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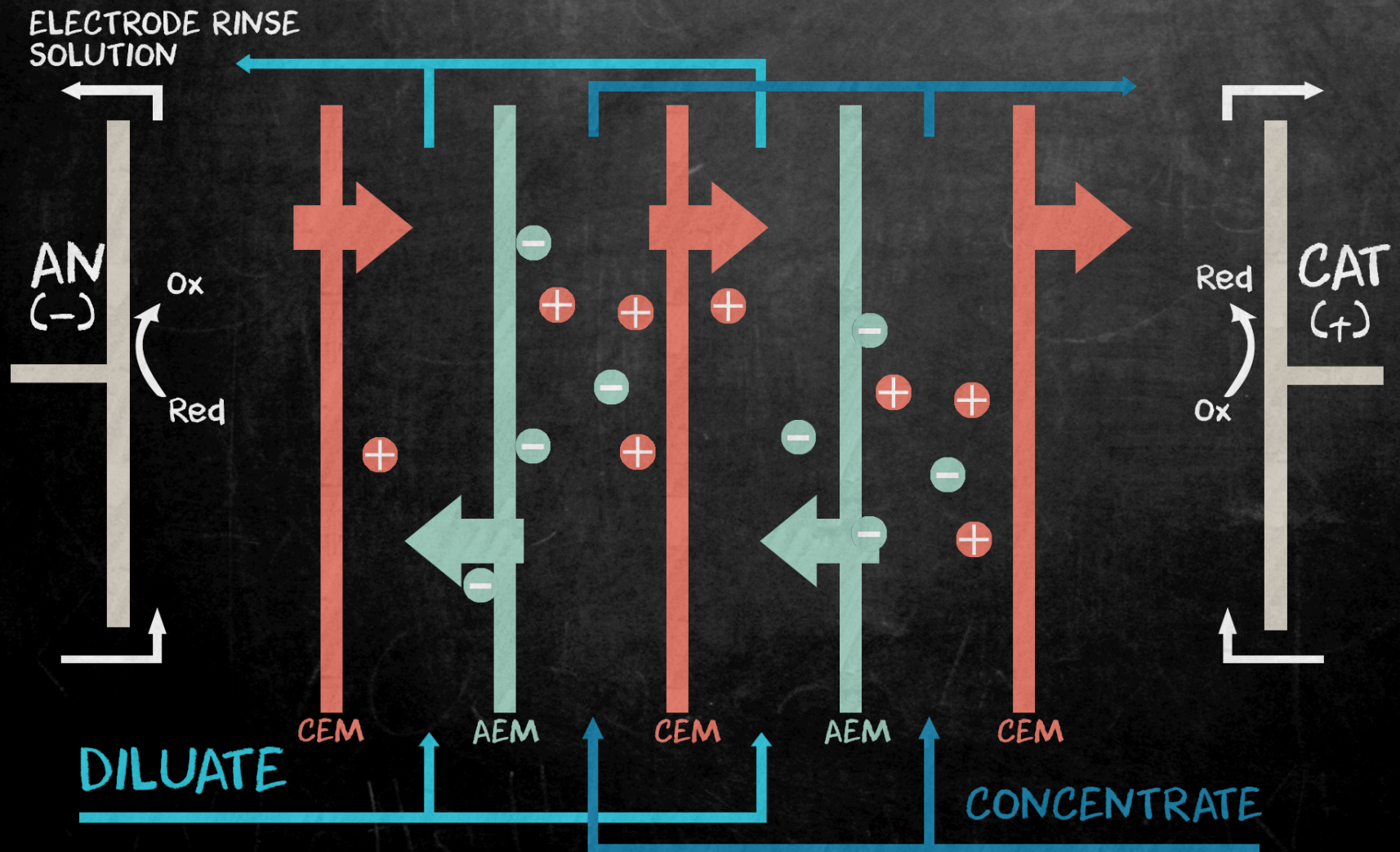
**REVERSE ELECTRODIALYSIS
WITH BRACKISH WATER AND CONCENTRATED BRINES:
UP-SCALED PILOT PLANT OPERATING
IN A REAL ENVIRONMENT**

ANDREA CIPOLLINA

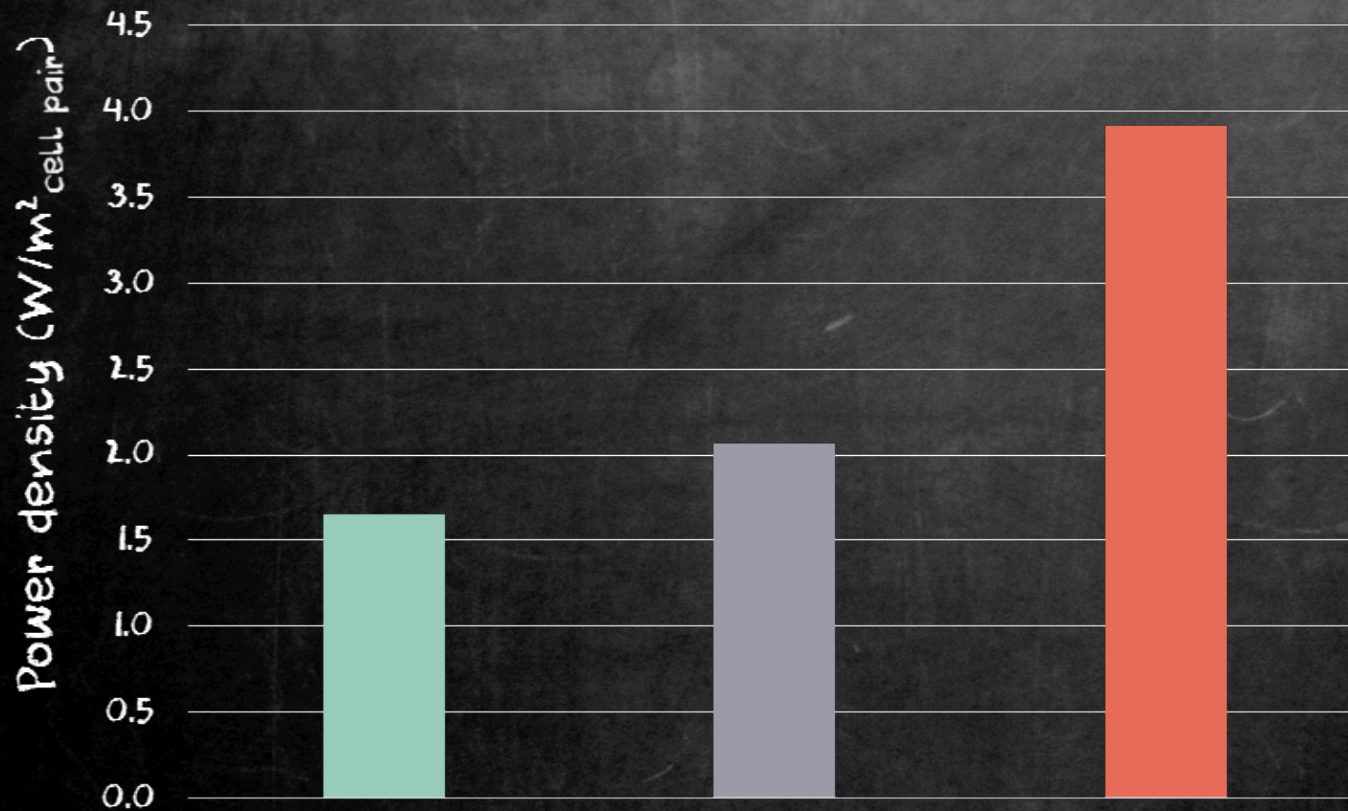
M. TEDESCO, A. TAMBURINI, G. MICALE

**EUROMEMBRANE 2015
6-10 SEPTEMBER 2015, AACHEN**

WHAT IS REVERSE ELECTRODIALYSIS?



WHICH FEED SOLUTIONS?



10x10 cm^2 stack
50-cells
270 μm spacers;
velocity: 1 cm/s;
T: 20° C.

LOW: Fresh water (1 g/L) Seawater (30 g/L) Brackish water (3 g/L)

HIGH: Seawater (30 g/L) Brine (200 g/L) Brine (200 g/L)

M. Tedesco et al., A simulation tool for analysis and design of reverse electrodialysis using concentrated brines, Chem. Eng. Res. Des. (2015)

Development of new components
(membranes, spacers, stack)

Economic analysis

FLuidynamics
investigation



REAPower

Reverse Electrodialysis Alternative Power

Design and testing of
RED pilot plant

Process simulator

Laboratory-scale
investigation

FOCUS: INSTALLATION AND TESTING OF RED PILOT PLANT FED WITH BRACKISH WATER AND BRINE



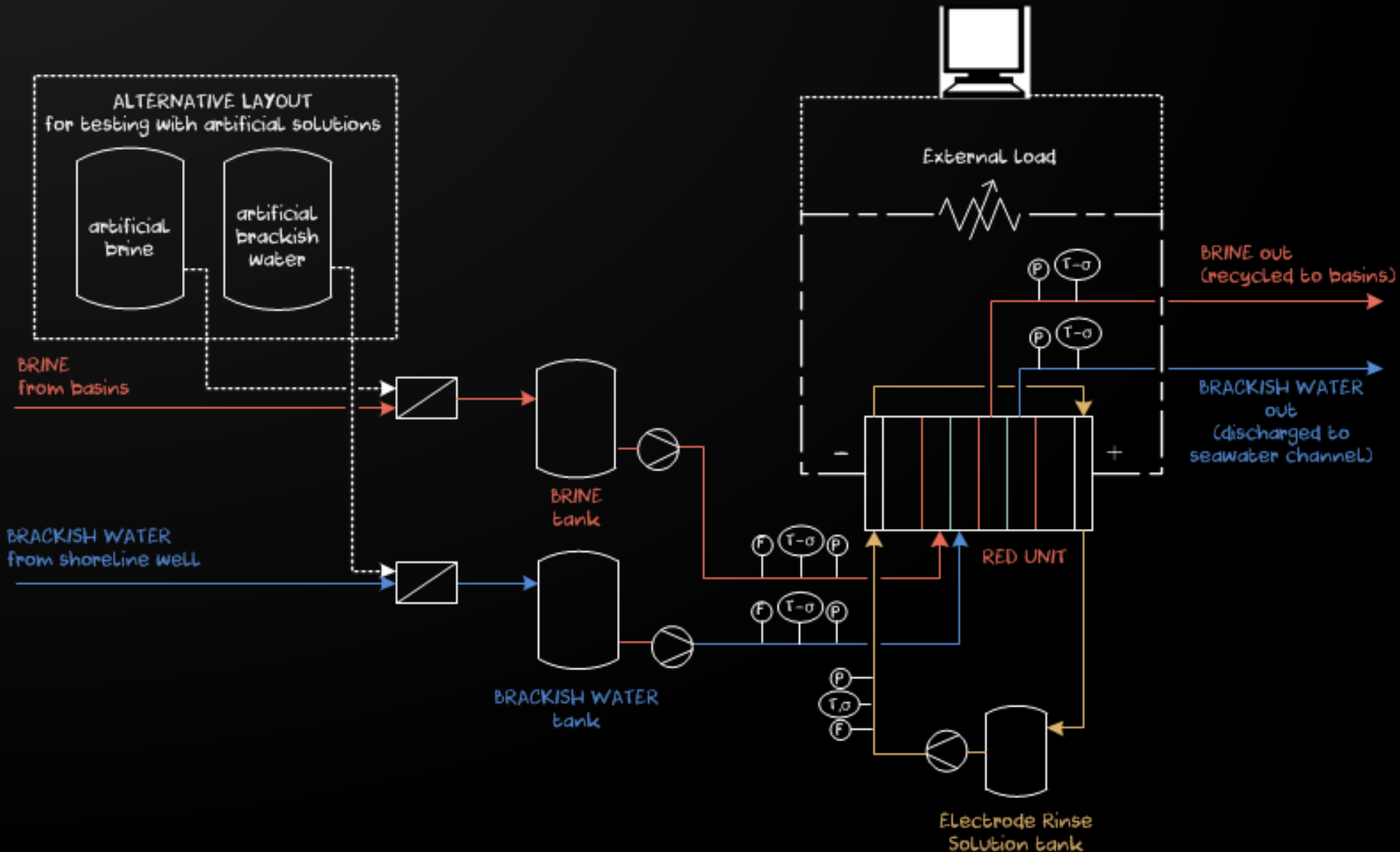
Feed solutions:

- ✓ saturated brine (conductivity: 200 mS/cm, \approx 250–300 g/L)
- ✓ brackish water (conductivity: 3.4 mS/cm, \approx 2 g/L)

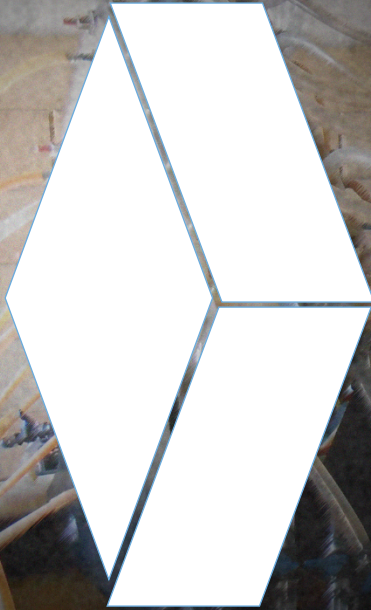
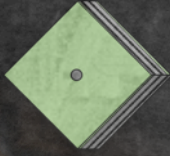
THE INSTALLATION SITE: ETTORE-INFERSA SALTWORKS (MARSALA, ITALY)



PLANT LAYOUT



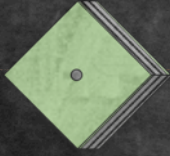
Small prototype
44 x 44 cm² – 125 cell pairs



RED **STACK**
FUJIFILM

Small prototype

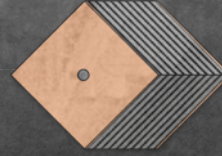
44 x 44 cm² - 125 cell pairs



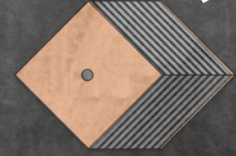
+

2 Large prototype

44 x 44 cm² - 500 cell pairs



+



>400 m²

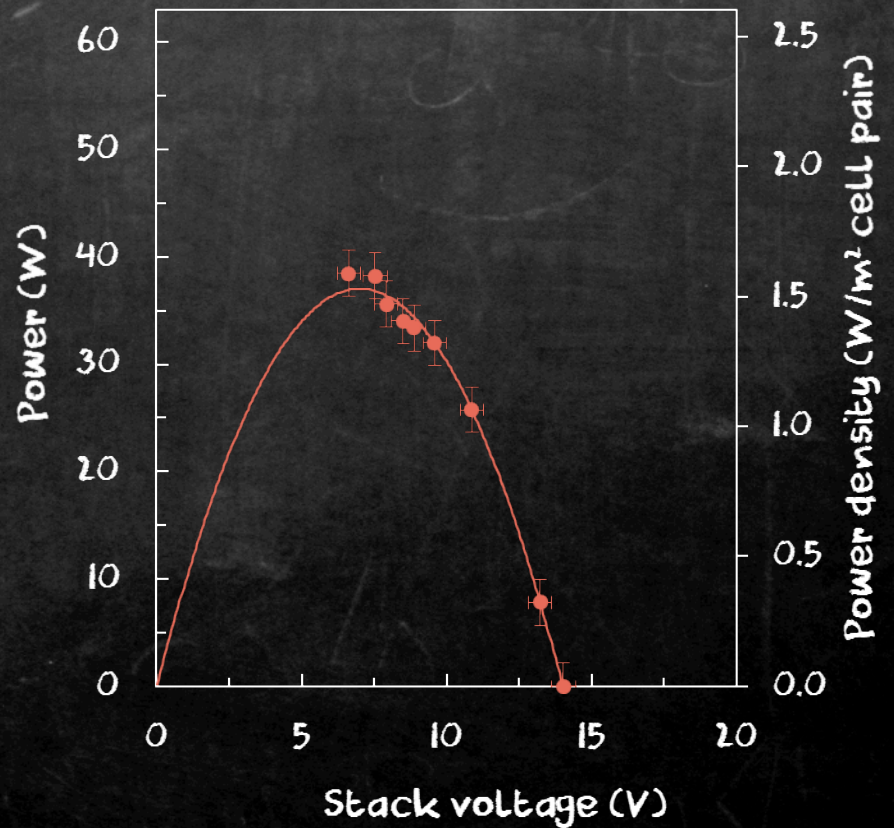
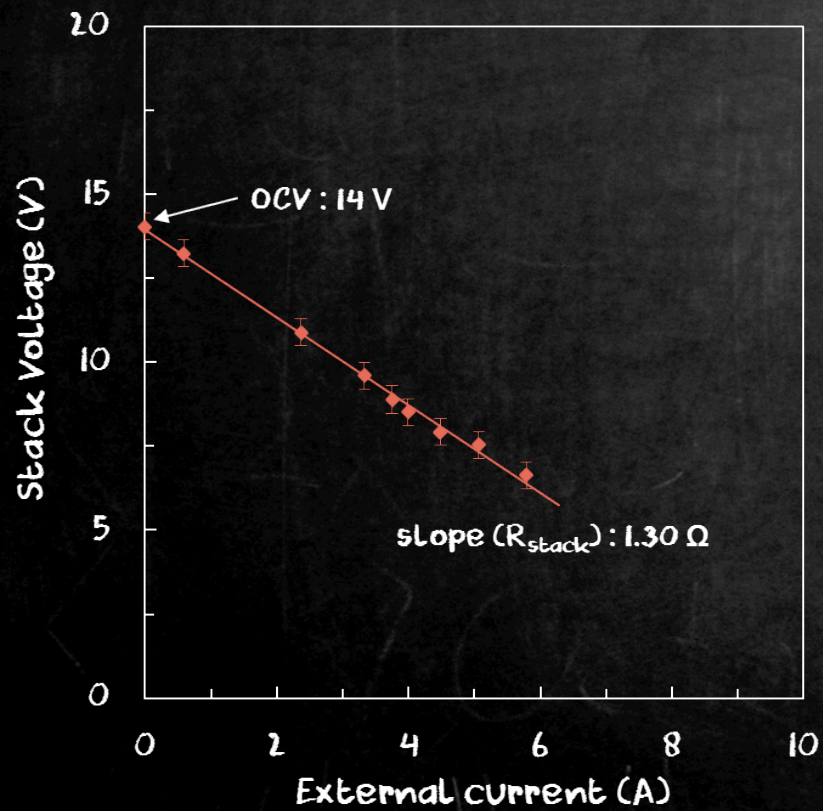
membrane area
installed

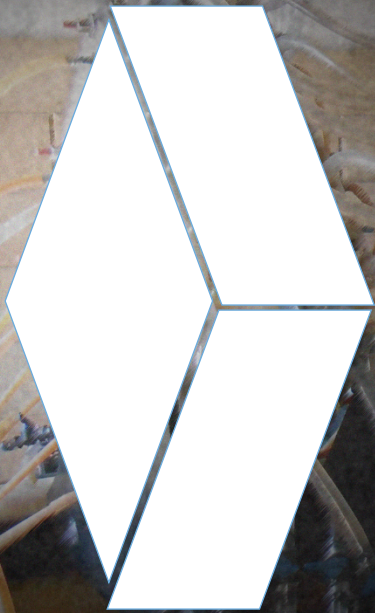
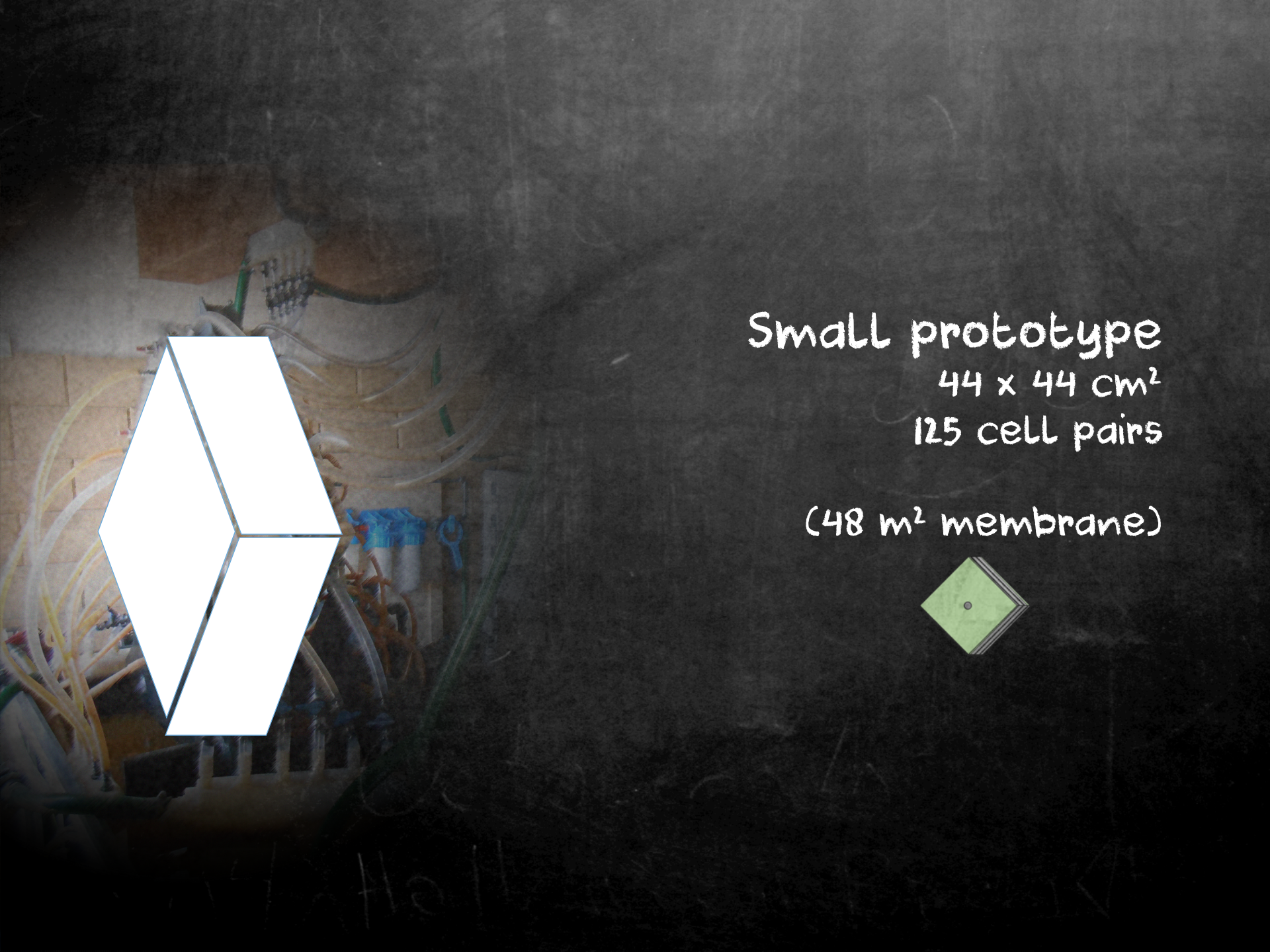
REDSTACK

FUJIFILM



EXPERIMENTAL PROCEDURE



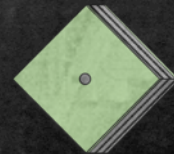


Small prototype

44 x 44 cm²

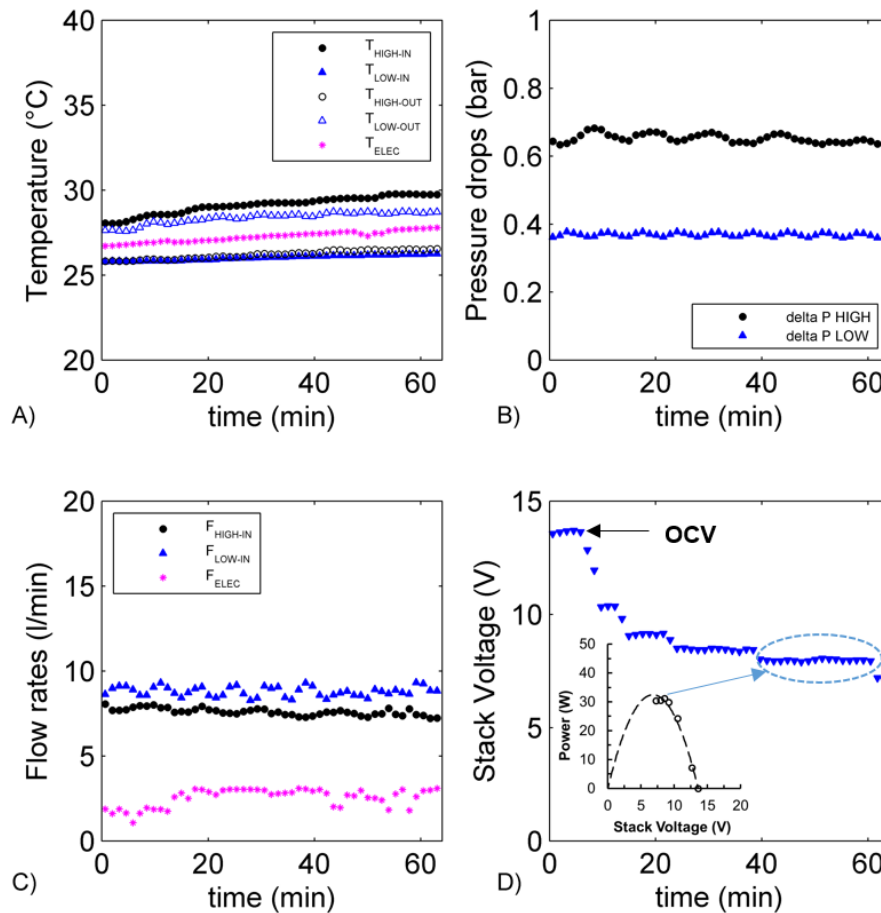
125 cell pairs

(48 m² membrane)



TEST WITH NATURAL SOLUTIONS (1/2)

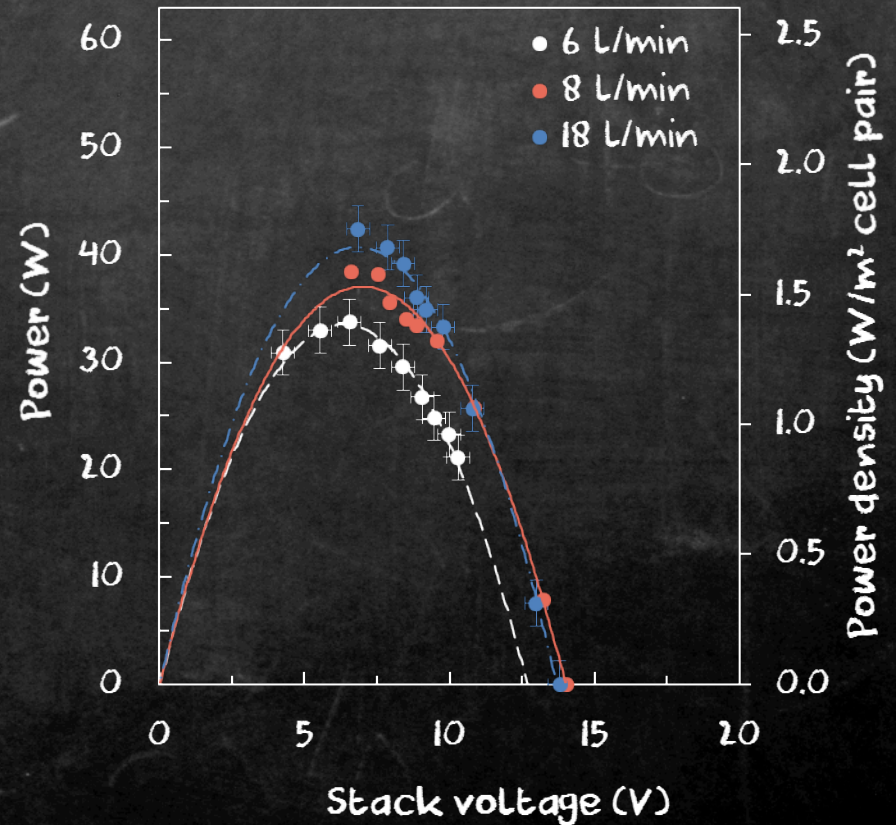
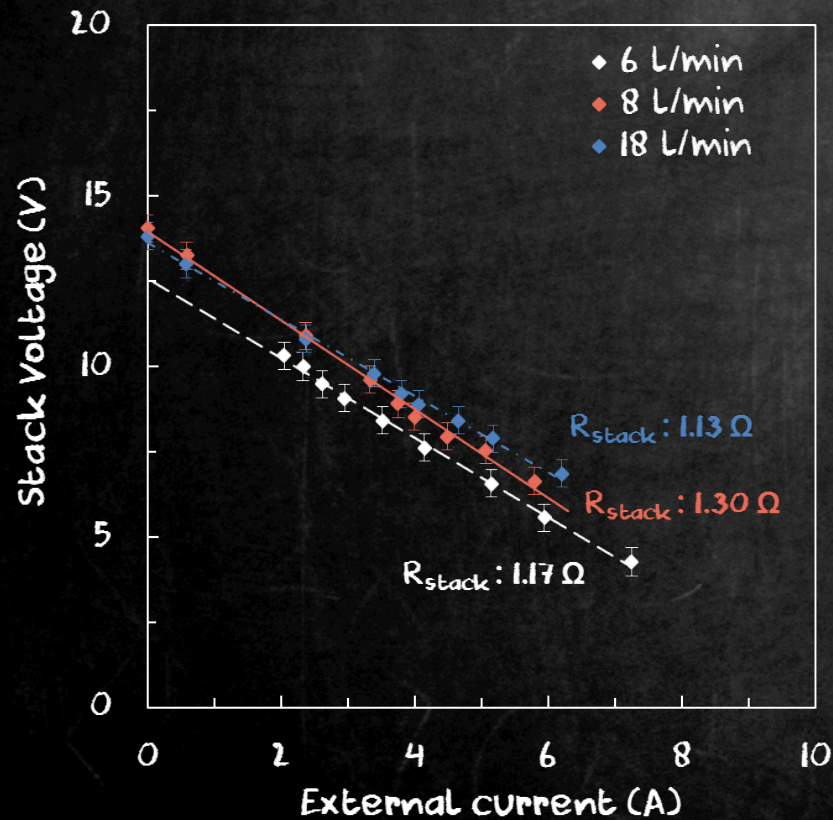
POWER MEASUREMENT



M. Tedesco et al., Performance of the first Reverse Electrodialysis pilot plant for power production from saline waters and concentrated (submitted)

TEST WITH NATURAL SOLUTIONS (2/2)

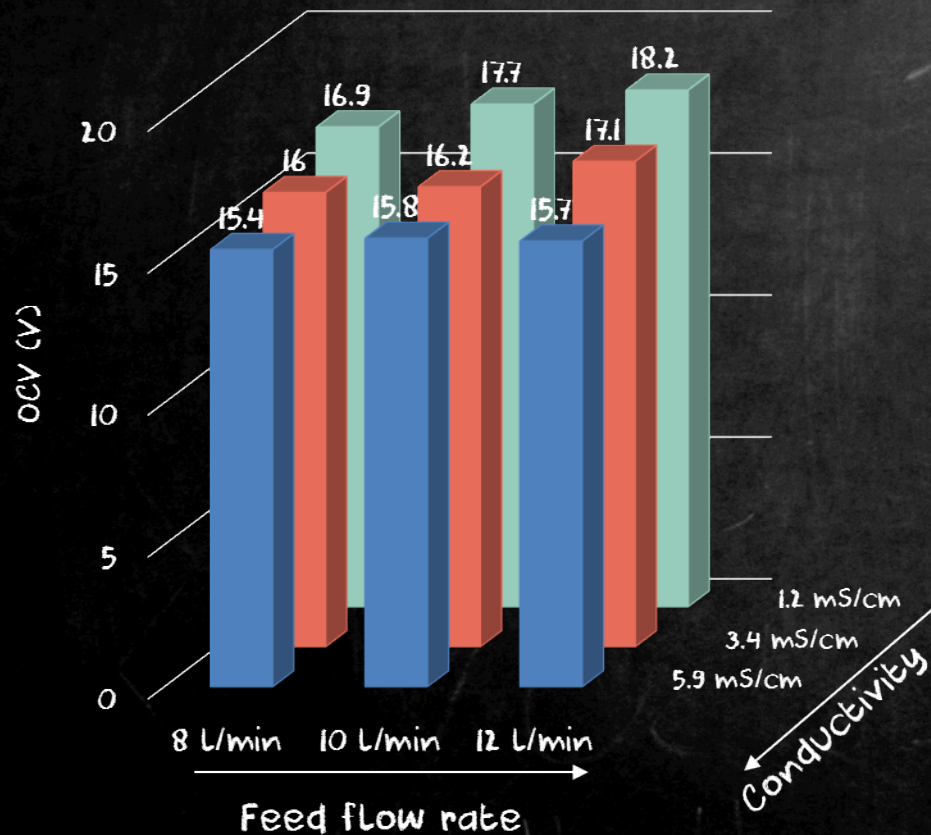
EFFECT OF FLOW RATES



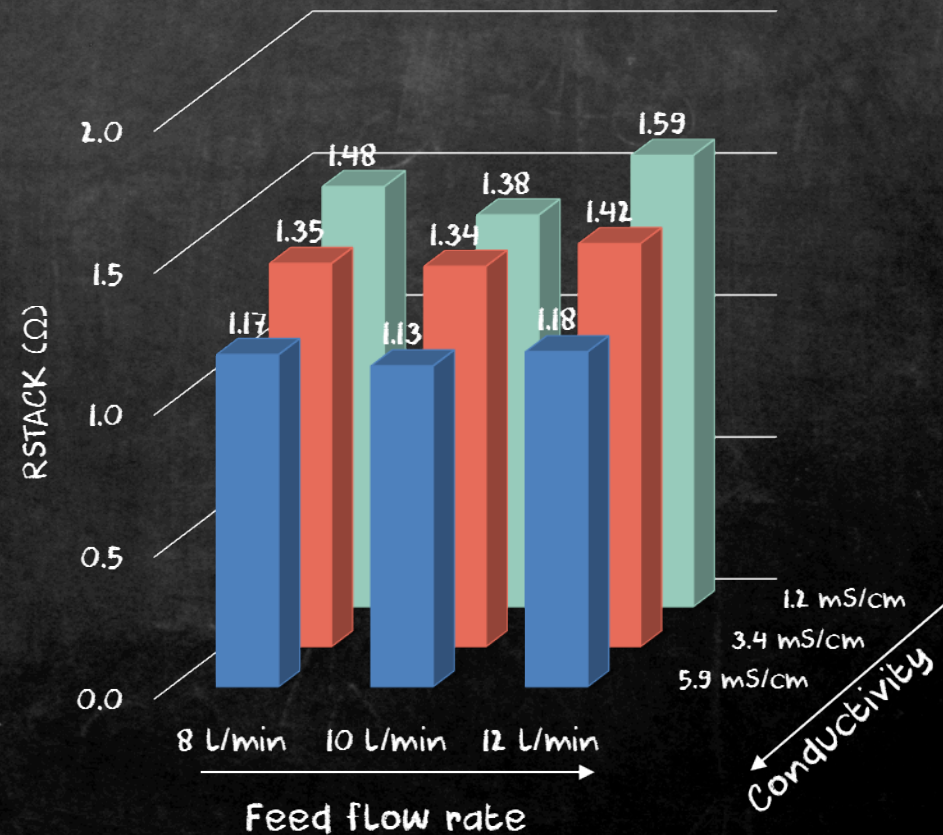
Feed solutions: brine (196 mS/cm) and brackish water (3.4 mS/cm).

TEST WITH ARTIFICIAL SOLUTIONS (1/2)

Open Circuit Voltage

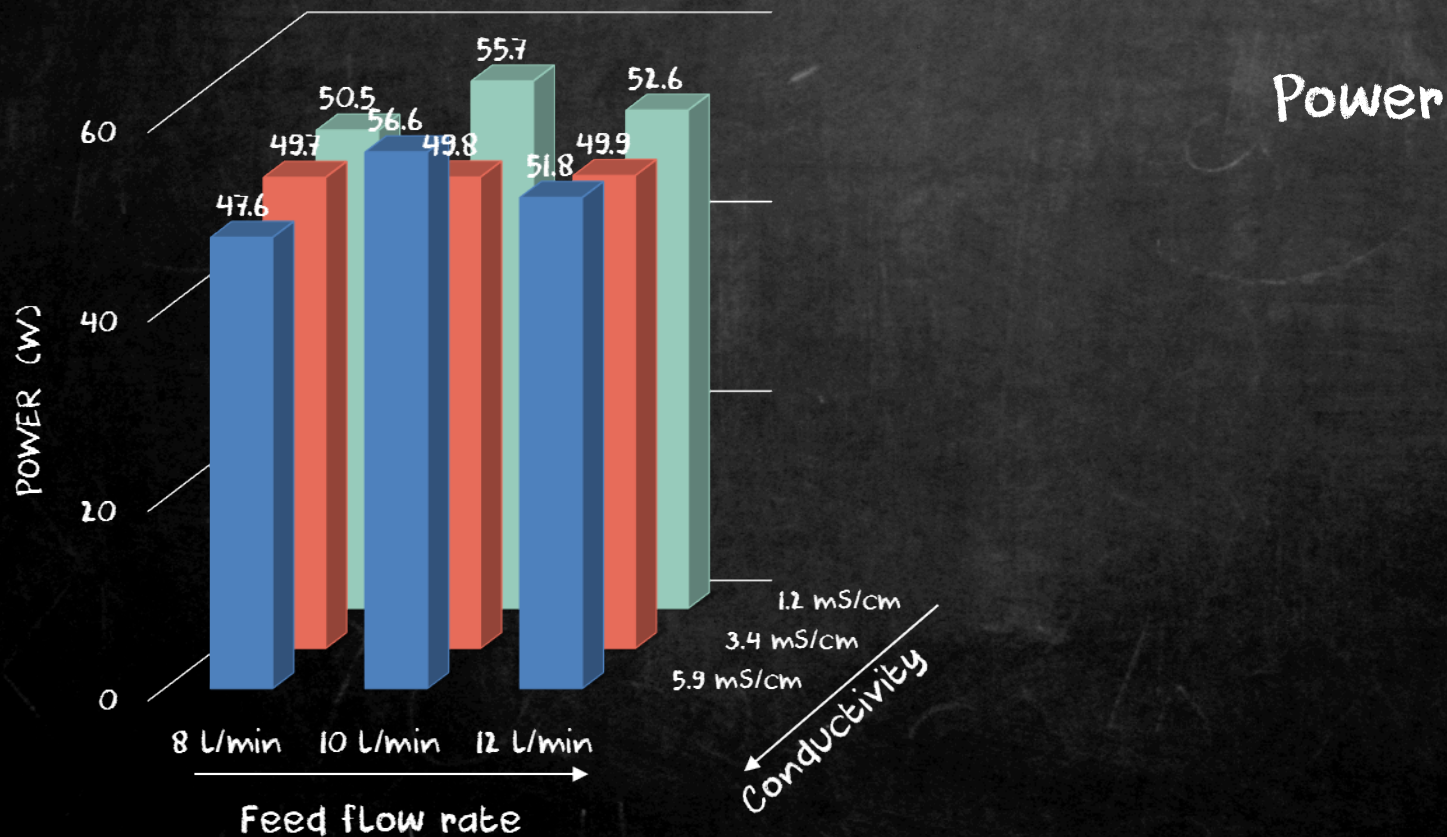


Stack resistance



Feed solutions: artificial brine (NaCl solution at 215 mS/cm, 8 L/min) and artificial brackish water (NaCl solution at 1.2 – 5.9 mS/cm)

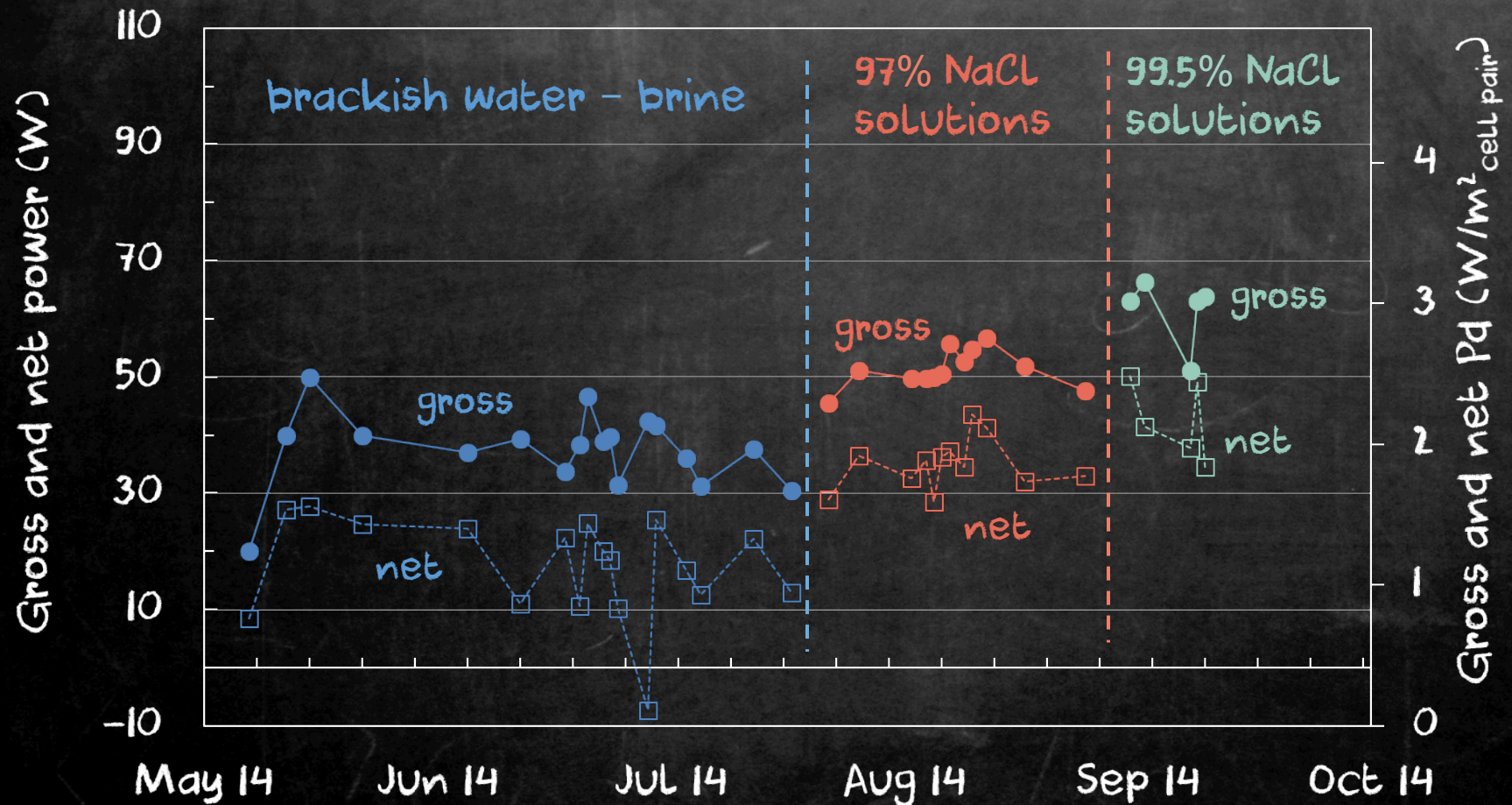
TEST WITH ARTIFICIAL SOLUTIONS (2/2)



Feed solutions: artificial brine (NaCl solution at 215 mS/cm, 8 L/min) and artificial brackish water (NaCl solution at 1.2 – 5.9 mS/cm)

OVERALL PLANT PERFORMANCE (1/3)

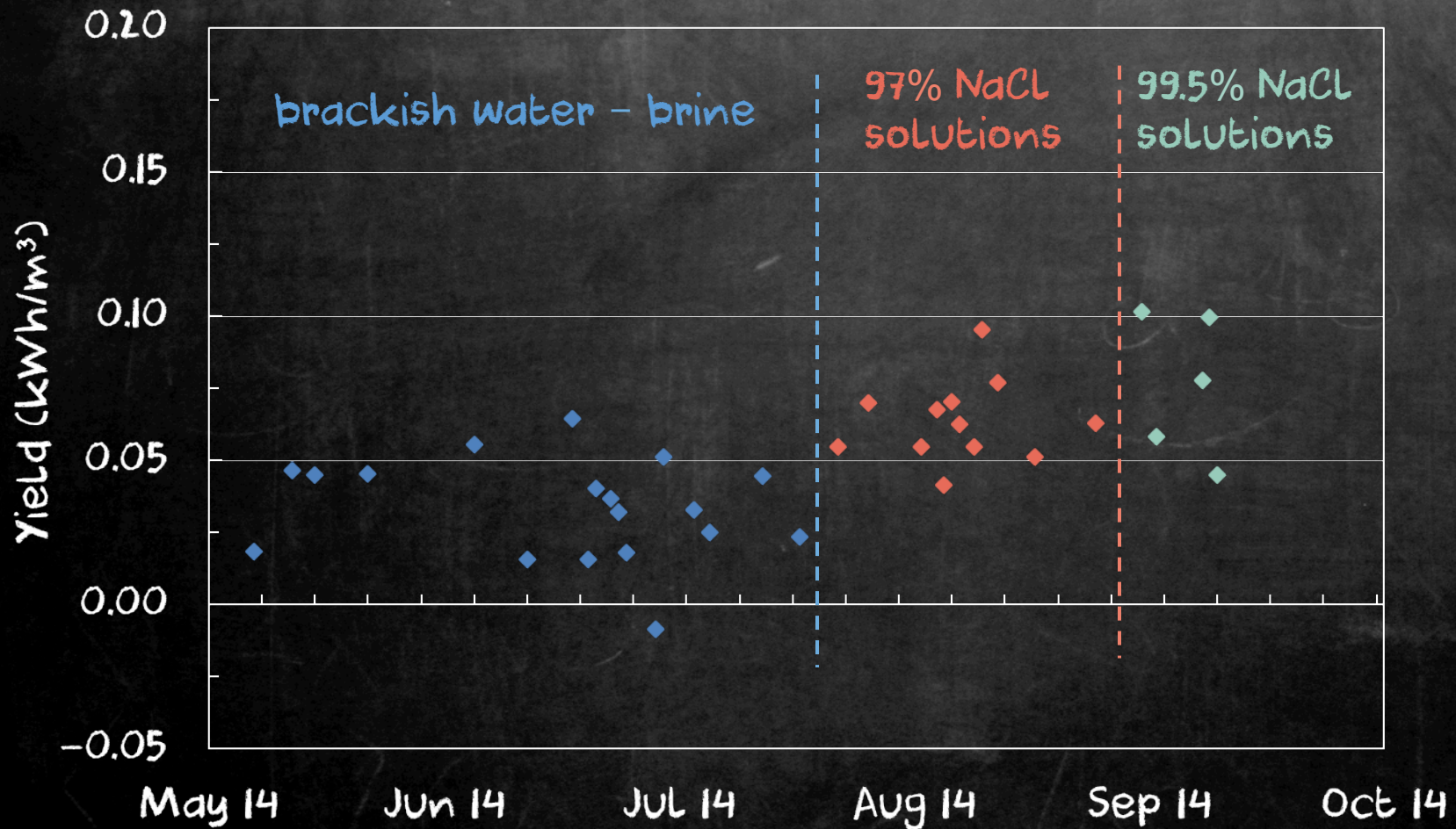
Power



Range of variable conditions: brine conductivity: 135 – 220 mS/cm, dilute conductivity: 0.6 – 6 mS/cm, T: 17–31°C, flow velocity: 0.8 – 2.4 cm/s

OVERALL PLANT PERFORMANCE (2/3)

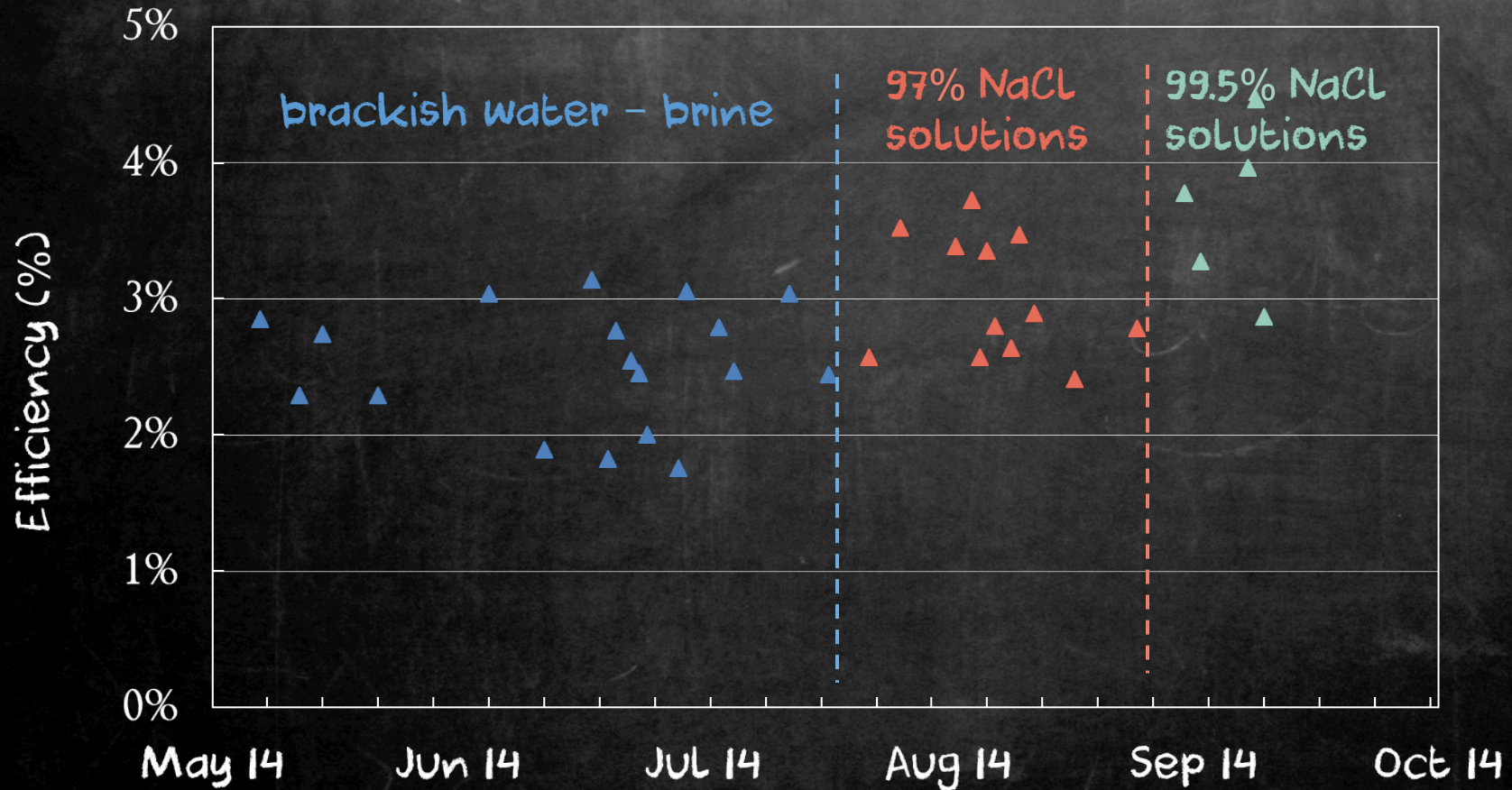
Yield



Range of variable conditions: brine conductivity: 135 – 220 mS/cm, dilute conductivity: 0.6 – 6 mS/cm, T: 17–31°C, flow velocity: 0.8 – 2.4 cm/s

OVERALL PLANT PERFORMANCE (3/3)

efficiency



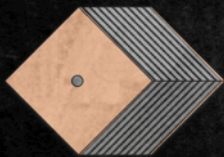
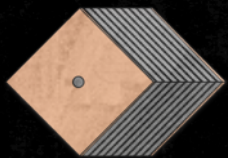
Range of variable conditions: brine conductivity: 135 – 220 mS/cm, dilute conductivity: 0.6 – 6 mS/cm, T: 17–31°C, flow velocity: 0.8 – 2.4 cm/s

Large prototypes

44 x 44 cm²

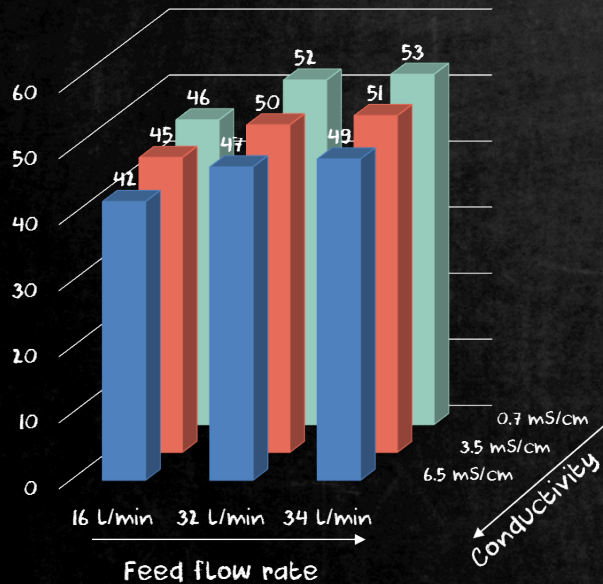
500 cell pairs

(194 m² membrane)

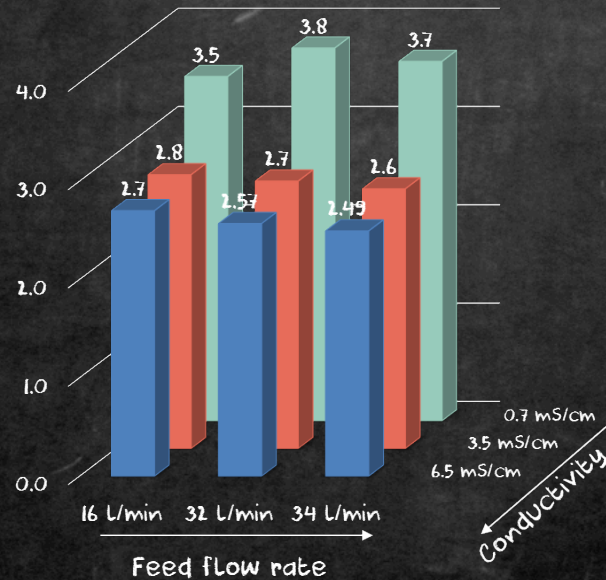


TEST WITH ARTIFICIAL SOLUTIONS – STACK 2

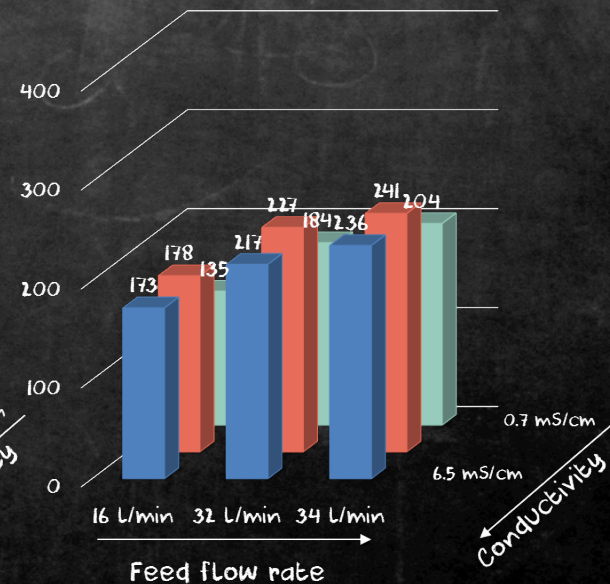
Open Circuit Voltage (V)



Stack resistance (Ω)



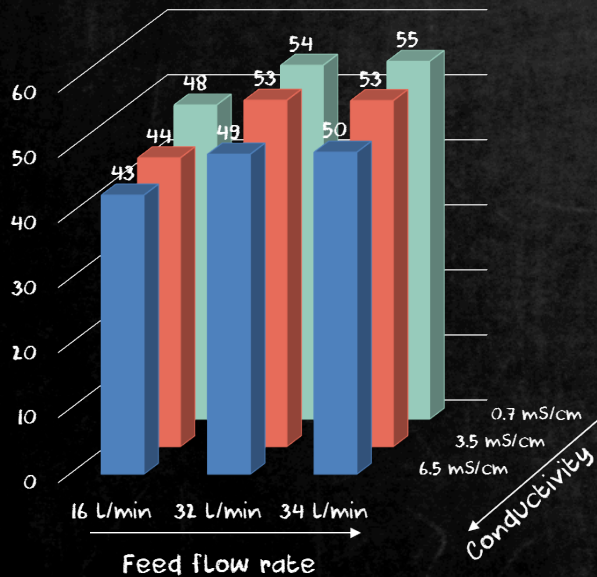
Power (W)



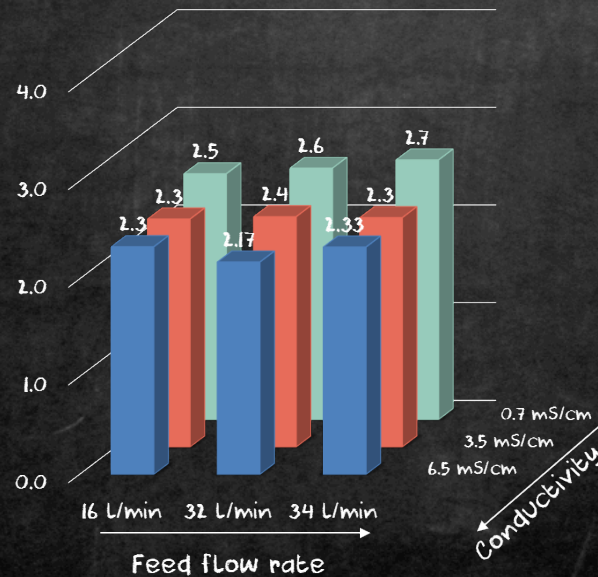
Feed solutions: artificial brine (NaCl solution at 215 mS/cm, 25 L/min) and artificial brackish water (NaCl solution at 0.7 – 6.5 mS/cm)

TEST WITH ARTIFICIAL SOLUTIONS – STACK 3

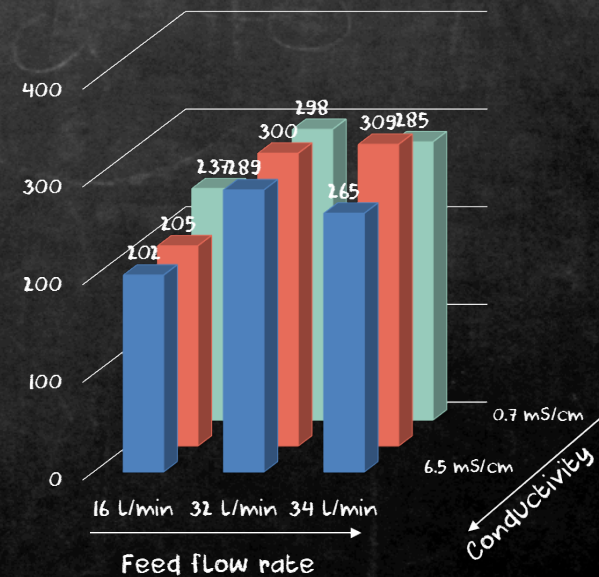
Open Circuit Voltage
(V)



Stack resistance
(Ω)

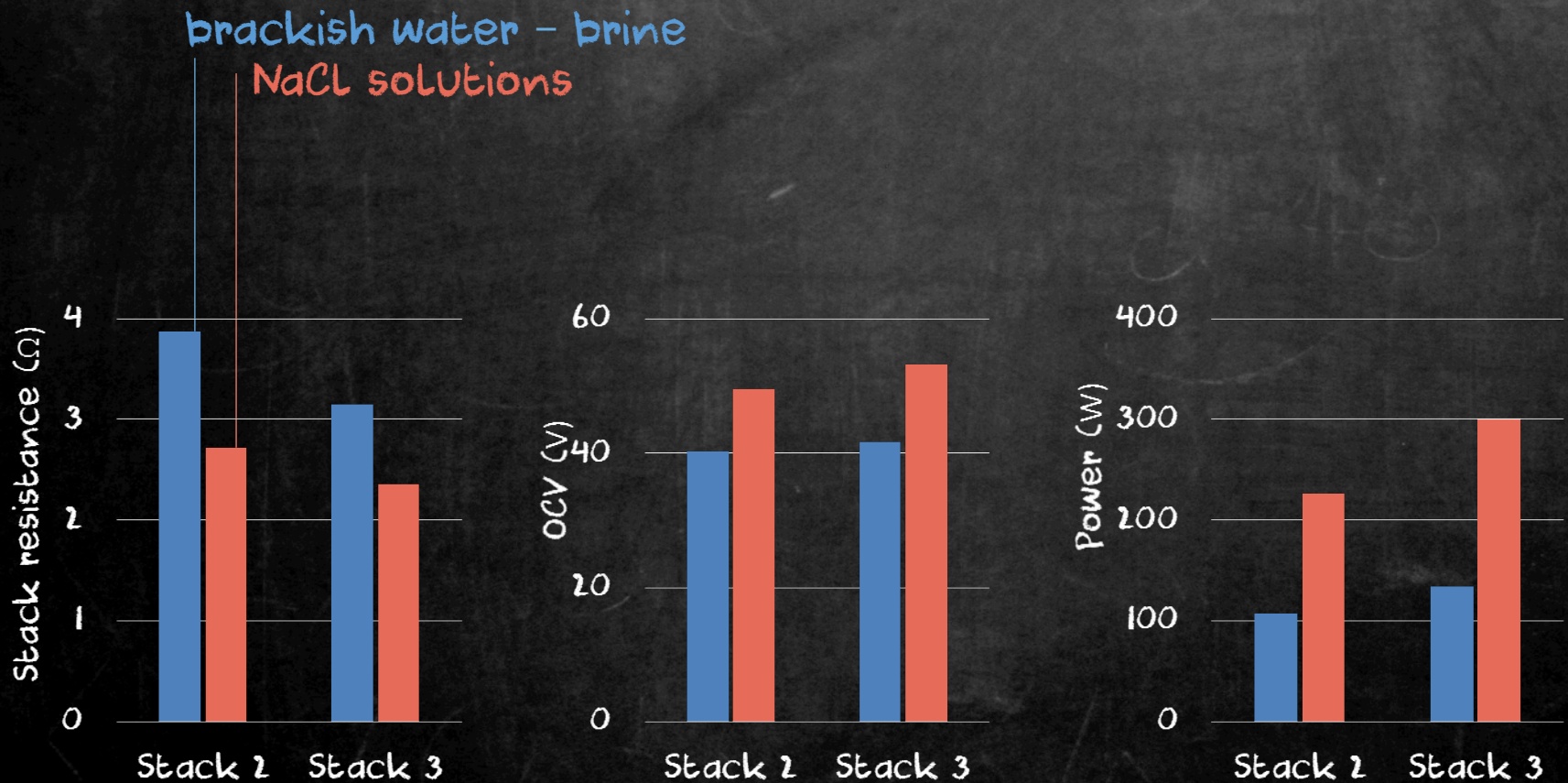


Power
(W)



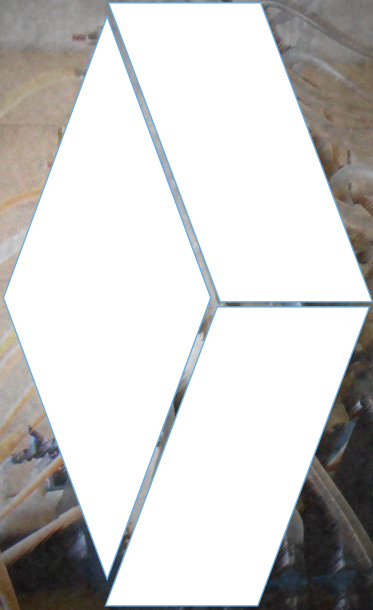
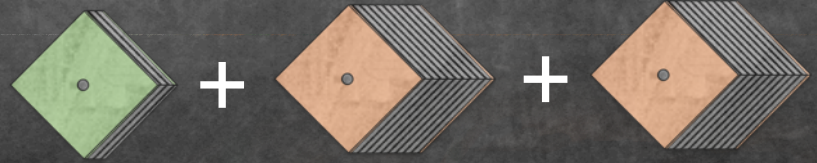
Feed solutions: artificial brine (NaCl solution at 215 mS/cm, 25 L/min) and artificial brackish water (NaCl solution at 0.7 – 6.5 mS/cm)

EFFECT OF NATURAL SOLUTIONS ON PROCESS PERFORMANCE

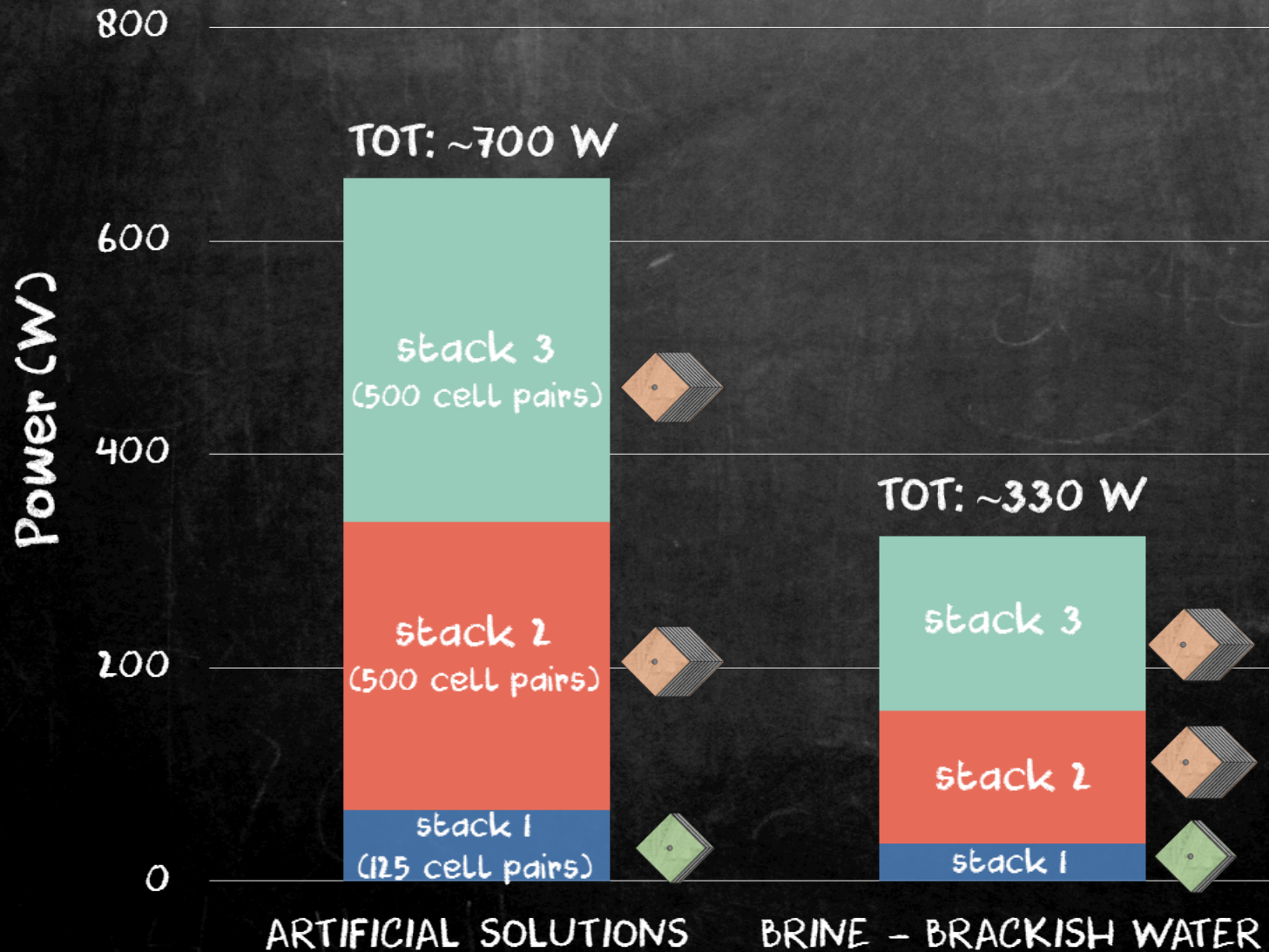


Brine conductivity: 182 mS/cm. Brackish water conductivity: 3.4 mS/cm.
Feed flow rates: 32 L/min (1 cm/s flow velocity); T: 25°C.

OVERALL PLANT CAPACITY



OVERALL PLANT CAPACITY



CONCLUSIONS

- ✓ **First** RED pilot plant fed with **brines** in **real environment**
- ✓ **No performance loss** after 5-month testing
- ✓ **Largest** power output generated by salinity-gradient systems so far operated with concentrated brines
- ✓ Demonstrated the achievement of a **Technology Readiness Level of 7** for **RED**

ACKNOWLEDGEMENTS

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Francesco Giacalone, Antonio Carubia



www.reapower.eu



THANK YOU

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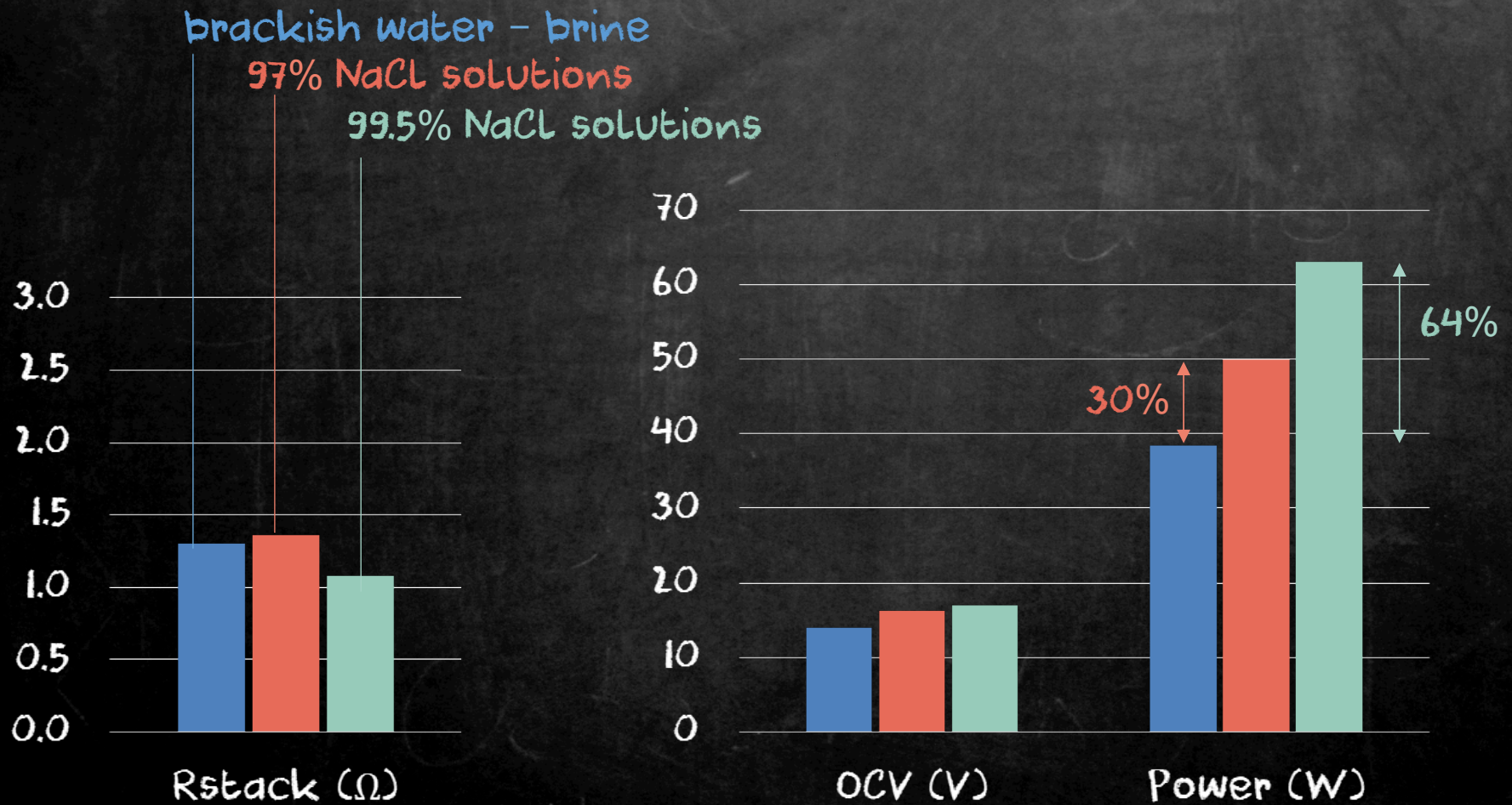
FEED STREAMS COMPOSITION

Solution	Conductivity (mS/cm)	Typical ion composition (g/l) ^b						Suspended solids (mg/l)
		Na ⁺	K ⁺	Ca ²⁺	Mg ²⁺	Cl ⁻	SO ₄ ²⁻	
Brine	160-220 ^a	64 (48-94)	10.5 (7-14)	0.4 (0-1.3)	44.8 (24-58)	192 (175-219)	39.2 (0-75)	20
Brackish water	3.4	1.52	0.049	0.101	0.323	3.56	0.335	-

^a The brine conductivity changes appreciably during seasons, ranging from 160 mS/cm in winter up to 220 mS/cm in summer.

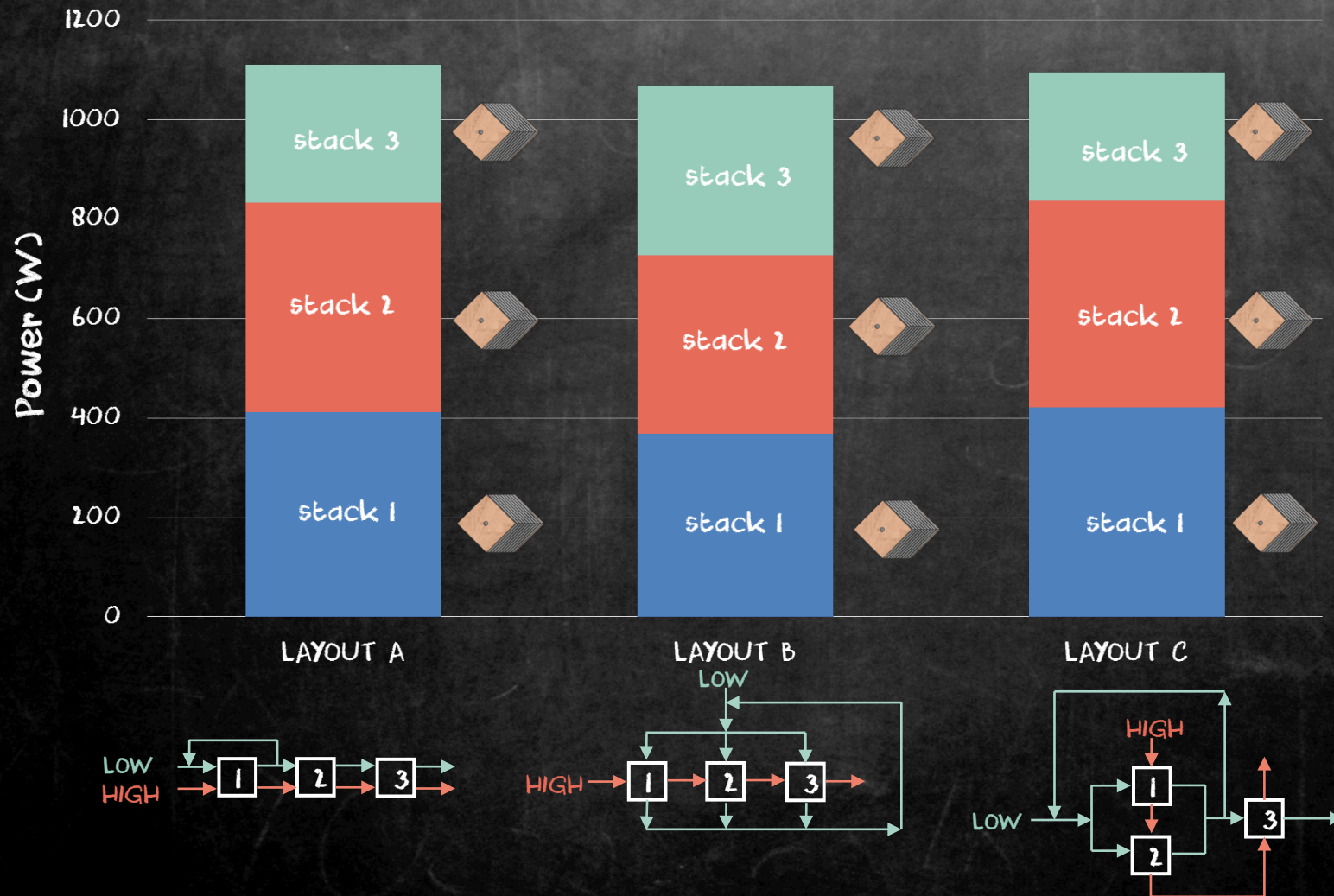
^b The range of ion composition for brine is reported between brackets.

EFFECT OF NATURAL SOLUTIONS ON PROCESS PERFORMANCE



Brine conductivity: 196 mS/cm. Brackish water conductivity: 3.4 mS/cm.
Feed flow rates: 8 L/min (1 cm/s flow velocity); T: 25°C.

SIMULATIONS OF DIFFERENT PLANT LAYOUTS

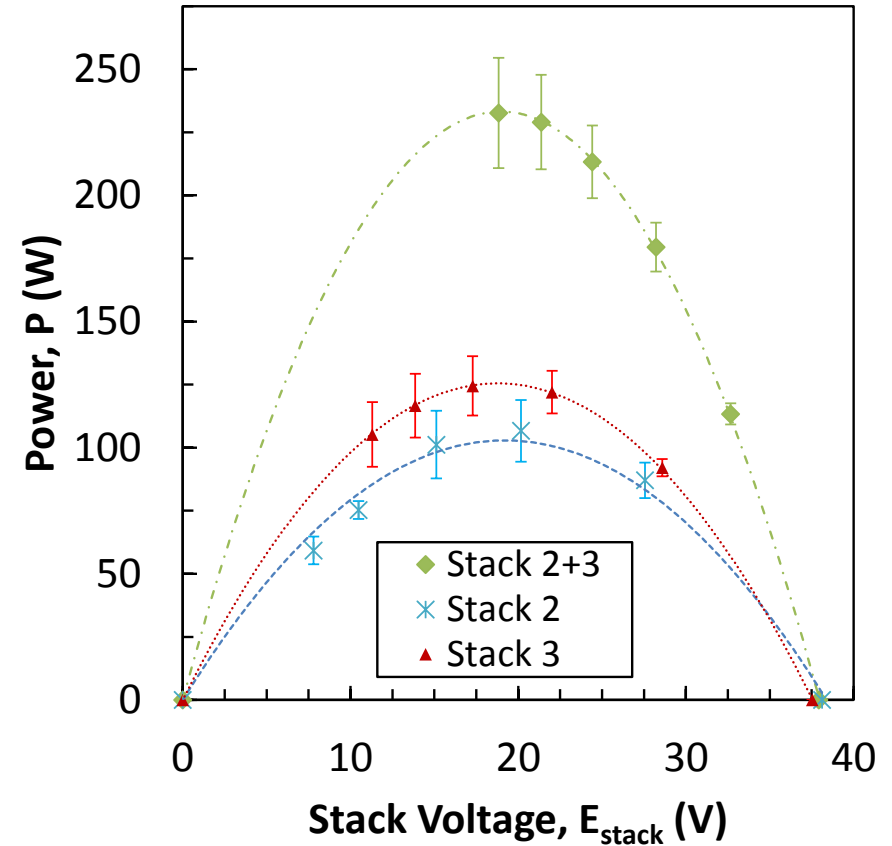
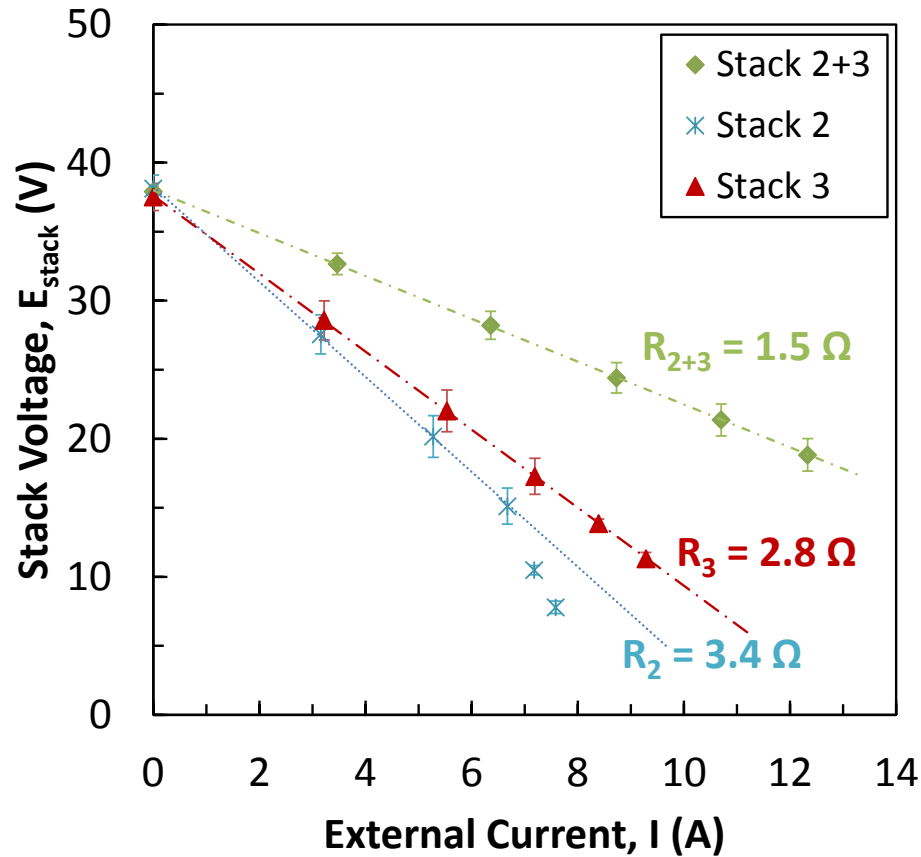


M. Tedesco et al., Analysis and simulation of scale-up potentials in reverse electrodialysis, Desalin. Water. Treat. (2014)

Simulations of stacks with Fujifilm membranes, 270 μm spacers; C_{LOW} : 0.1 M; C_{HIGH} : 5 M; T: 30° C.

POWER MEASUREMENTS WITH NATURAL SOLUTIONS

COMPARISON BETWEEN LARGE PROTOTYPES (STACK 2 - STACK 3)



Brine conditions: conductivity 194 mS/cm, T : 28°C, flow rate 26 L/min.

Brackish water conditions: conductivity 3.4 mS/cm, T : 25°C, flow rate 38 L/min