Capacitive Deionization of Sea and Brackish Waters

Clean Drinking Water and Storing Energy!

OECD Paris 2009
In the Land of the Lilliputians…

But Not POORLY!
Particle Flavors

- $\text{Fe}_2\text{O}_3$
- $\text{MnO}_2$
- $\text{CdS}$
- $\text{Al}_2\text{O}_3$
- $\text{MgO}$
- $\text{NiO}$
- $\text{SiO}_2$
- $\text{ZrO}_2$
- $\text{TiO}_2$
Adsorption 1974-
Suspensions

Platelets

Natures Nanoparticulate “Tongue Depressors”
α-FeOOH  “Goethite”

150nm

Adsorbs...

- Arsenate
- Phosphate
- Protons!!
Without $\text{PO}_4^{-3}$
With $\text{PO}_4^{-3}$
From Suspensions to Thin-Films
Platelets

γ– AlOOH
“Boehmite”

Ceramic Membranes 1983-

Now – Smaller Particles
Nanofiltration
Films vs Suspensions

No Separation Needed
Better Light Penetration
Photoelectrodes
Transparent Semiconducting Thin-Films

- Photoelectrochemistry
- Grätzel Cells
- Porous Electrodes

Lubomir Spanhel

Hirofumi Kikkawa

Brian O'Regan
Qunyin Xu
Energy Storage

- Batteries
- Capacitors
Ultracapacitors
1994-

\[ C = \varepsilon \frac{A}{d} \]

\( \text{MnO}_2 \) 8nm

Ion Distance to Surface = Angstroms
Energy Density \( \Rightarrow \) Power Density

- Batteries
- Ultracaps
- Capacitors

Faster Response
Longer Cycle Life
Load-Leveling

USA
Alkaline Battery
ENERGY

WATER

ENERGY
POWER PLANTS NEED WATER!
WATER PLANTS NEED ENERGY!
DESALINATION PLANTS USING GIVEN TECHNOLOGIES

MEMBRANE PROCESSES
- RO: 86%
- ED: 14%

THERMAL SYSTEMS
- MVC: 33%
- MED: 24%
- MSF: 43%
DELIVER WATER & STORE ENERGY?
CAPACITIVE DEIONIZATION!

Diagram showing the process of separating ions from hard water to produce deionized water.
History of CDI

Caudle et al 1960’s
Oren et al 1970-1980’s
Farmer et al 1990’s

FIFTY YEARS BUT NO COMMERCIAL SUCCESS?
Our System
Proton is a Potential Determining Ion

\[ S\text{-OH}_2^+ = S\text{-OH}^0 + H^+ \]

\[ S\text{-OH}^0 = S\text{-O}^- + H^+ \]

THE PROTON HAS RETURNED!
Choosing Capacitor Materials

The pH range of Normal Waters.
CaCl$_2$ Removal
How Effective is Coating?

Zero Removal in 20 minutes for Uncoated Carbon
CaCl₂ Removal with Coatings

90% Removal in 20 minutes
Other Ion Removal

Note: Calcium is Difficult if Not Impossible to Remove with Carbon Aerogels Capacitive Systems!
Regeneration buy
Reversing the Voltage!!

Repulsion Between Surface Charge and Ions
Flush Water
CaCl$_2$ Regeneration

A Little Push!

Ca$^{++}$ Concentration [mg/L]

Time [min]
CDI vs RO

- Reduced Energy (>30%)
- Reduced Fouling (>60%)
- Less Brine (>40%)
- Low Maintenance Cost (>50%)
- Higher Throughput (>70%)
- Lower Capital Costs (>40%)
Third World Water
Solar Powered CDI For A Family of Four
Where Do We Go From Here?
Senior 5-Year Proposal
To Be Continued . . .