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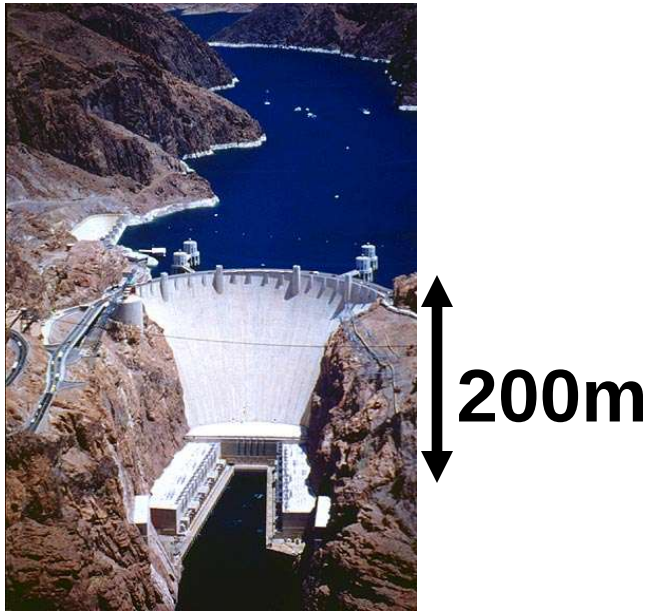
european centre of **excellence**
for sustainable **water technology**

Mixing Energy as hidden Energy Resource

Bert Hamelers

Hidden as we cannot feel it



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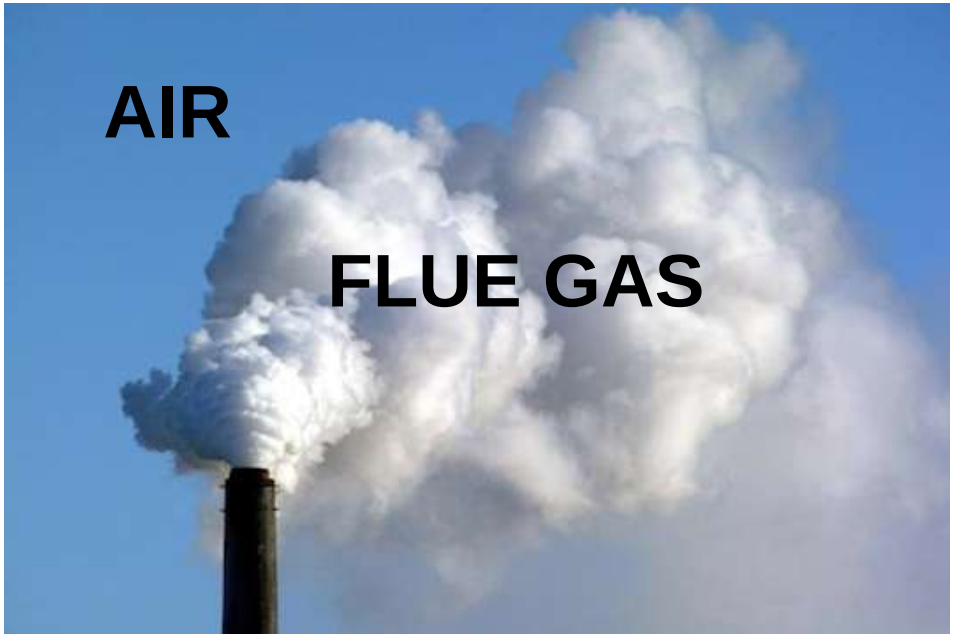
Important marine source

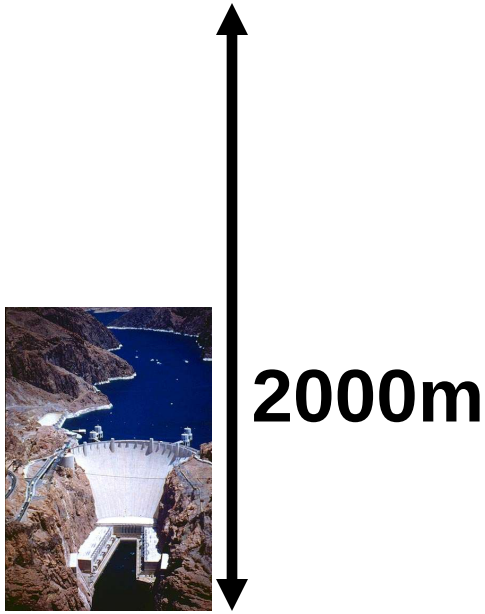
TABLE 1.
MARINE RENEWABLE RESOURCES

Resource	Power (TW)	Energy Density (m)
Ocean Currents	0.05	0.05
Ocean Waves	2.7	1.5
Tides	0.03	10
Thermal Gradient	2.0	210
Salinity Gradient	2.6	240

(Source) G.L. Wick and W.R. Schmitt, “Prospects for Renewable Energy from the Sea,” *Marine Technology Society Journal*, 1977, vol. 11, pp. 16-21

CO_2 Gradient Energy





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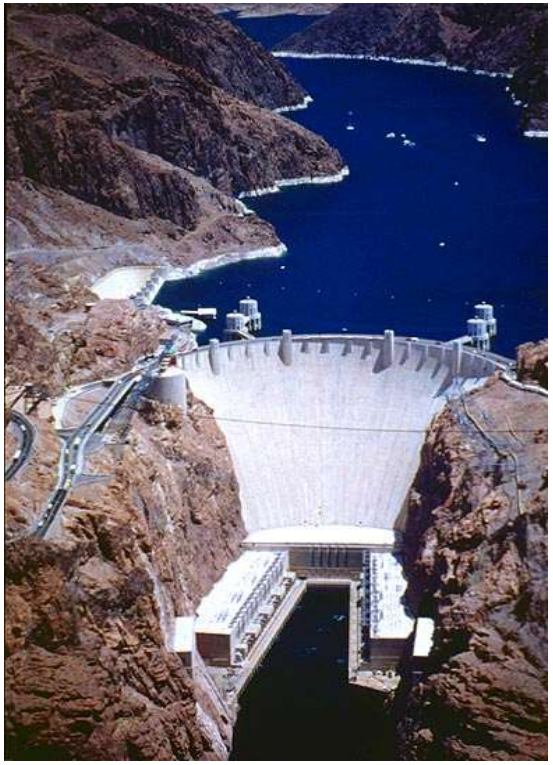
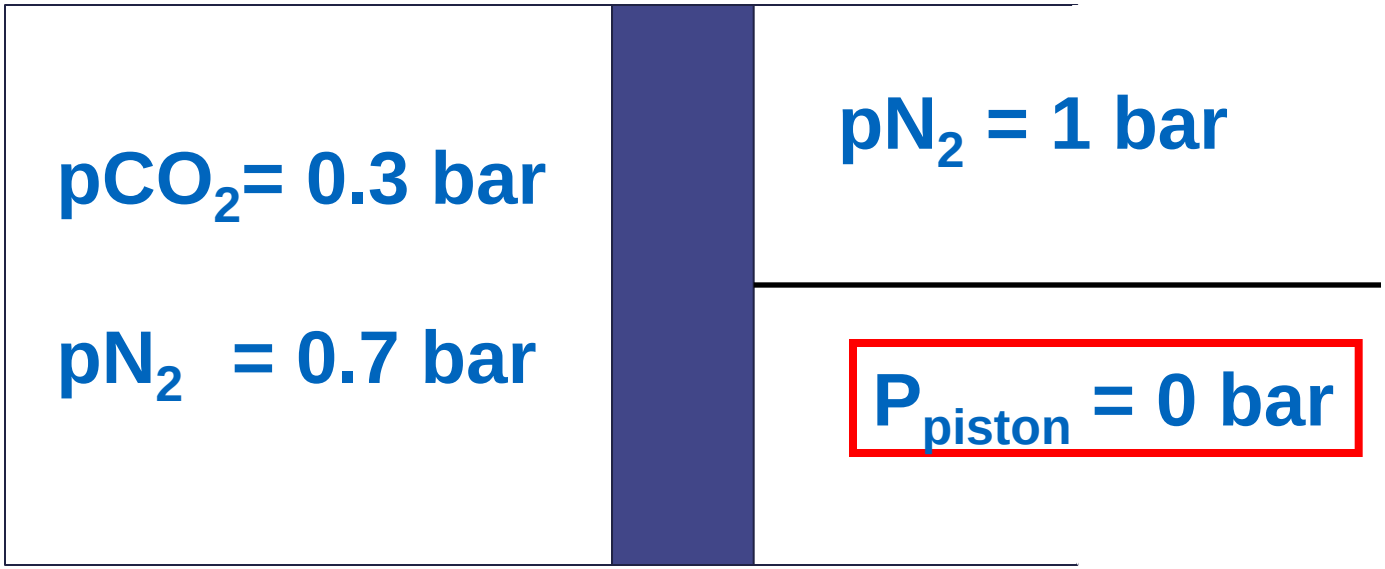
Potential of Stationary Sources

Power Plant CO_2 = 12Gt/yr = 850 TWh/yr
Heating & Industry CO_2 = 11 Gt/yr = 720 TWh/yr

Globally: 1570 TWh/yr ≈ 400



ORIGIN ENERGY



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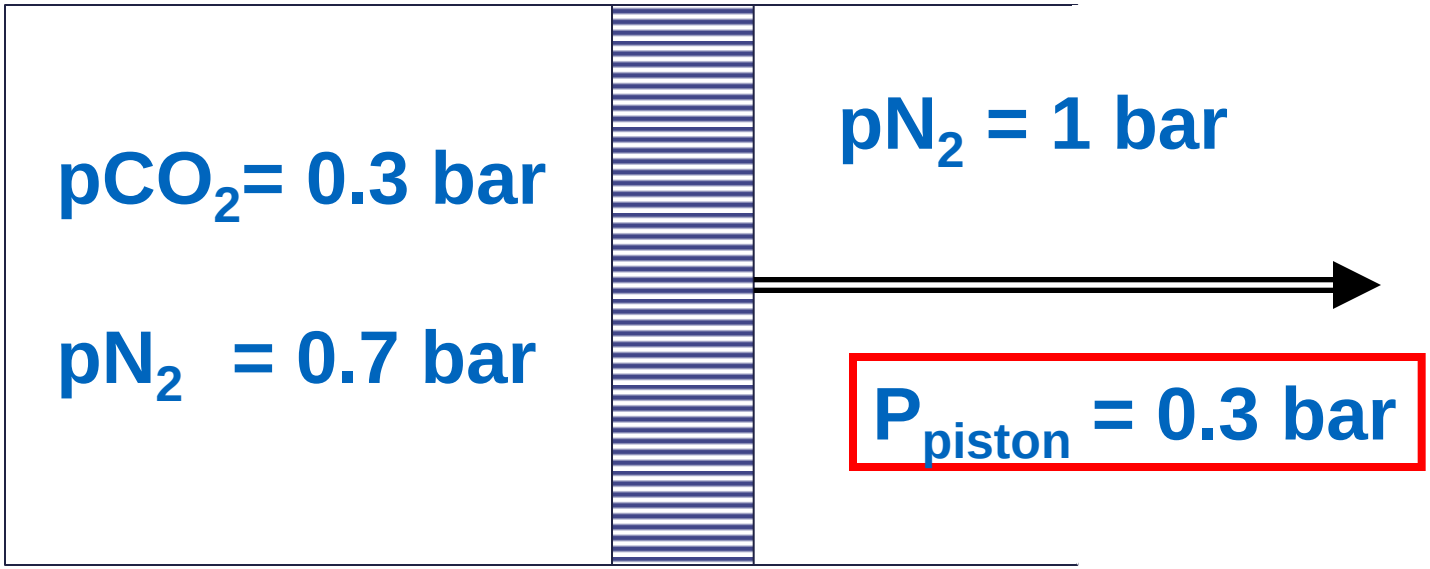
SELECTIVE MIXING KEY



Ideal N_2 permeable membrane

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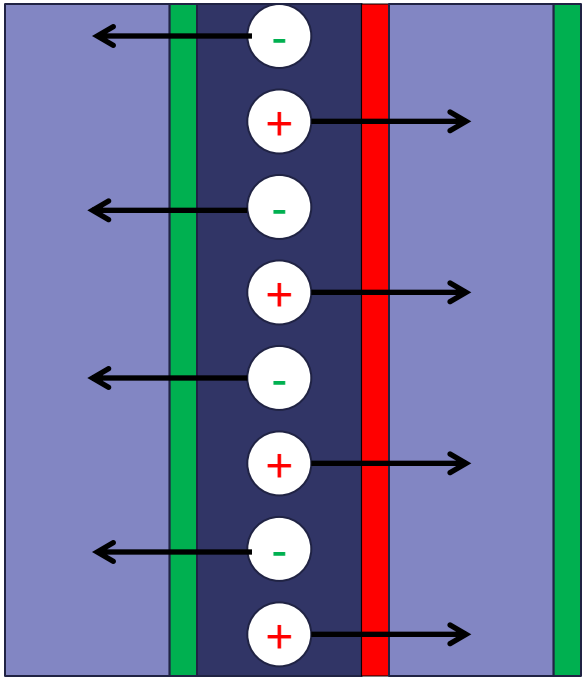
Diffusion Driven Ionic Current & Potential

E_1 E_2



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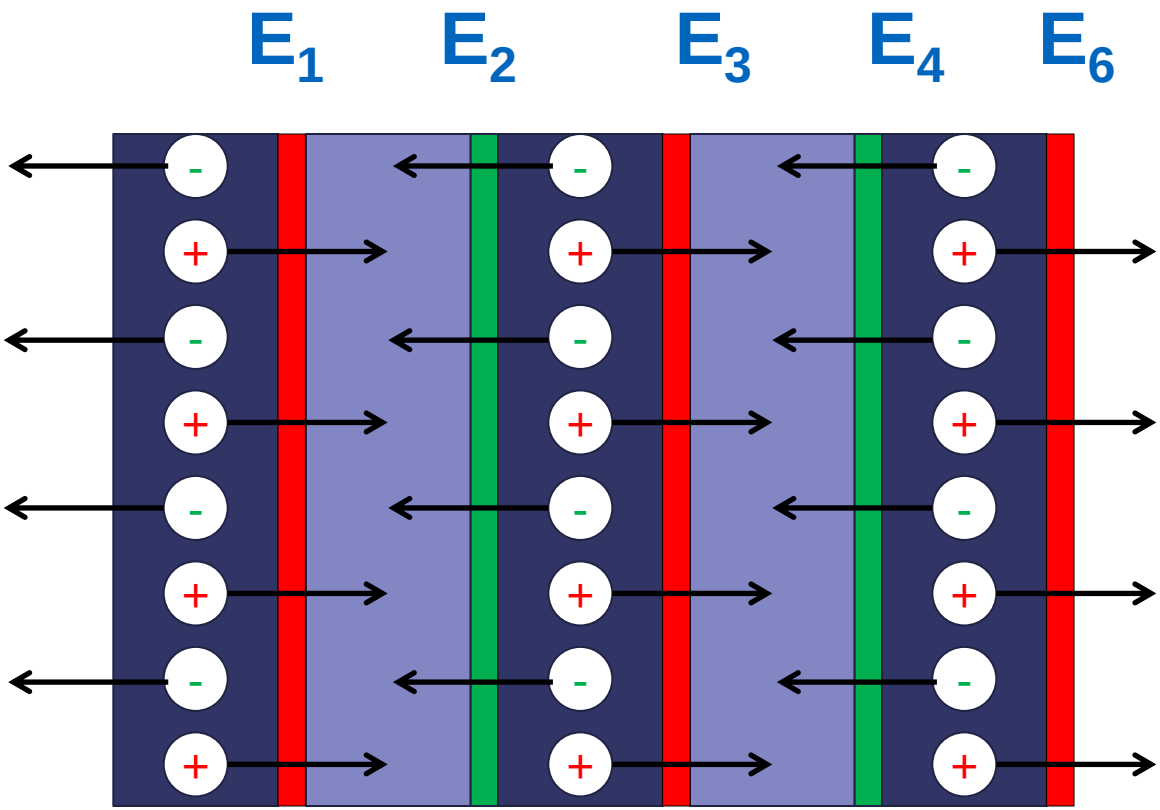
Stacking Increases Potential



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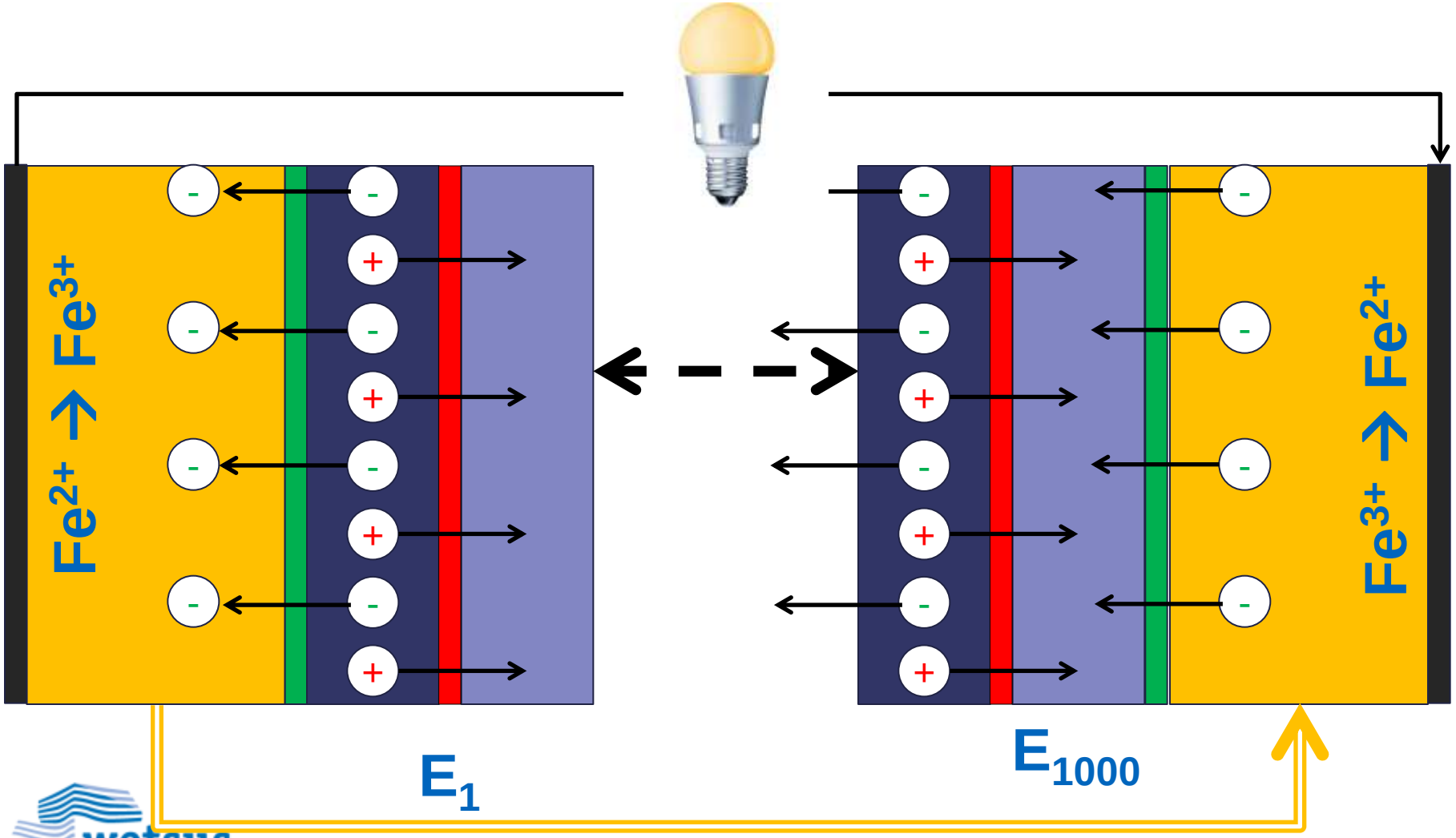
Ionic to Electronic Flow



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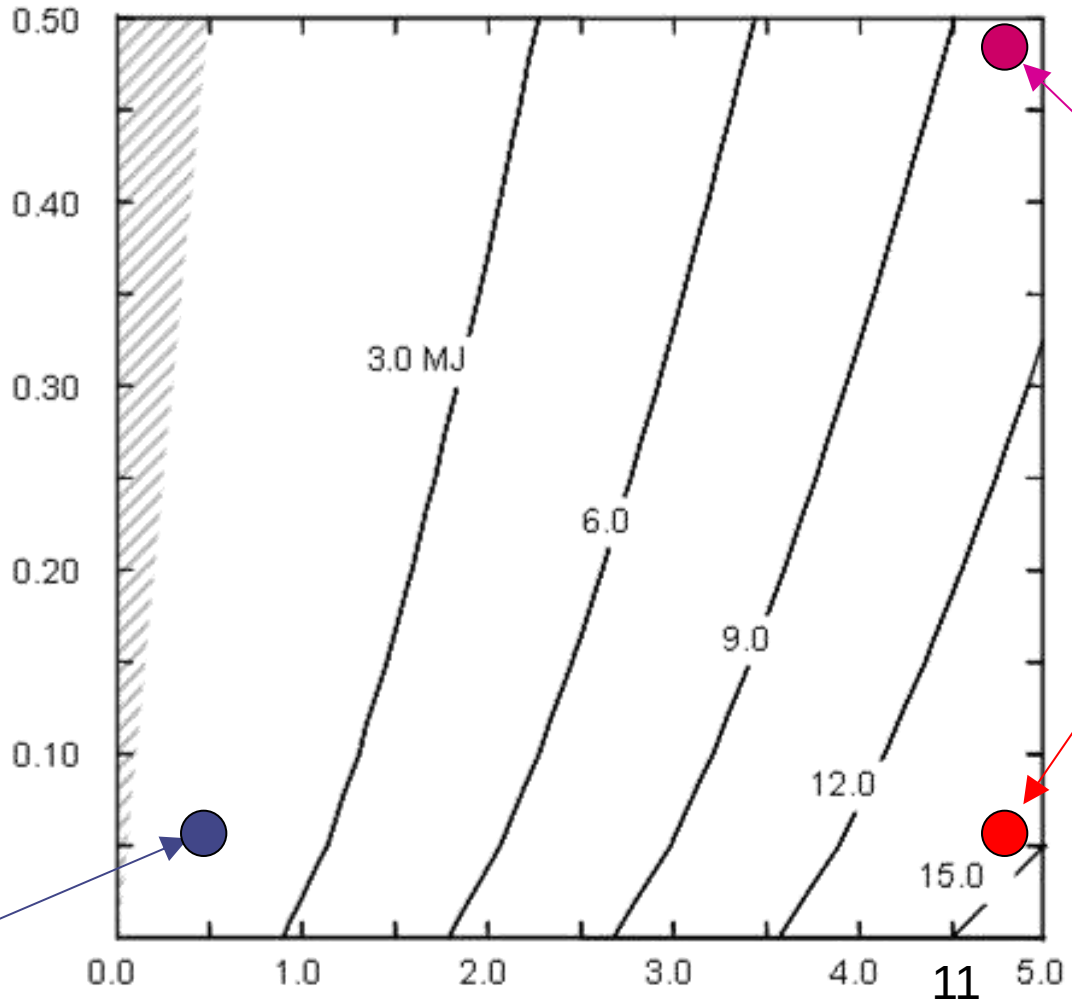
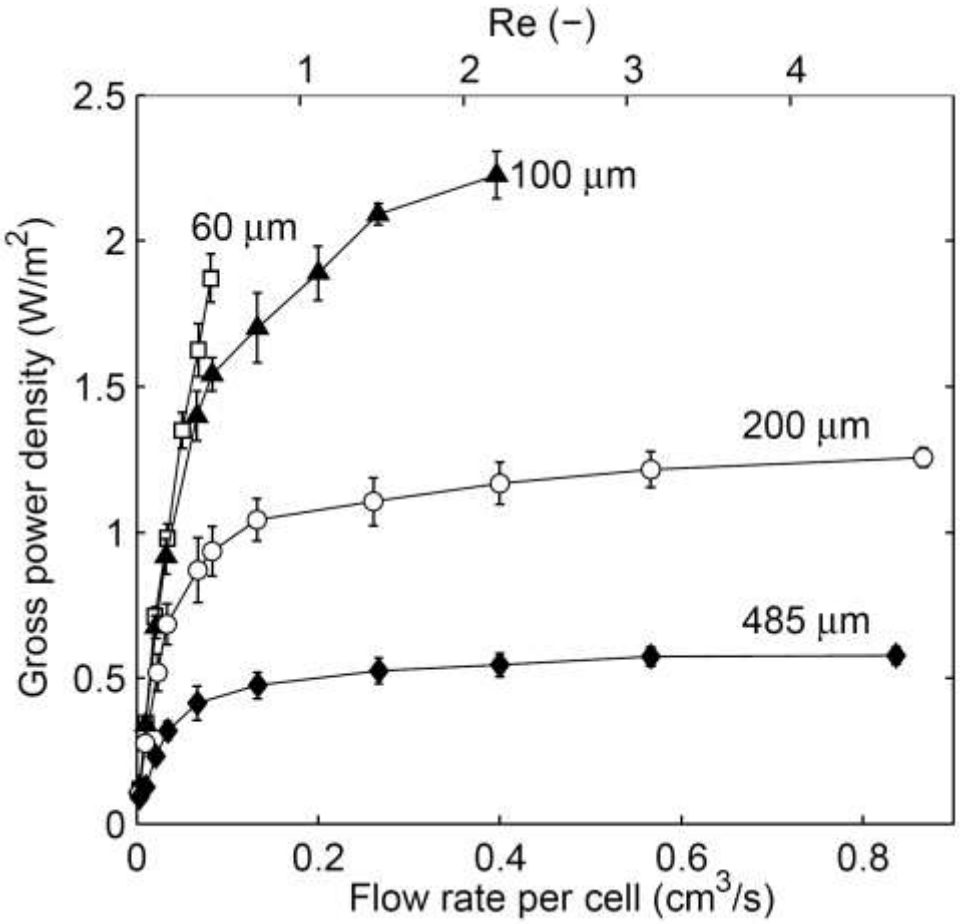
Potential amount of energy

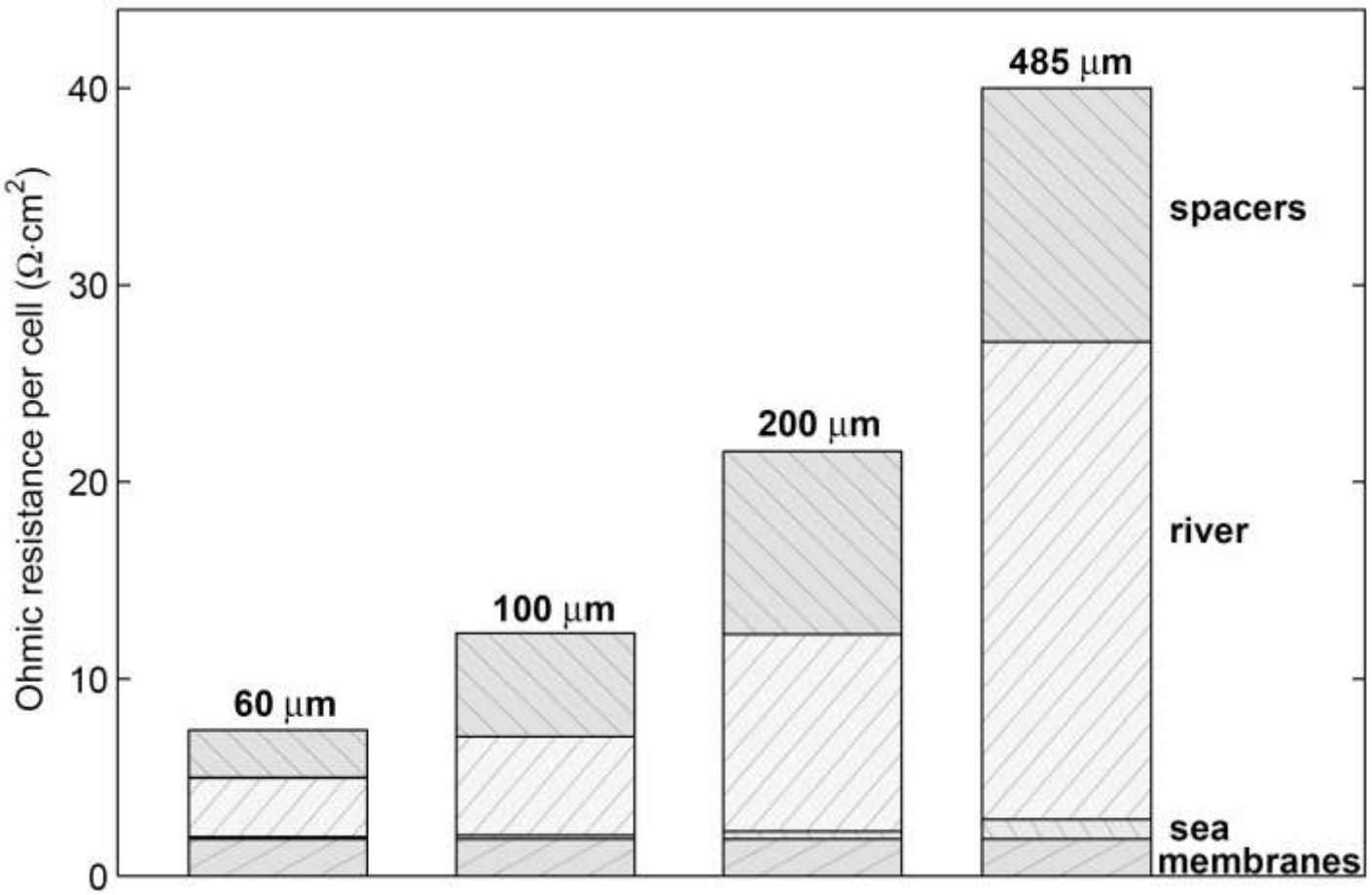


Do not lose the Power



Vermaas *et al*, 2011, Environ. Sci. Technol., DOI 10.1021/es2012758

Internal Resistance is Key



Vermaas *et al*, 2011, Environ. Sci. Technol., DOI 10.1021/es2012758

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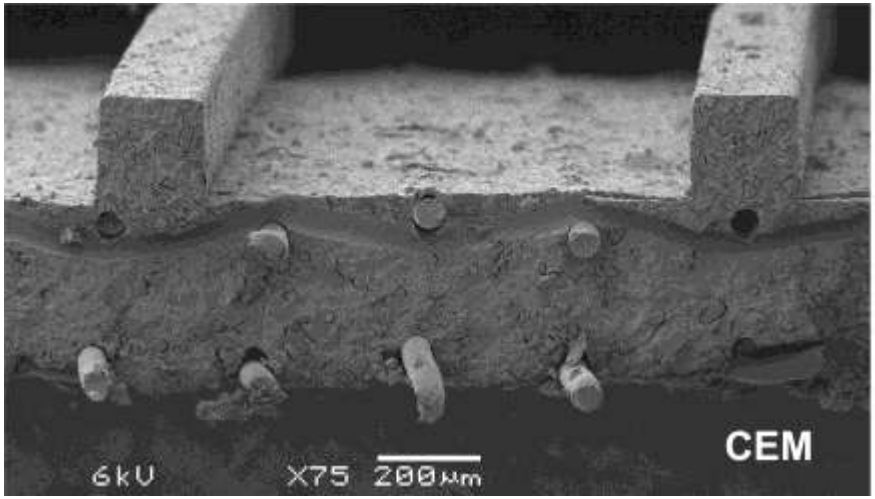
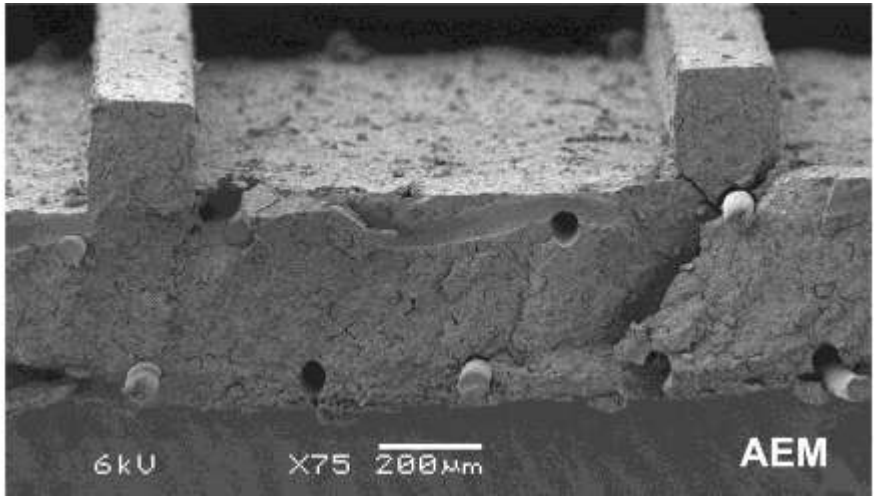
Profiled membranes



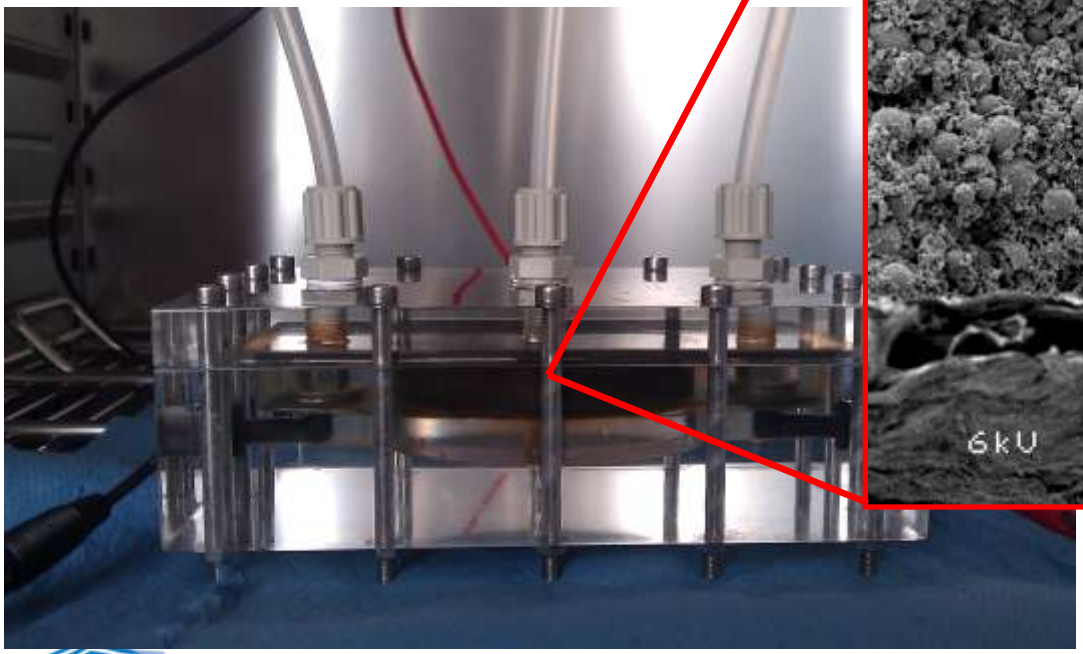


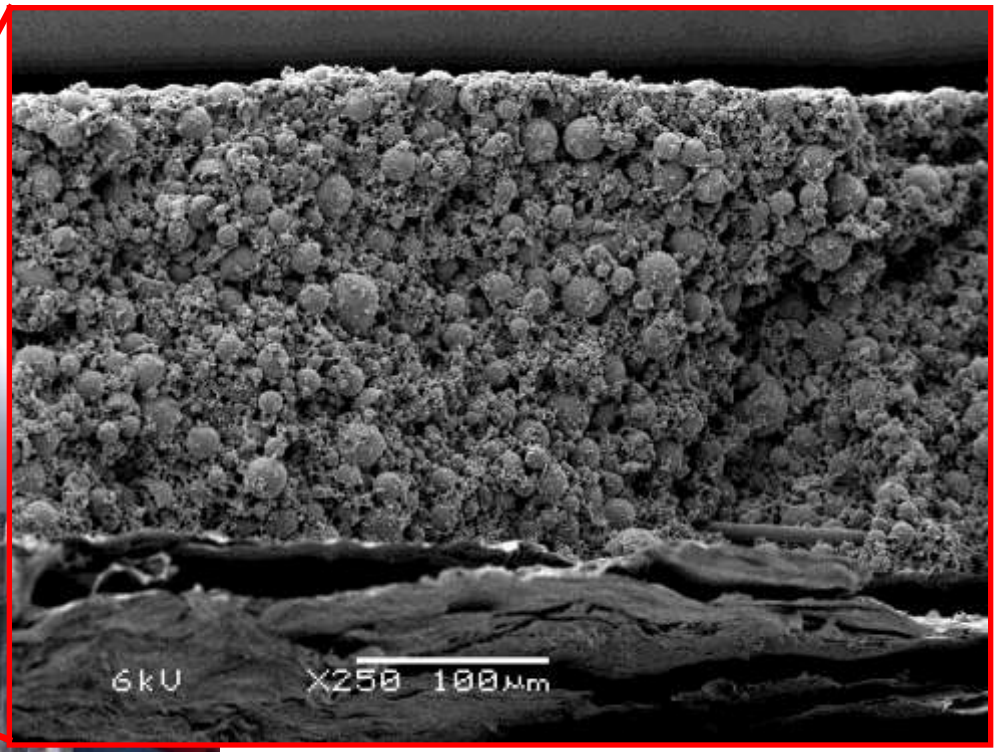
Vermaas *et al*, 2011, J. Membr.Sci., DOI 10.1016/j.memsci.2011.09.043

Mixing Energy Harvesting Technologies

Salinity gradient technologies	Selectivity	Electricity generation
Pressure Retarded Osmosis (PRO)	Water	Turbine
Reverse Electro-Dialyses	Ions	Electrochemical reactions
Capacitive technology	Ions	Capacitor

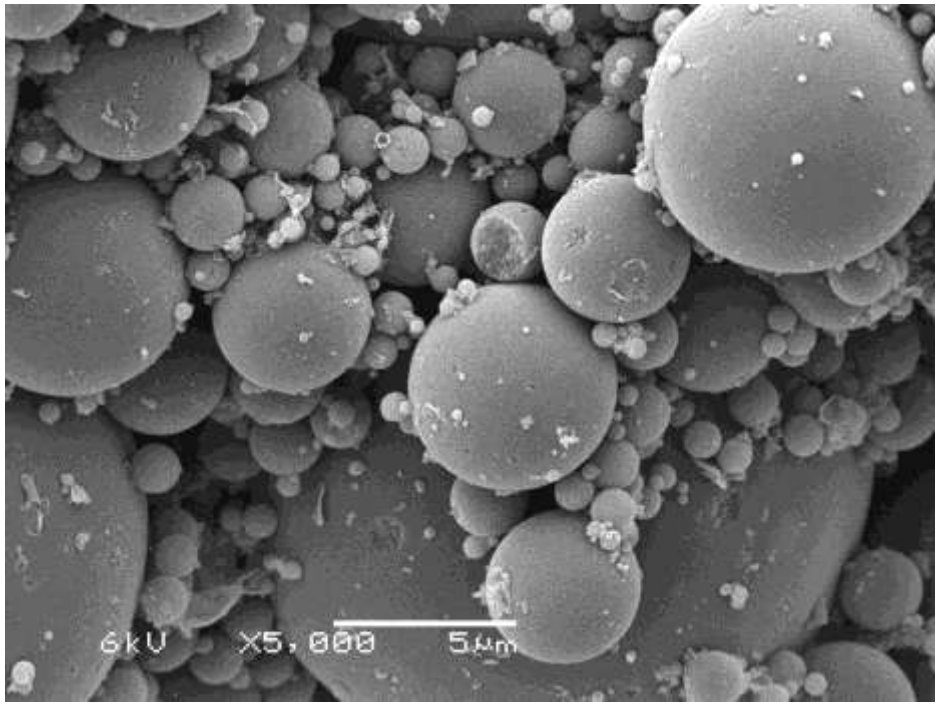
Capacitive Blue Energy Electrodes



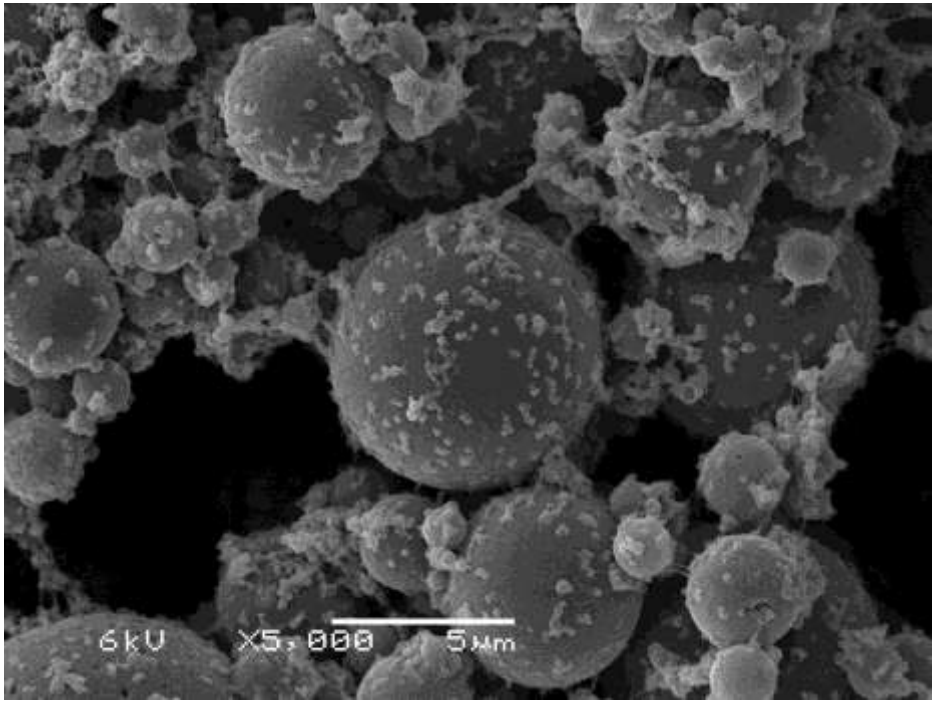


Salt adsorbing electrodes

Activated Carbon + polyvinylidene fluoride (PVDF) binder

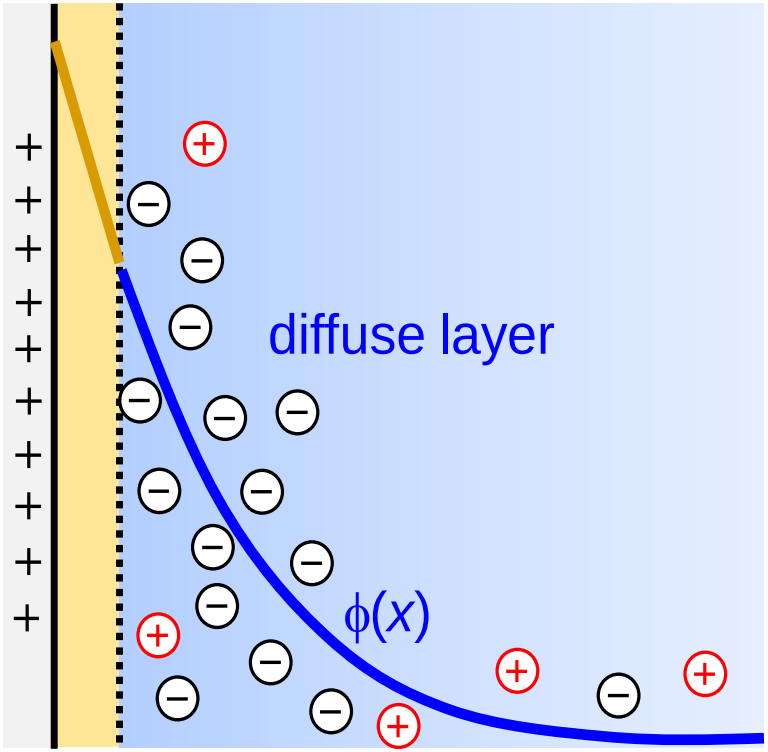


Raw carbon material (x 5000)



Carbon + binder (x 5000)

classical GCS EDL-theory



electronic charge + ionic charge=0

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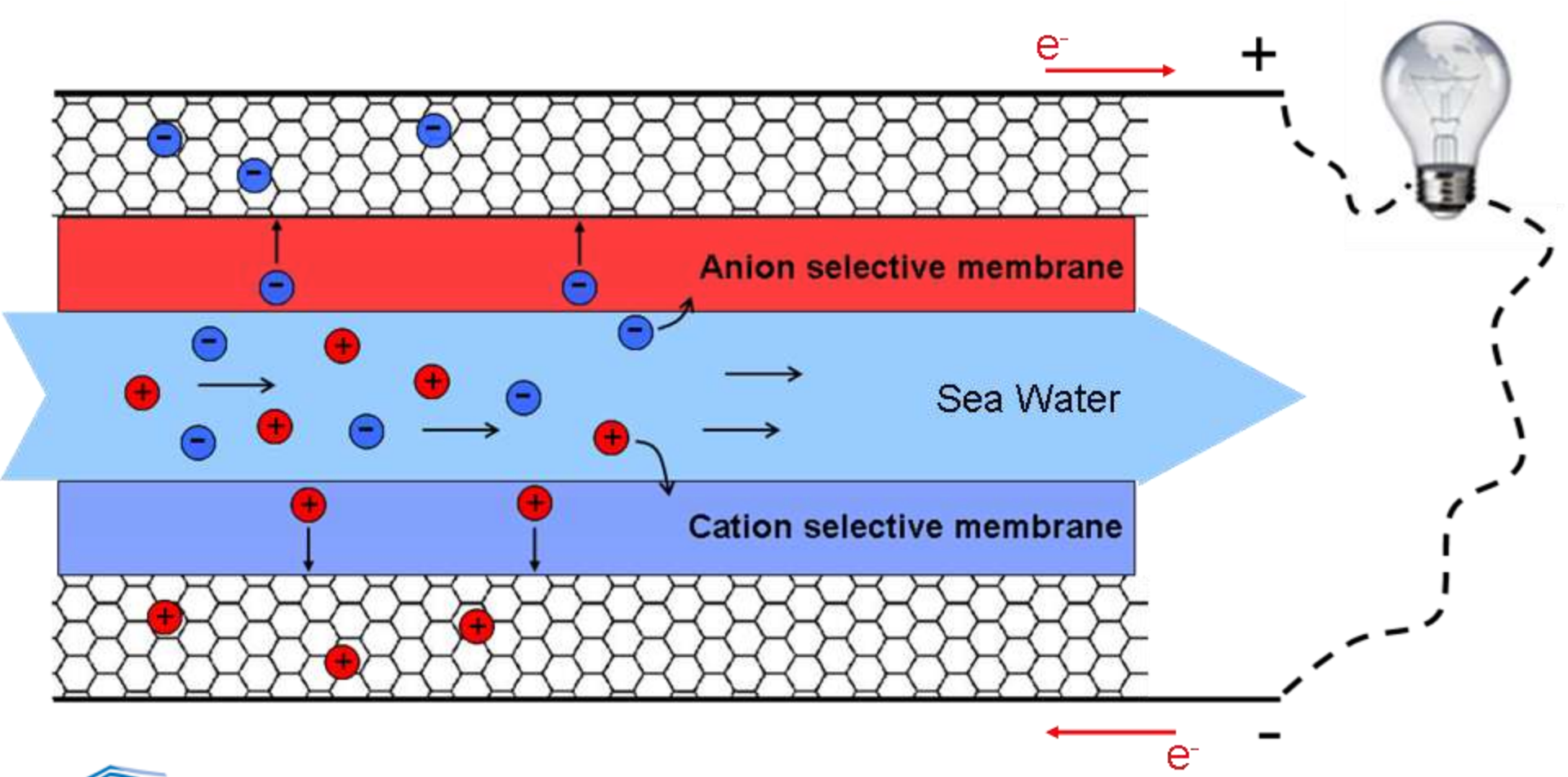
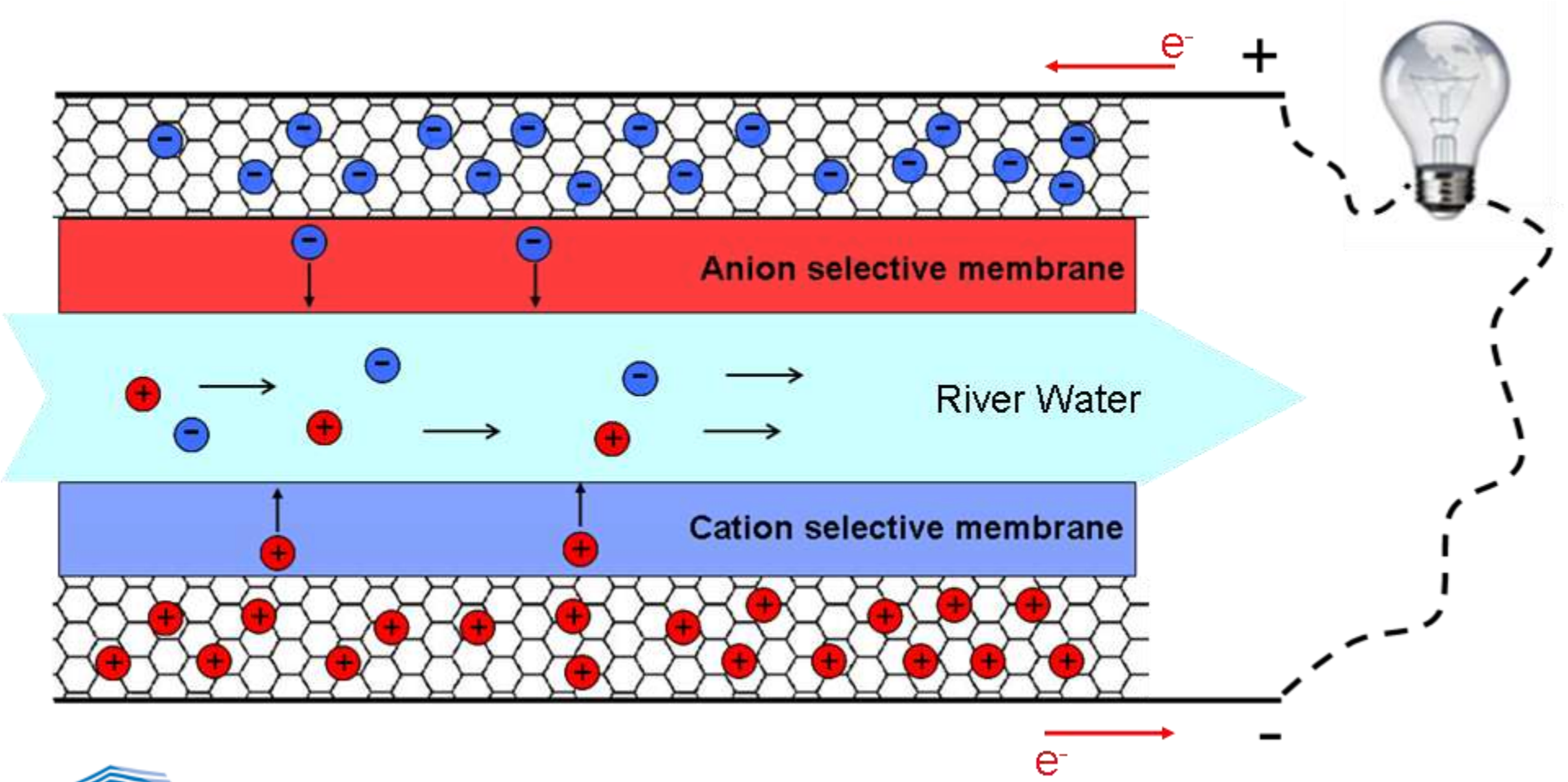
Donnan driven process: Charging



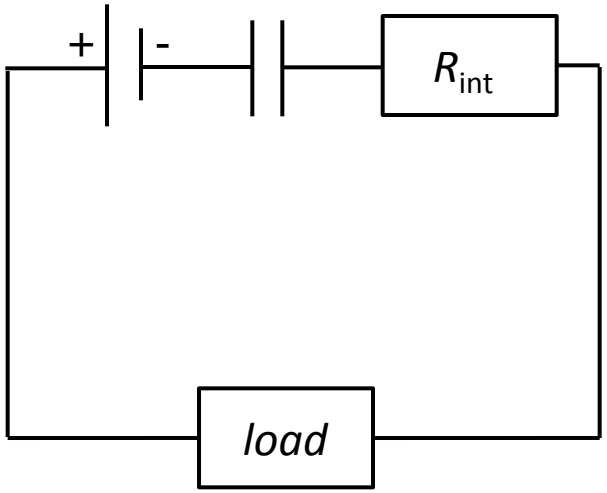
(Sales et al., 2010)

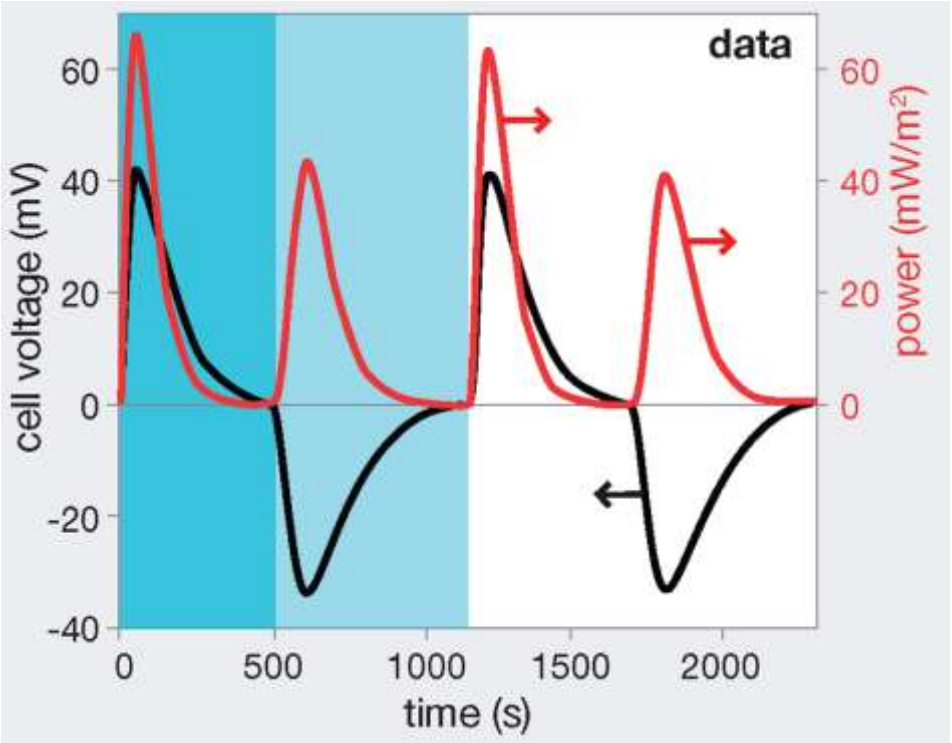
Donnan driven process: Discharging



(Sales et al., 2010)

CDP with constant load





Sales et al., 2010, ES&T

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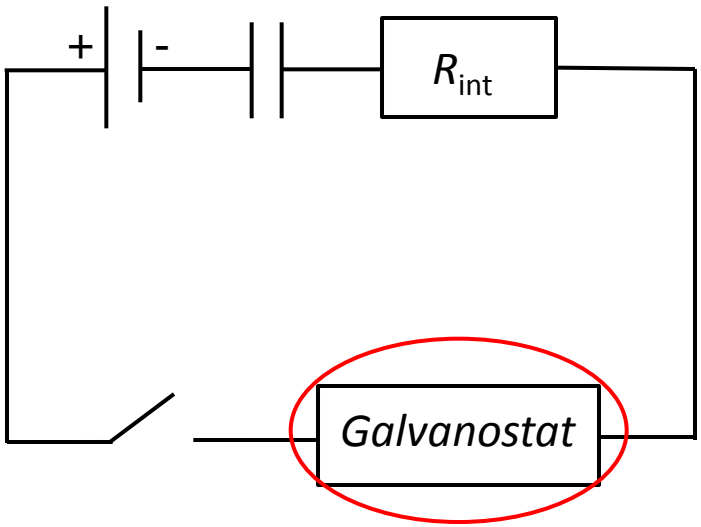
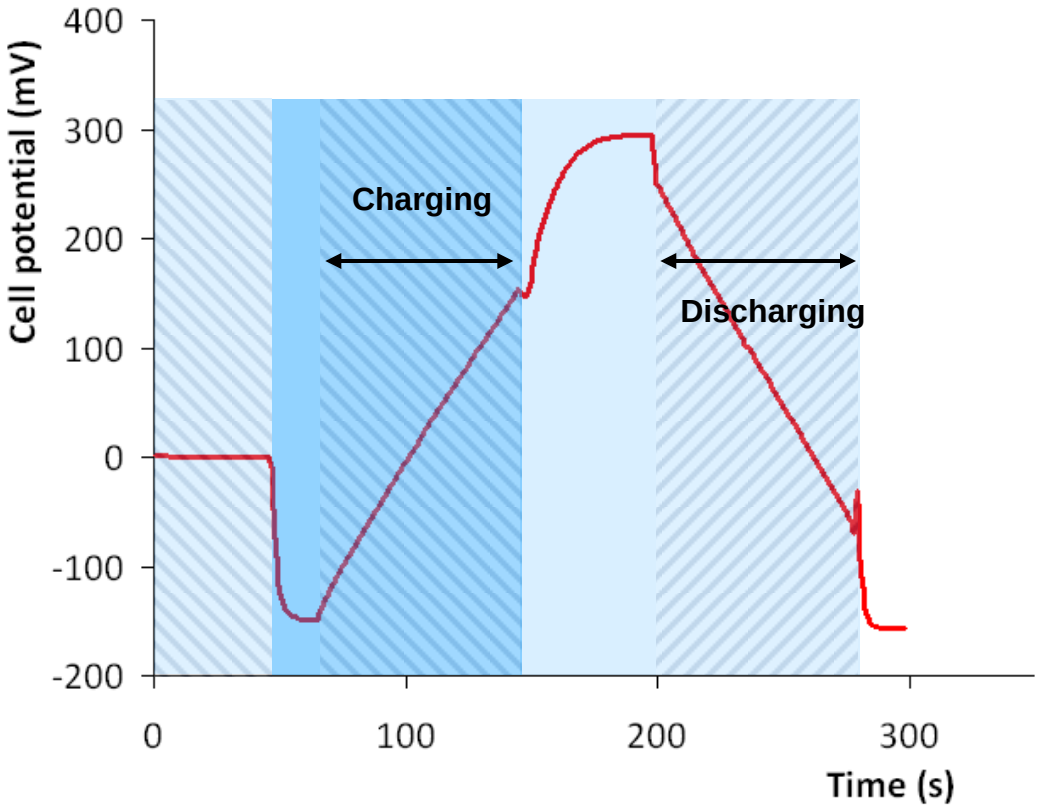
Constant Current = Constant Loss





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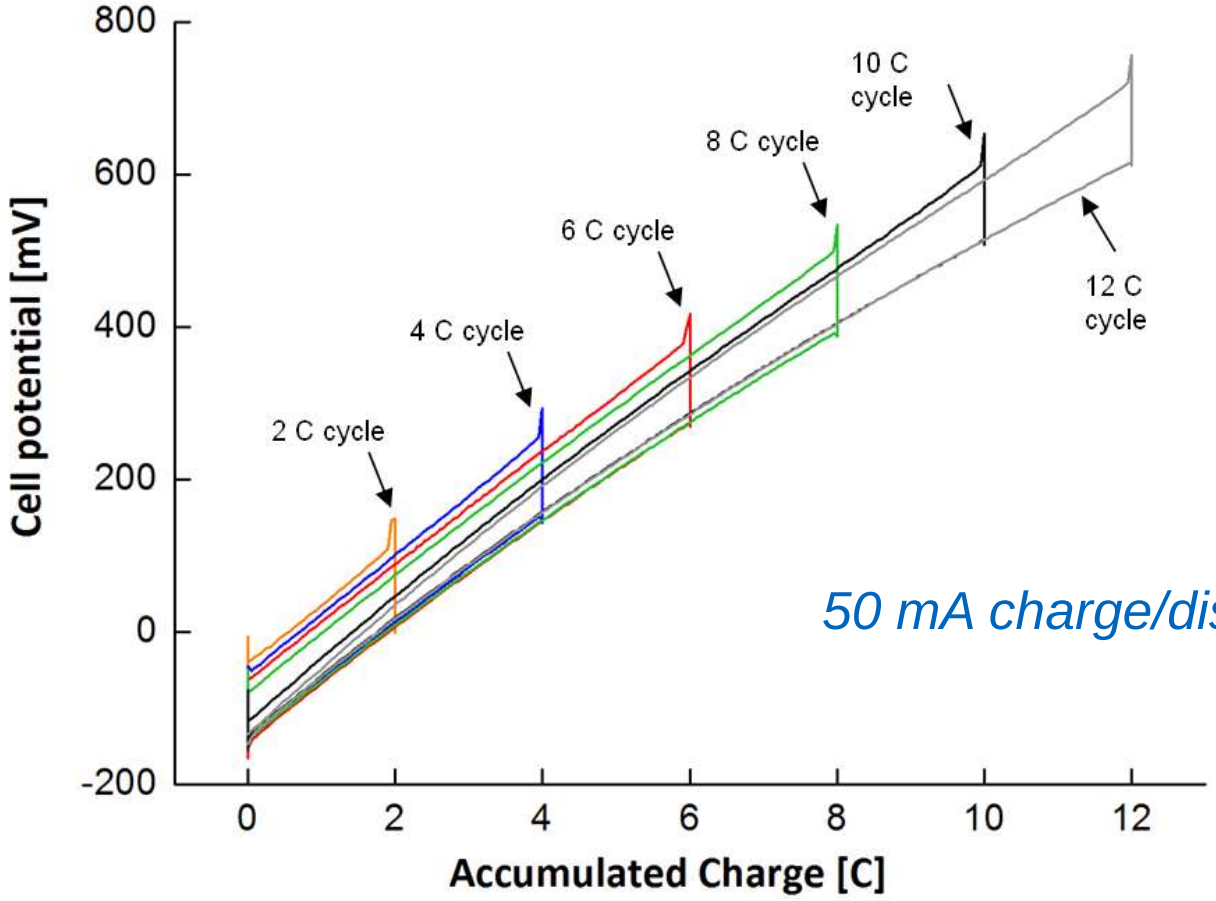
Energy cycle expanded



50 mA charge/discharge

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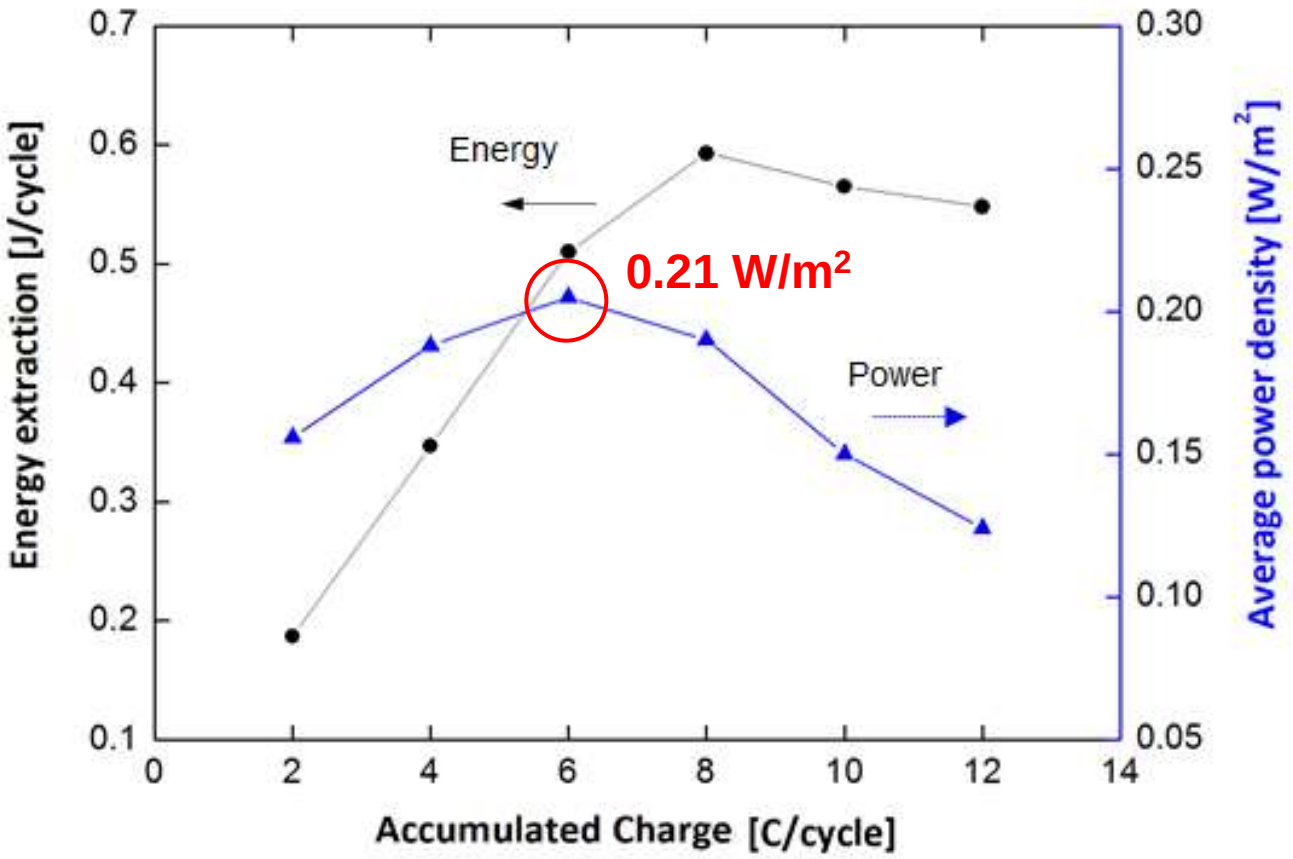
Energy extraction and power density



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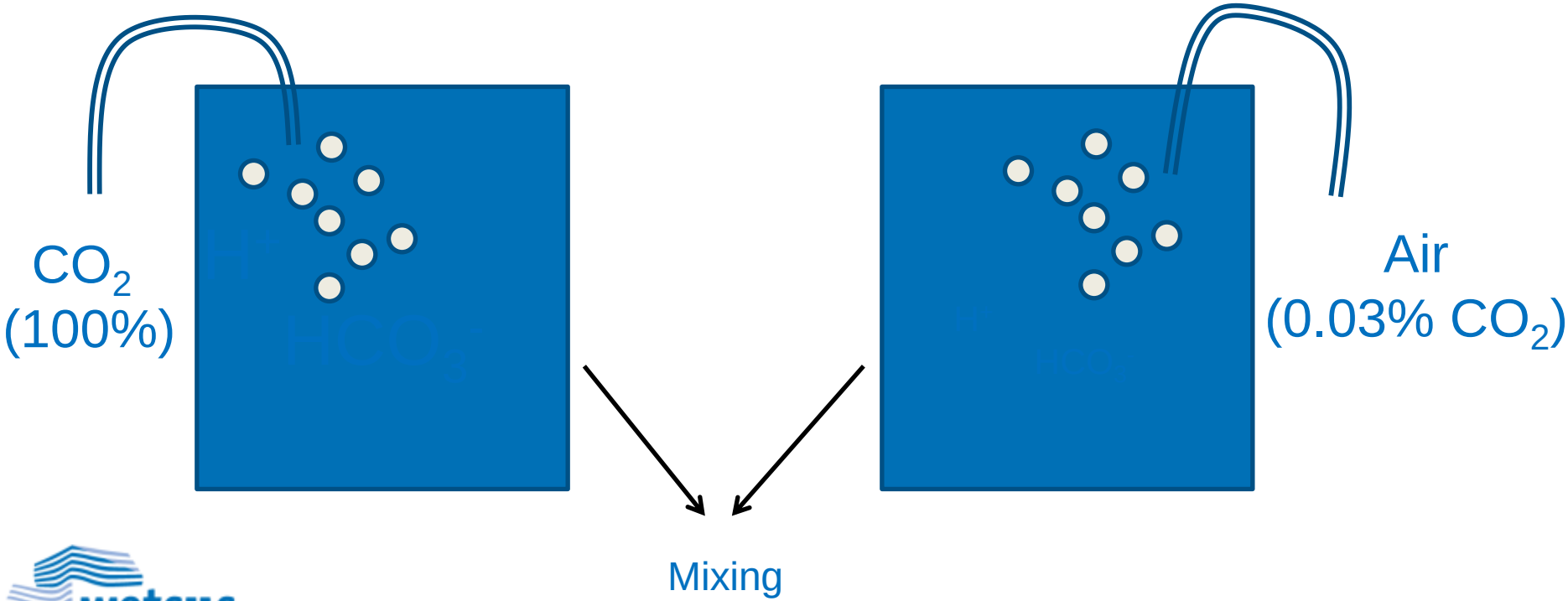
CO_2 ENERGY

$$CO_2 + H_2O \longleftrightarrow H_2CO_3 \longleftrightarrow H^+ + HCO_3^-$$

$$(Na^+ + Cl^-)$$



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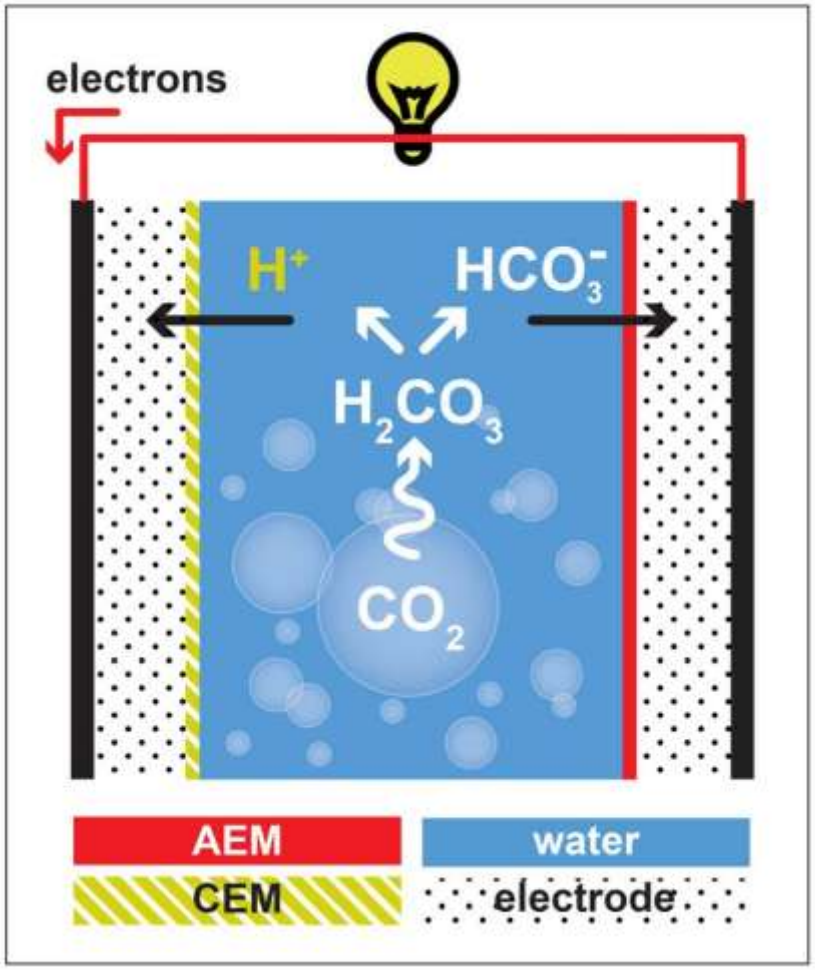
WATER is KEY



$$p_{CO_2} = K_H \left[H_2CO_3^* \right]$$

$$\left[H_2CO_3 \right] \rightleftarrows \left[H^+ \right] + \left[HCO_3^- \right]$$

$$\left[HCO_3^- \right] \rightleftarrows \left[H^+ \right] + \left[CO_3^{2-} \right]$$

$$\left[H_2O \right] \rightleftarrows \left[H^+ \right] + \left[OH^- \right]$$

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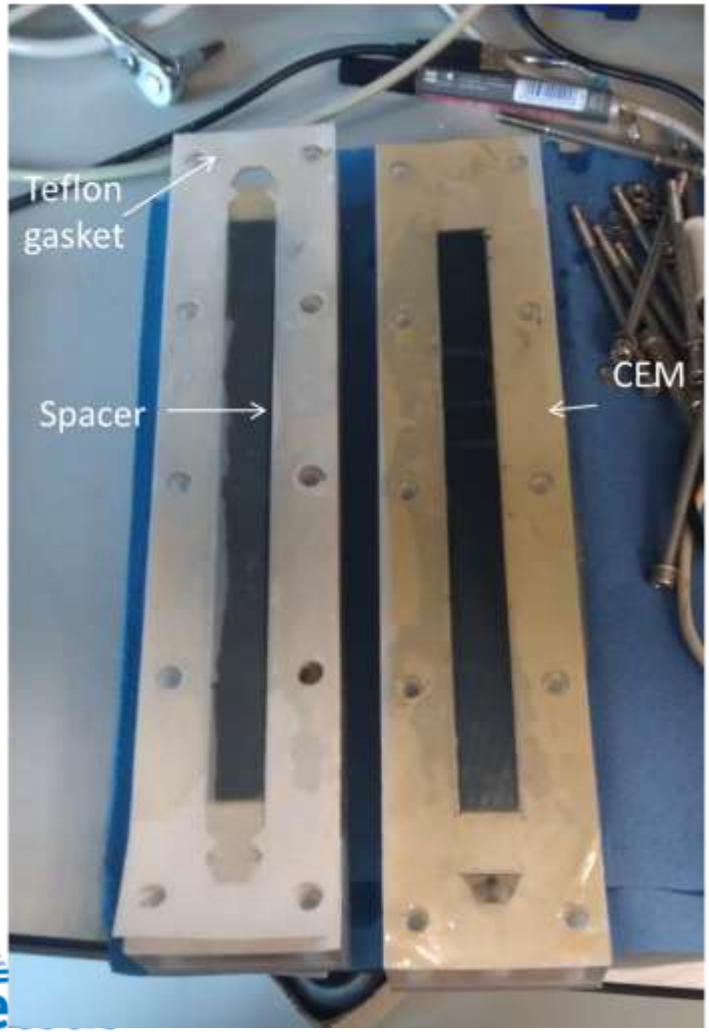
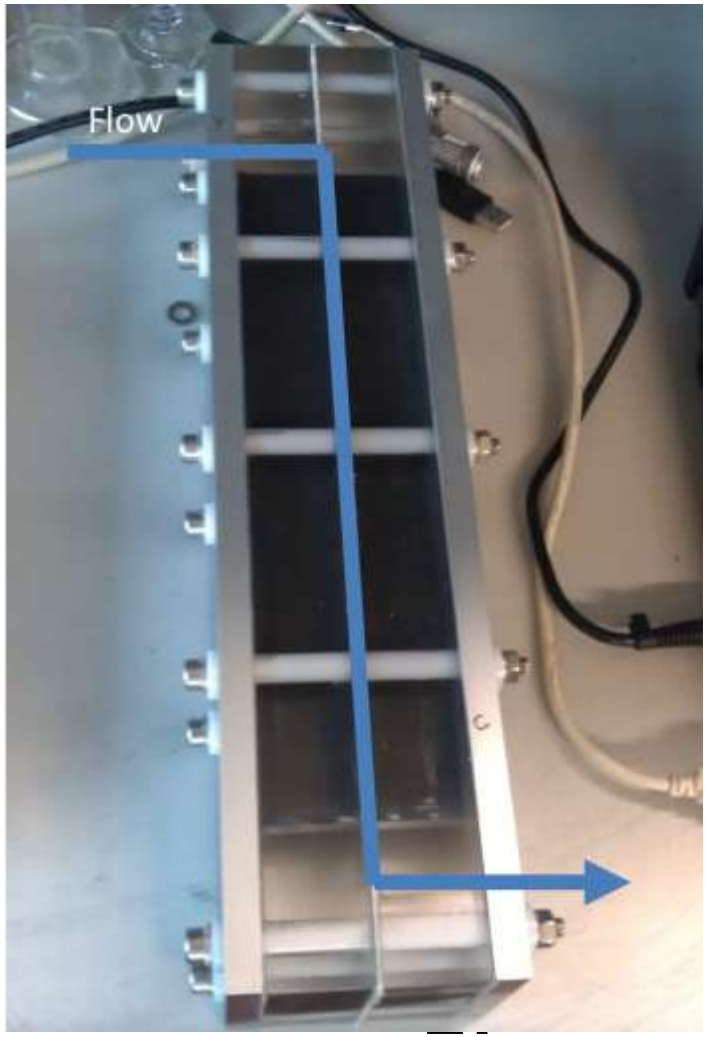
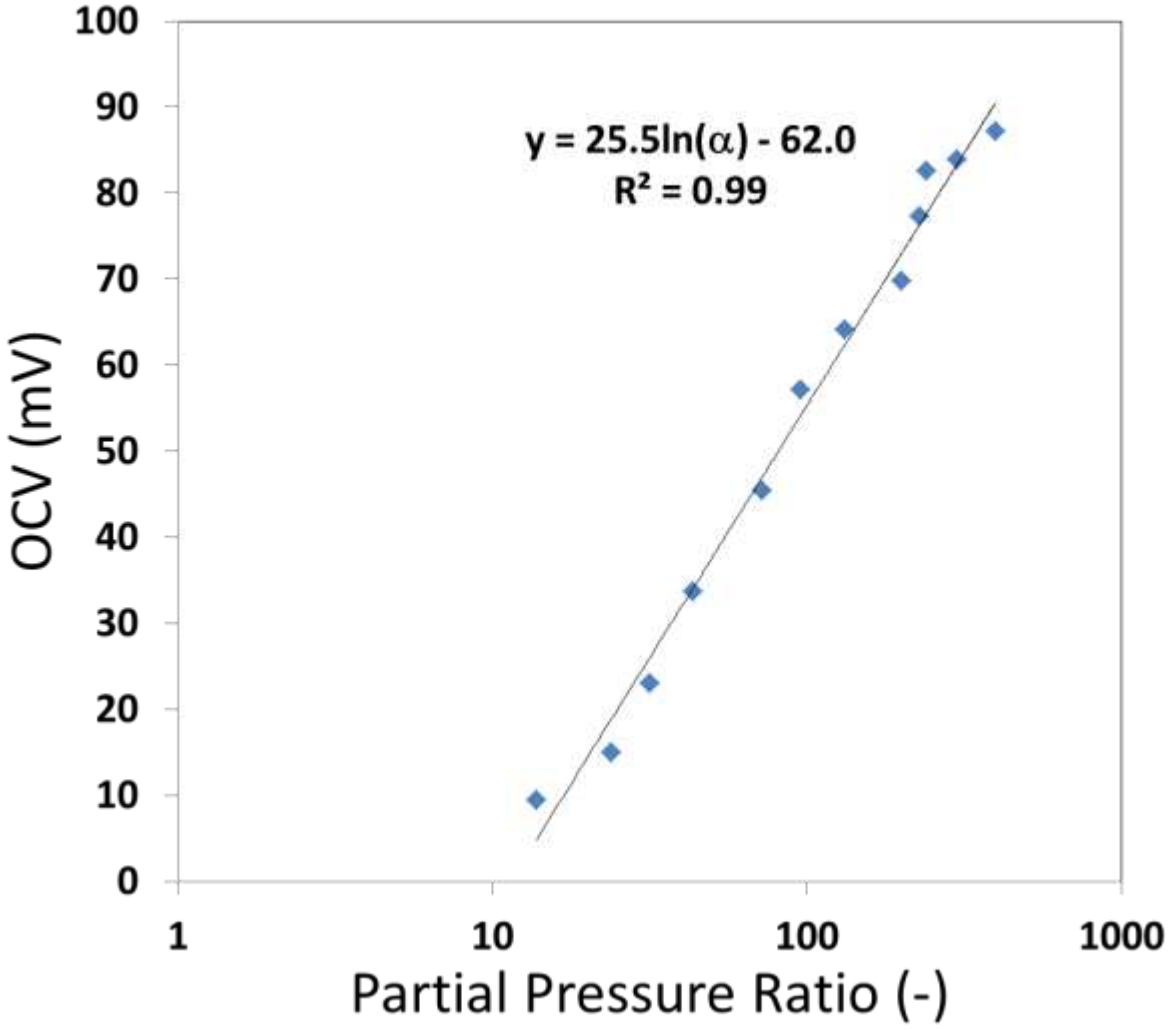
Experimental set-up





OCV versus pCO_2



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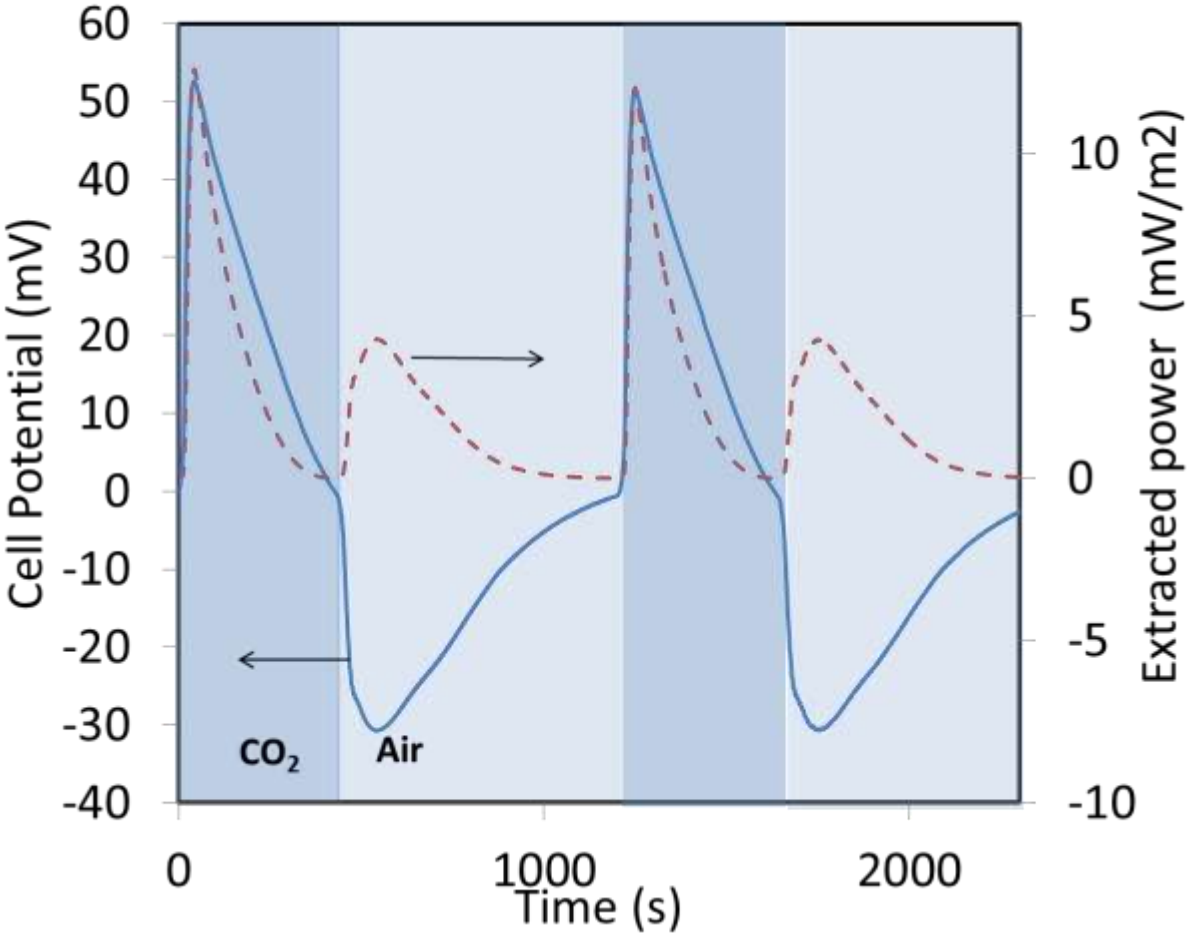
Energy Extraction Possible



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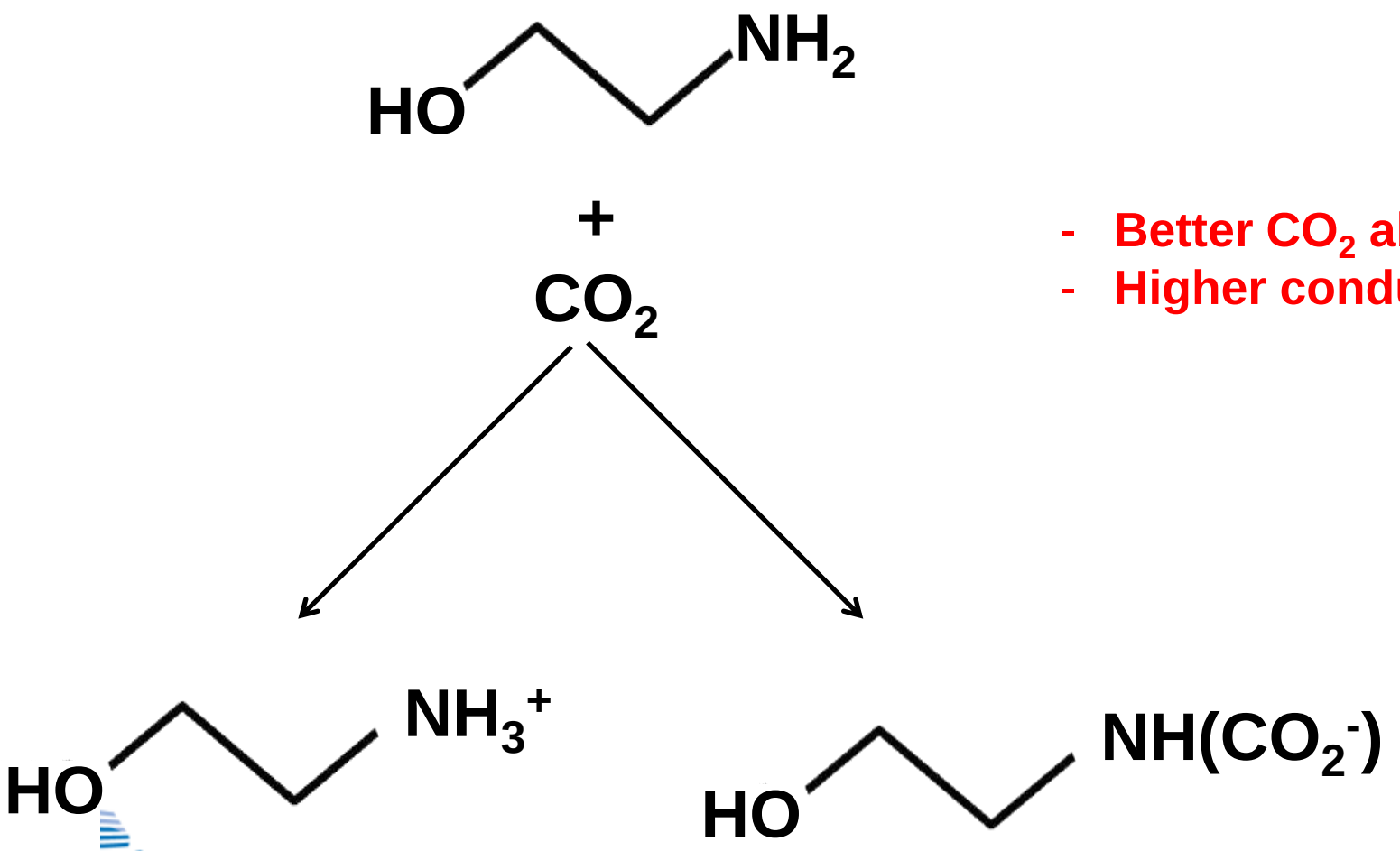
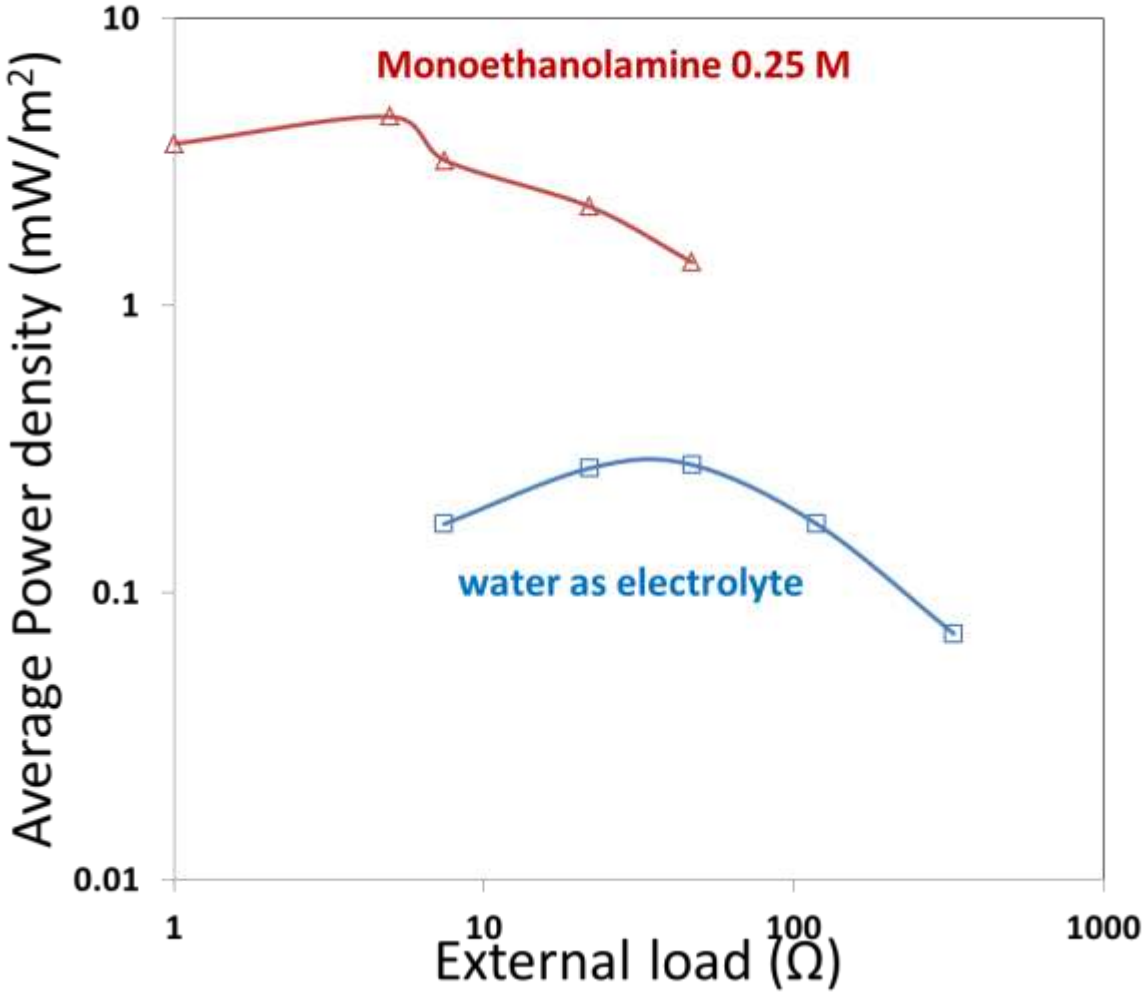
Mono-Ethanolamine absorbs CO_2



- Better CO_2 absorption
- Higher conductivity

MEA improves performance



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24/07/2013 | **Mise à jour:** 24 juillet 2013 | 16:31

On pourrait obtenir de ... du CO2

Ter, 23 de Julho de 2013

Cientistas conseguem fazer eletricidade com gás do efeito estufa

Foto: Divulgação

Cientistas divulgaram nesta terça-feira um novo método que produz energia com o uso de dióxido de carbono (CO2), um dos "vilões" do aquecimento global. Segundo os pesquisadores, a ideia é reaproveitar o gás produzido em termelétricas e outras chaminés ao redor do planeta.

Anualmente, as usinas termelétricas - que usam carvão, petróleo ou gás - produzem 12 bilhões de toneladas de CO2. Aquecimento industrial e residencial produz outras 11 bilhões de toneladas. O objetivo do grupo é que todo esse gás fosse reaproveitado de alguma forma.

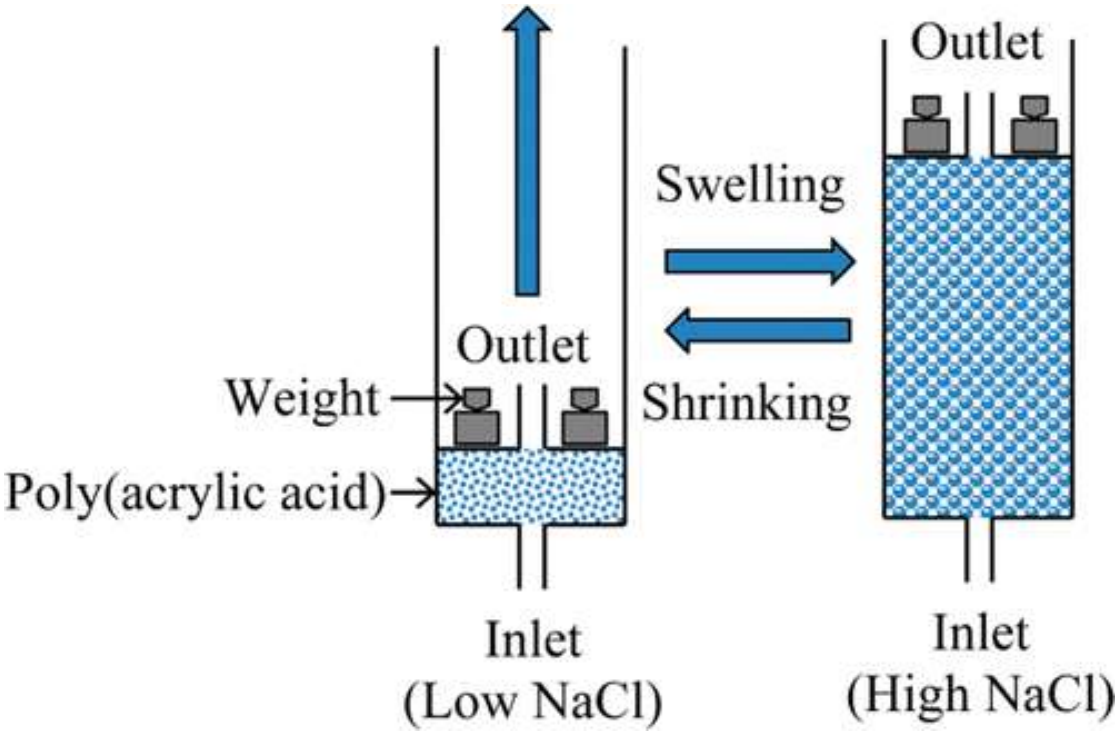
A tecnologia desenvolvida utiliza o gás estufa e água ou outro meio líquido para produzir uma corrente de elétrons. "No final, nenhuma substância é produzida ou consumida. O CO2, contudo, ainda vai para o ambiente no final", explica ao **Terra** Bert Hamelers,do Centro de Excelência para Tecnologia Sustentável e Água, em Wetsus, nos Países Baixos.

Archives Métro

rund 12 Milliarde
rund 11 Billioner
Kilowattstunder
12 Nullen und fa
zusätzliches CO2

Un groupe de chercheurs néerlandais croit être en mesure de développer une

New Principle



Zhu, Xiuping; Yang, Wulin; Hatzell, Marta; Logan, Bruce E; ,
Environmental science & technology, 2014,

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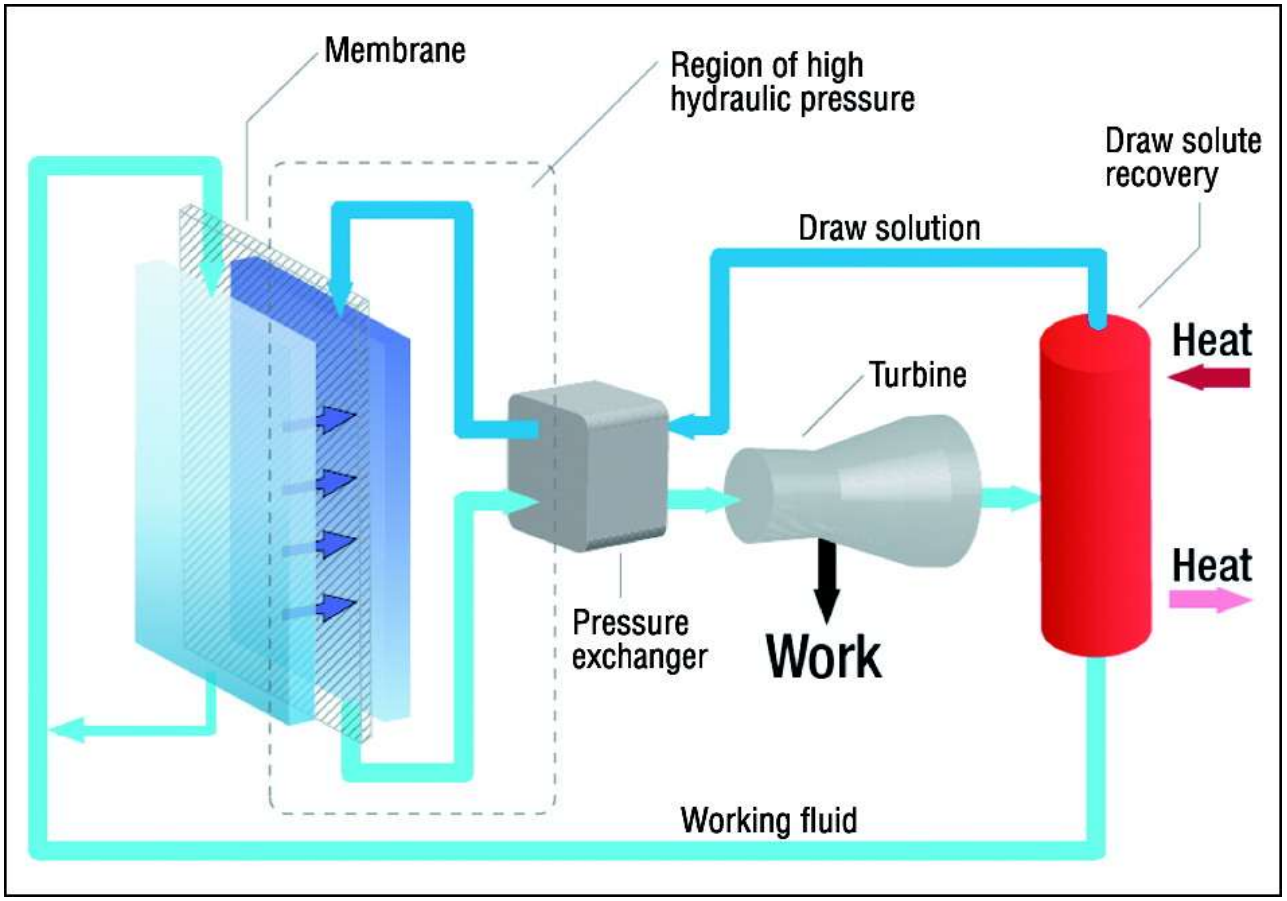
Thermal Gradients



Robert L. McGinnis and Menachem Elimelech
Environ. Sci. Technol., 2008, 42 (23), pp 8625–8629

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Brine-Brakish

http://www.reapower.eu/news.html

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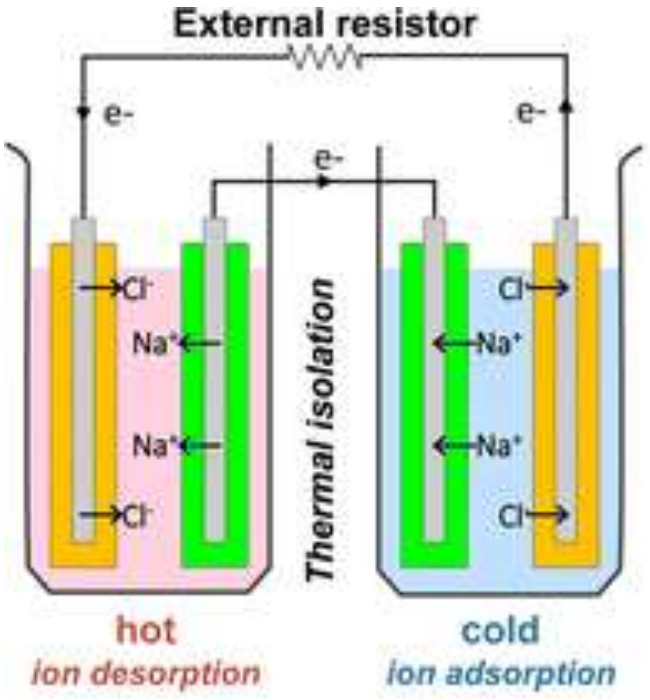
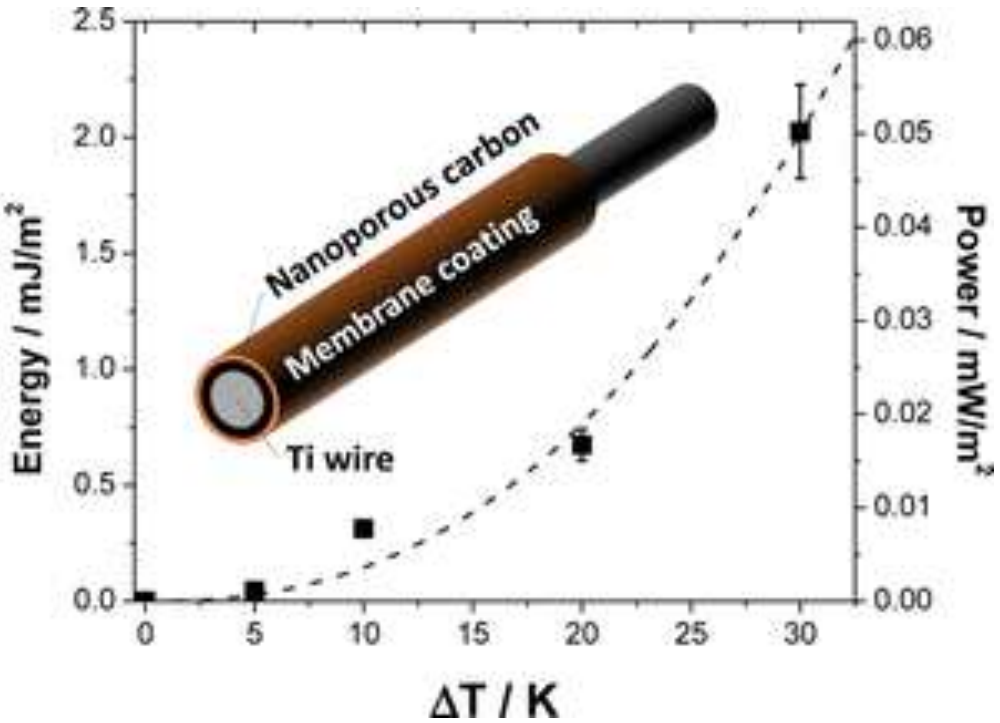
REAPower

Direct Thermal





Sales et al; ES&T letters 2014

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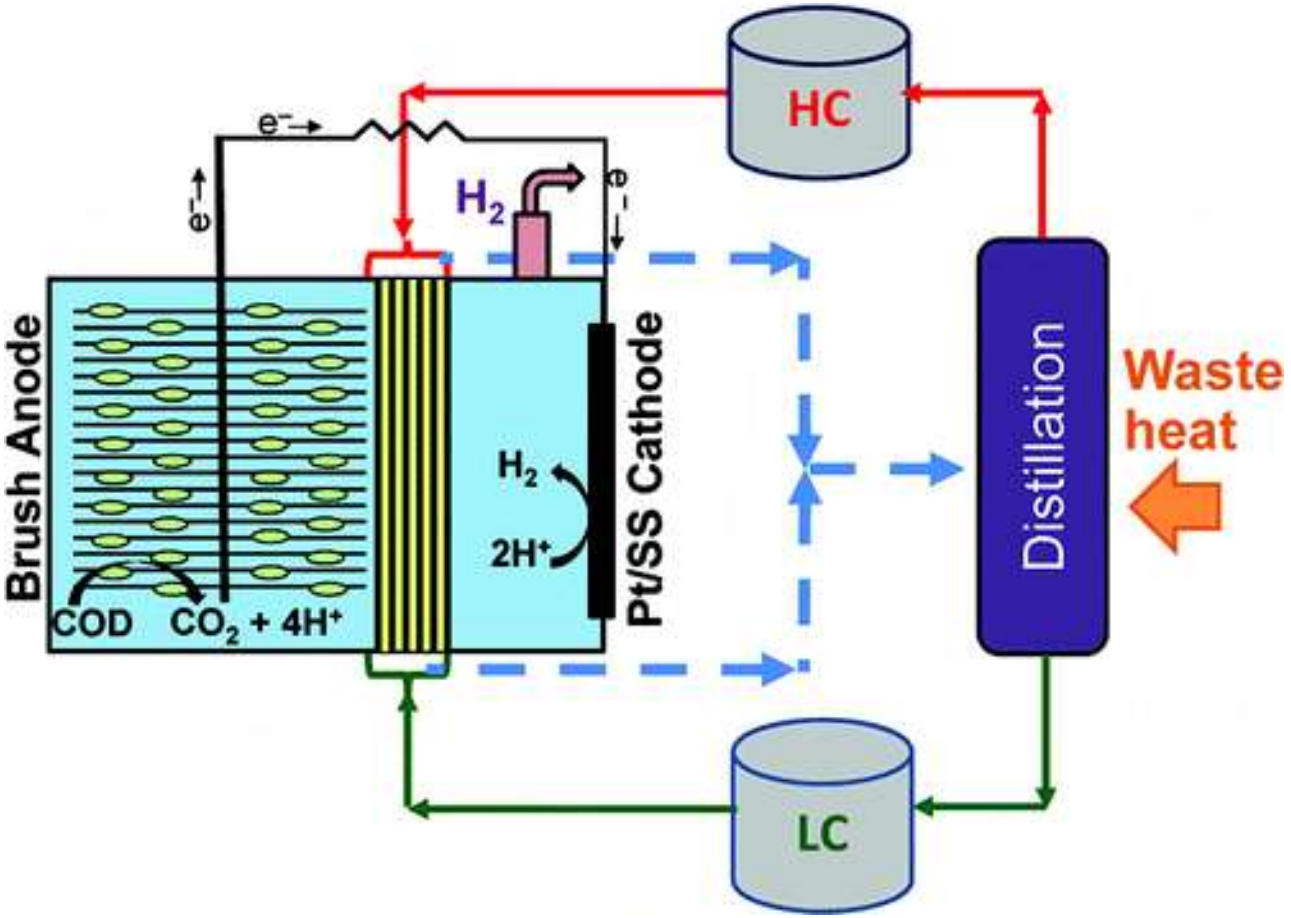
Hybrid systems



Joo-Youn Nam , Roland D. Cusick , Younggy Kim , and Bruce E. Logan *
Environ. Sci. Technol., 2012, 46 (9), pp 5240–5246

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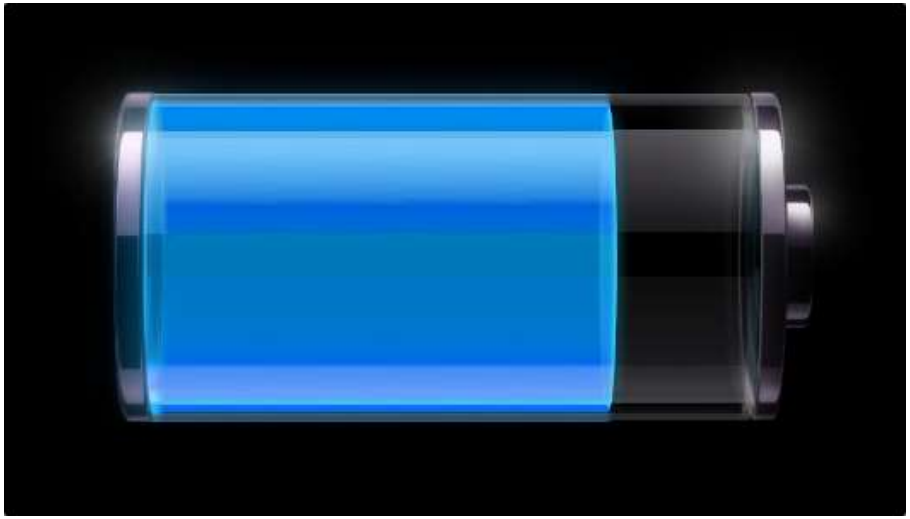
Battery



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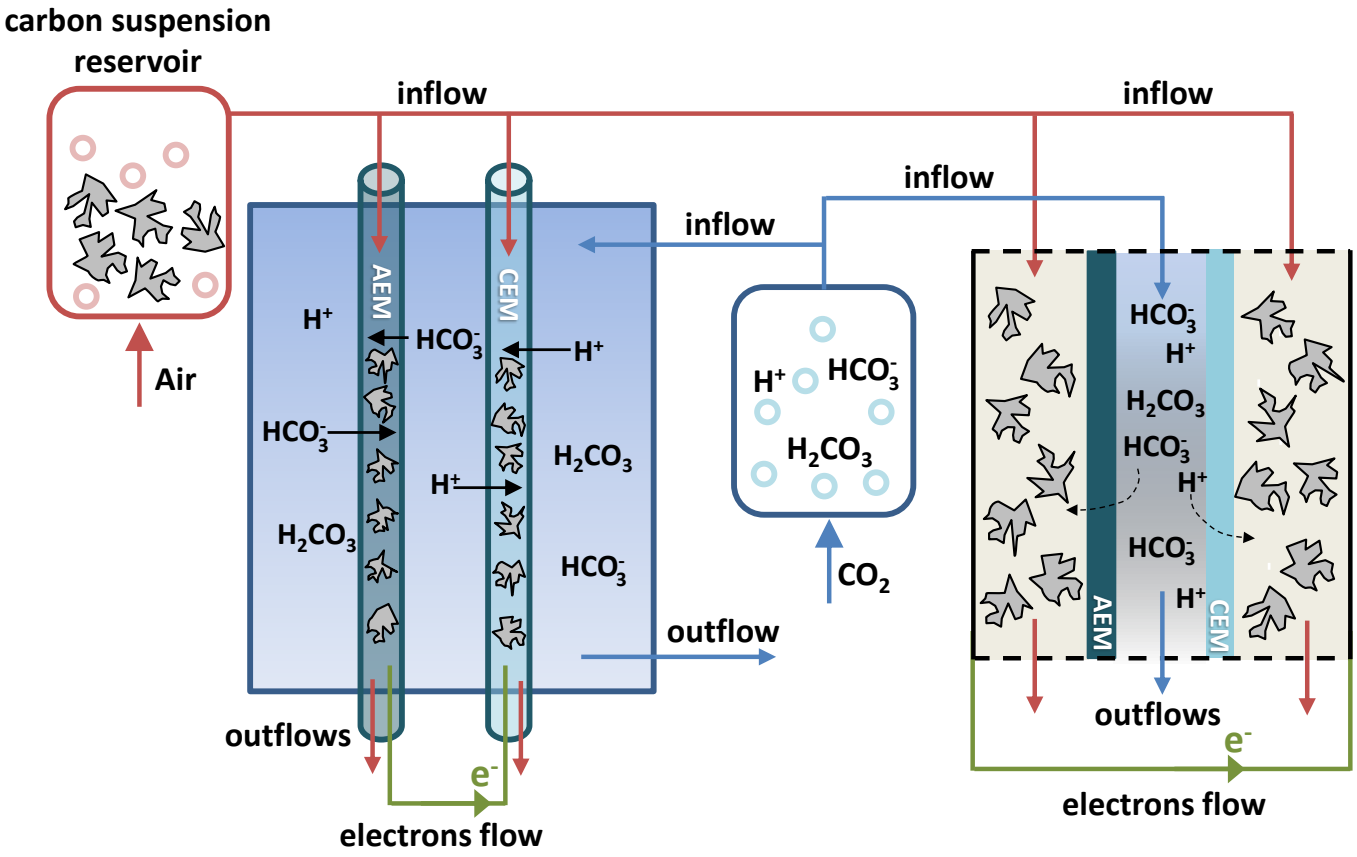
Flowable electrodes



Porada, S., et al. *Journal of Materials Chemistry A* **2014**, 2, 9313

Mixing Energy

- Everywhere concentrations differences are
- Selective mixing crucial
- Huge potential
- Technologies under development
- Inspiring new directions

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