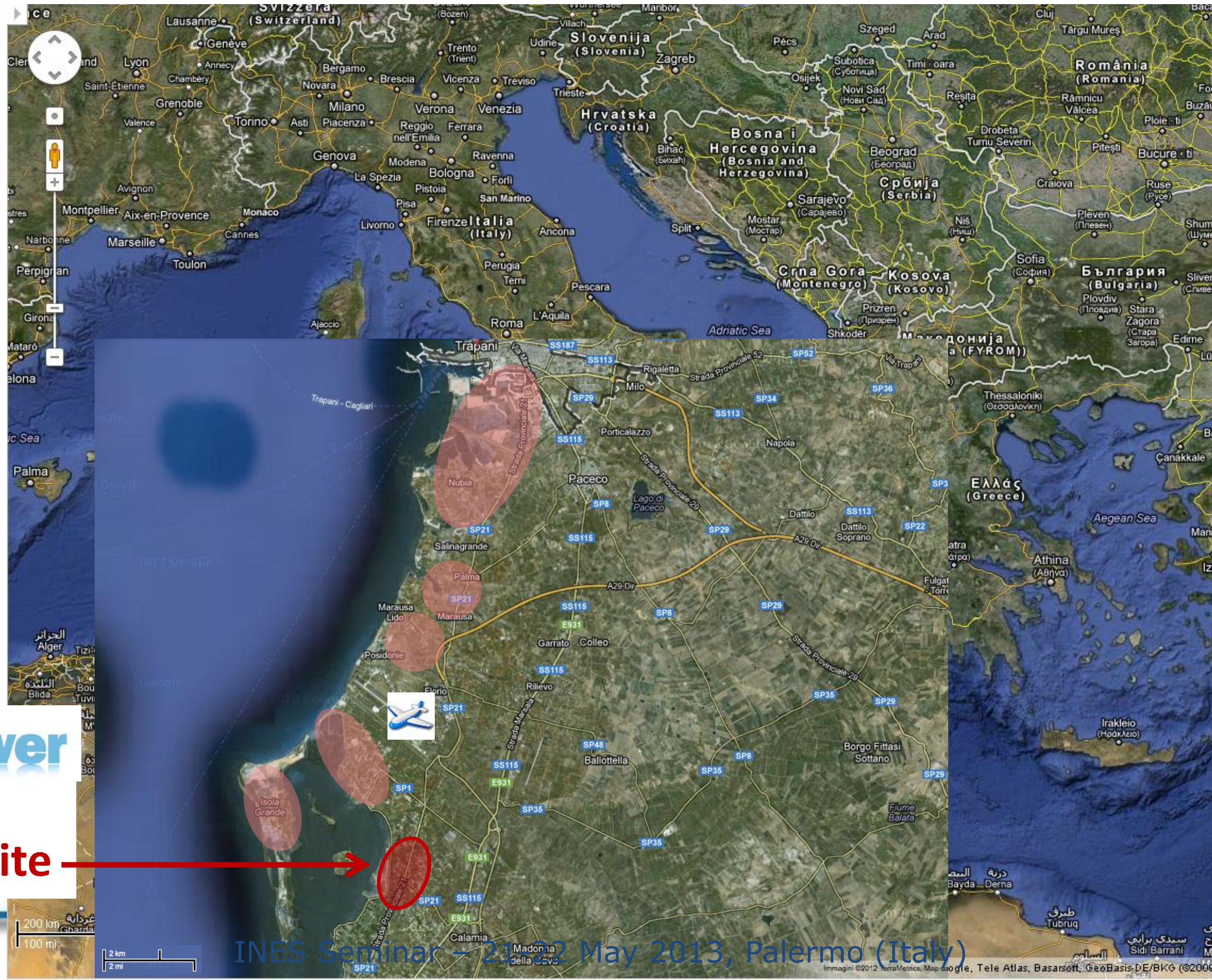


BEST conditions:
brackish water
(0.05 – 0.1 M)
+
brine (4 M)

Simulations of a 50-cells stack equipped with Fujifilm membranes, Deukum spacers; linear velocity inside channels: 1 cm/s. Power density defined with respect to the cell pair area (N*A).

Which brines for the SGP-RE process?

Prototype installation site: the singular framework of Trapani saltworks



Prototype installation site

Which brines for the SGP-RE process?

Prototype installation site: 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: ≈ 60 m^2;

-Expected power density: > 5 W/m^2;

-Expected power output: > 300W

REAPower website

http://www.reapower.eu/

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Thank you for your attention

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