Advances in Capacitive Deionization Using Reticle Carbon

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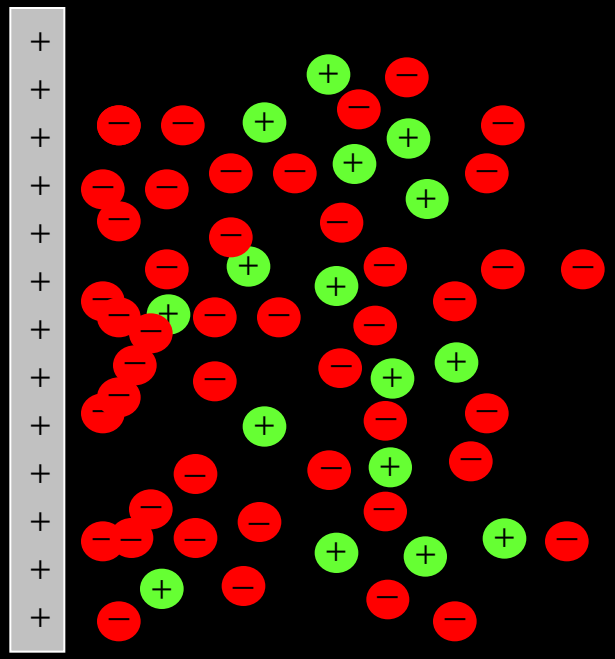
Key Historical Dates

- 1550 B.C. Egyptians used Activated C for medicinal adsorption of poisons
- 18th Century – Activated C used to purify liquids
- 20th Century – Activated C used to purify gold
- 1970s Patent for capacitive deionization
  - Ion absorbed into Stern-layer (double layer)
  - Search for high surface area material begins

Stern Layer Theory--Charged Ions Cluster on a Charged Surface



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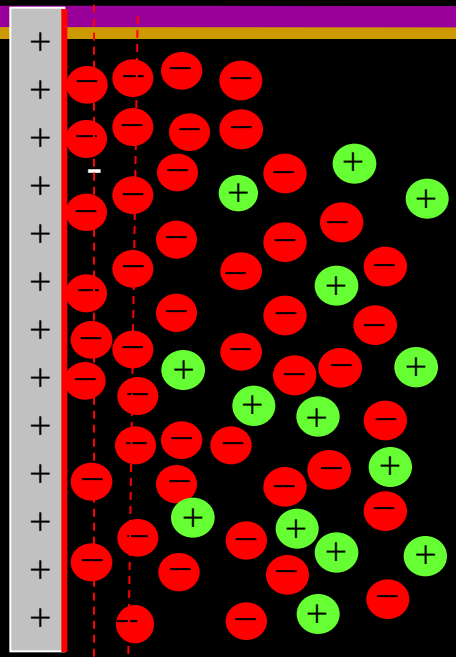
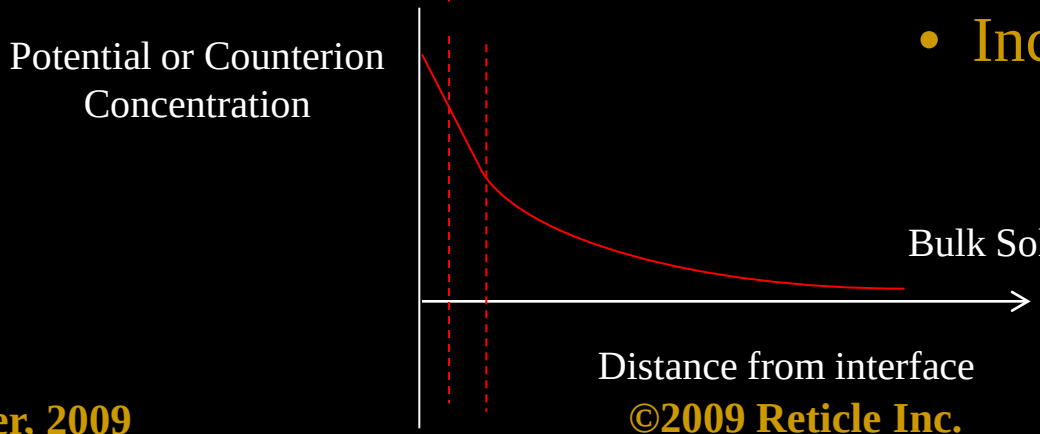
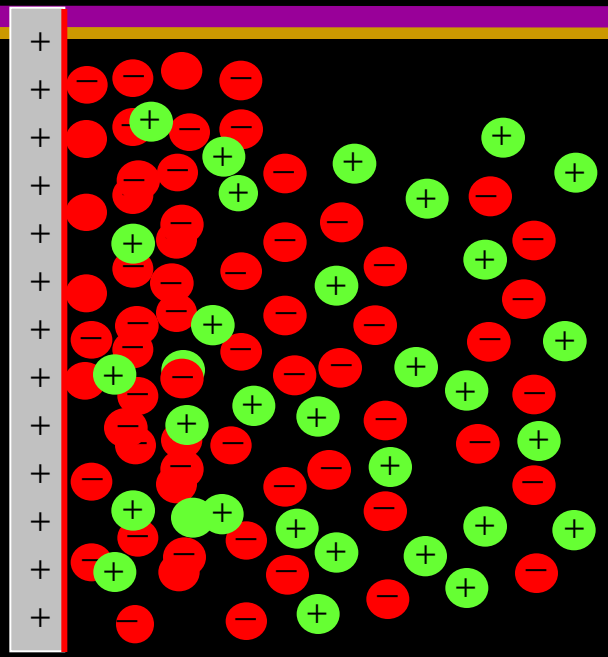




Only ways to increase charge:

- Increase the charge
- Increase the surface area

Regeneration



Potential or Counterion Concentration

Bulk Solution = Equipotential

Distance from interface

Activated Carbon

- **Range of available surface areas**
  - **Coconut shell - 800 to 1400 m^2/g**
  - **Hard wood – 1000 to 1600 m^2/g**
  - **Pet Coke – 1400 to 3000 m^2/g**
  - **Coal and Peat – 1200 to 2000 m^2/g**

- **Activated carbon is sold as granular powder with huge surface area**
  - **Individual particles can't be charged uniformly**
  - **How do we improve it?**

Activated carbon material: Two methods for manufacture

- Binding of activated carbon particles
  - Inorganic binders (salts of iron, cadmium, etc.)
  - Organic binders (plastics, elastomers, etc.)
- Production of activated carbon from polymeric material
  - Plastic carburization
  - Aerogel and Xerogel carburization
  - Carbon Nanotubes
- Organic binders used to “glue” then pyrolized to form carbon bonds

Reticle Consolidated Activated Carbon

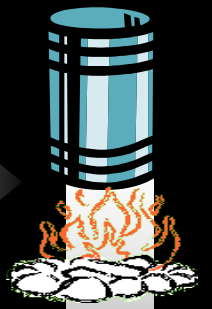
- Consolidation process “just welds” the activate carbon particles together
  - Maintains over 85% of the original properties of the activated carbon particles
  - Process times are short
    - 2-4 hours
  - The process can be tailored to optimize properties
    - Surface area
    - Conductivity
    - Porosity

Reticle Carbon Is Made by Simple Canning-Evacuating-Compressing

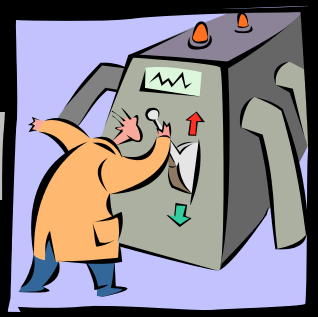
Get Granulated Activated Carbon

Put it in a can

Seal it

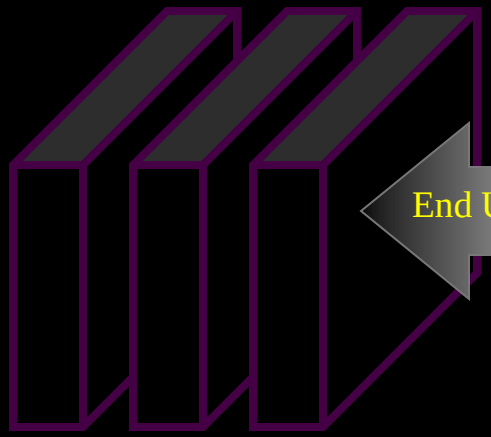


Compress It

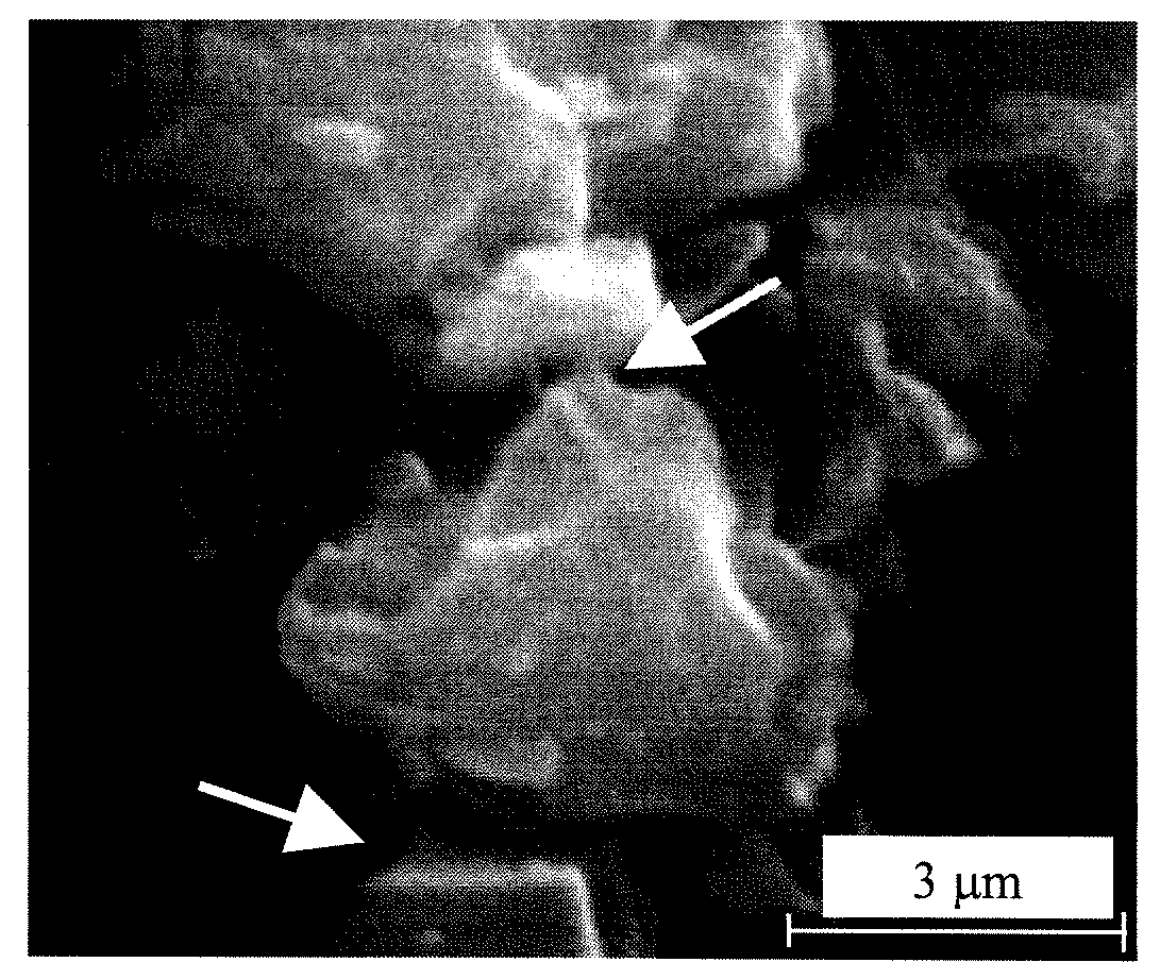


Reticle Carbon

End Use



Electron Micrograph of Reticle Carbon



Carbon Property as a Function of Operating Conditions

Operation Conditions	Surface Area (m^2/g)	Porosity (%)	ρ_{bulk} (g/cm^3)	Resistivity ($\Omega \cdot cm$)
Low	1,238 ± 21	31.0	0.75	0.134
Medium	1,026 ± 20	16.8	0.94	0.060
High	931 ± 15	11.9	1.05	0.047
Raw Activated Carbon	1,400 ± 22	19.8	0.66	-

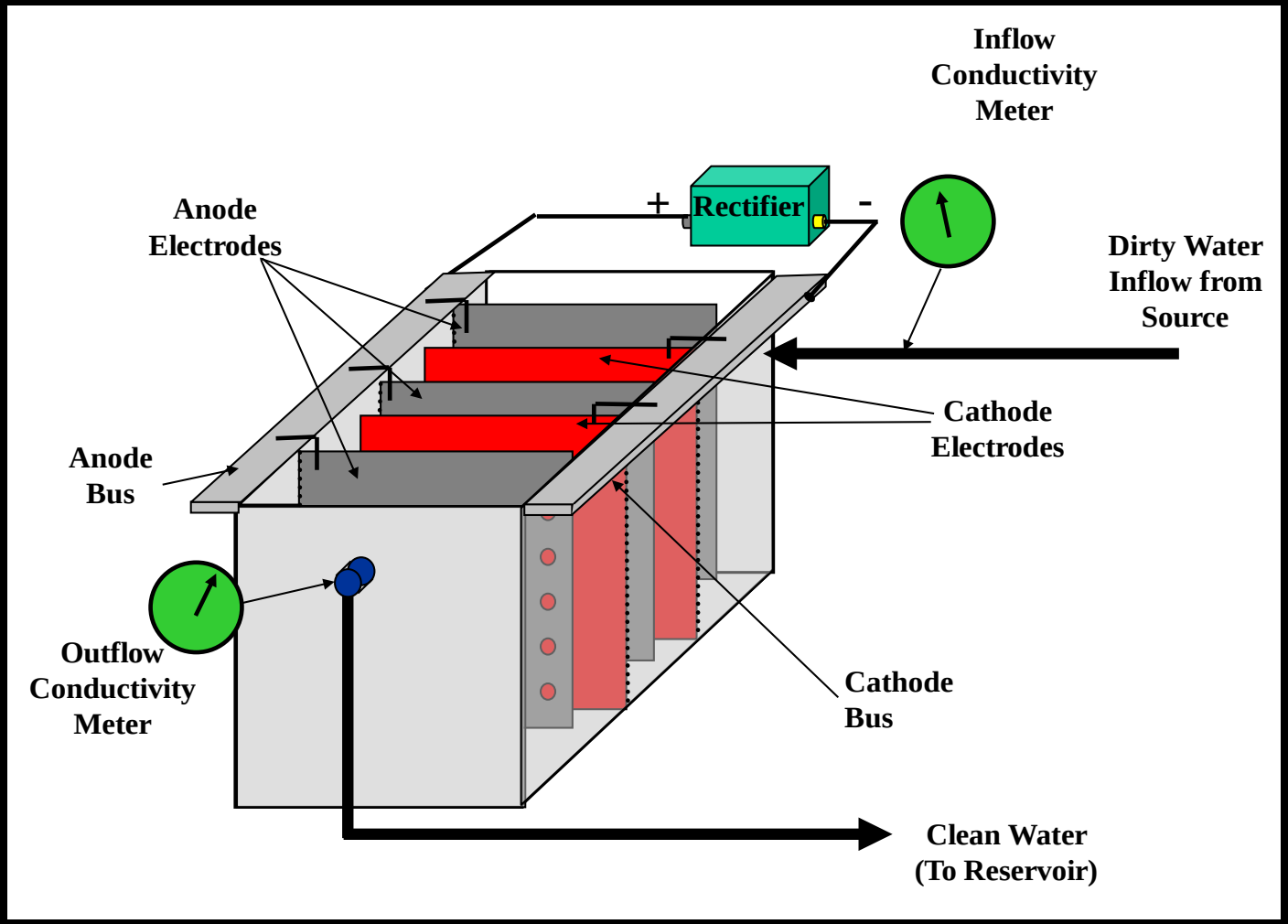
Exceptional and Unmatched Properties

Specific Attribute	Reticle Carbon Properties	Aerogel Carbon Properties[1]	Carbon Nanotube Properties[2]
Surface Area	1250 – 1950 m^2/g	424 – 600 m^2/g	125 – 250 m^2/g
Bulk Density	0.75 – 1.0 g/cm^3	0.78 g/cm^3	1.3 – 1.4 g/cm^3
Manufactured Cost	$50/kg	$250/kg	>$10,000/kg

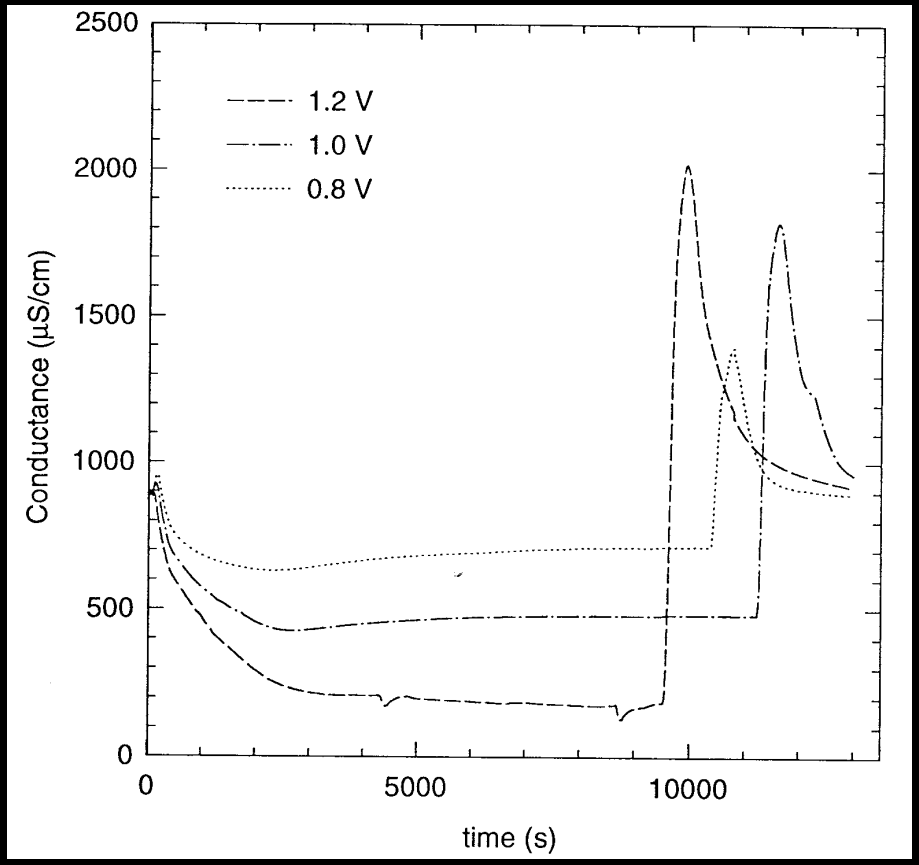
[1] From *www.cdtwater.com/carbonaerogel.php*, and Lawrence Livermore National Laboratory

[2] From. *www.cheaptubesinc.com* , journal articles in *Carbon*, *www.pa.msu.edu/cmp/csc/ntproperties*, and *lees-web.mit.edu/lees/projects/cnt_ultracap_project.htm*.

Capacitive Deionization Cells Used in the Desalination Tests



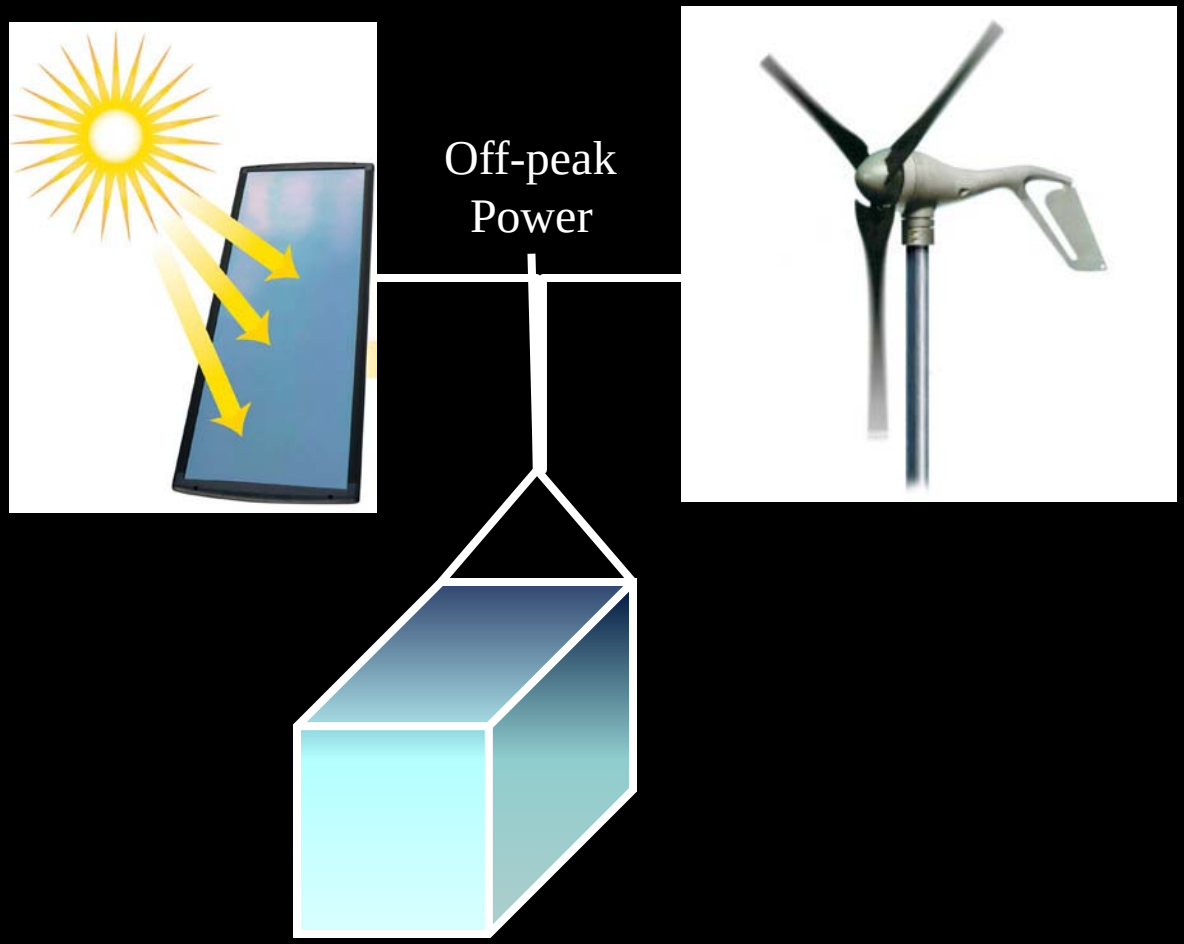
Desalination Results



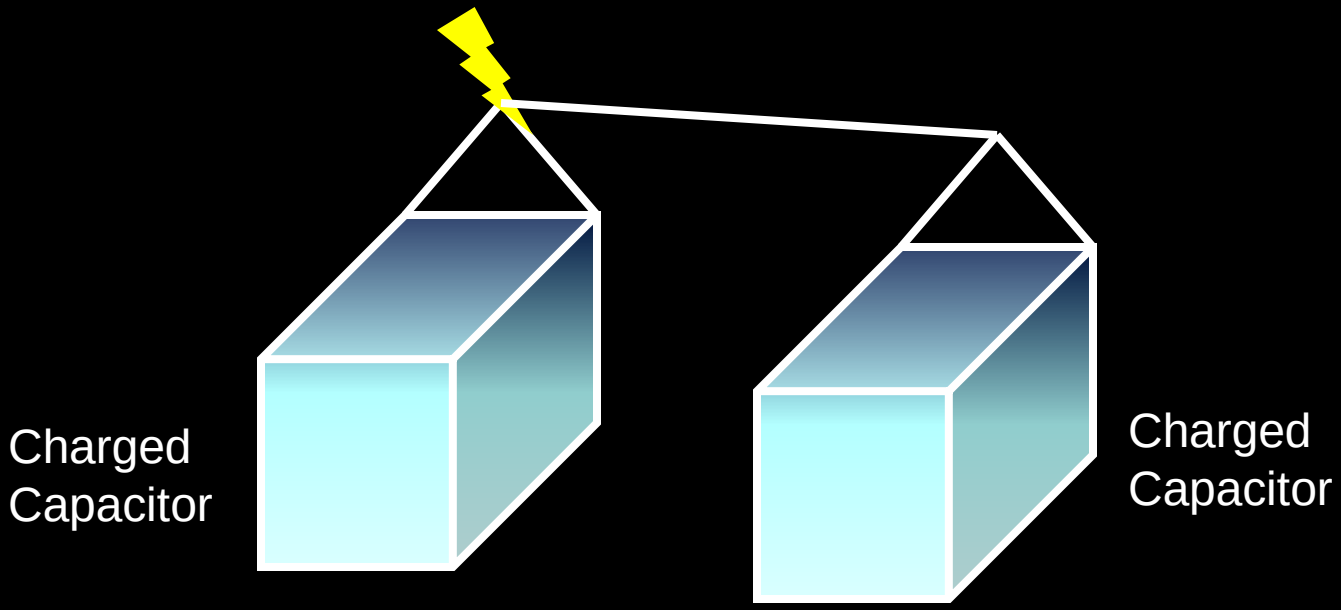
Desalination and Regeneration of a 500 ppm NaCl solution at different potentials

Low voltage, high amperage devices that use DC power

Energy Management
Renewable Energy Sources



Energy Management
Transfering Stored Energy



Regenerating cells can be used to charge a second cell
We anticipate at least 50% of the energy can be reused

Comparison of Energy Consumption for Deionizing Water

Technology	Energy Consumption (Wh/L)	Energy Consumption (kWh/1000 gal)	Energy Cost to Deionize*
Distillation	53[1]	200.6	$16/kgal
Reverse Osmosis	9.3[1]	35.2	$2.80/kgal
Reticle CDI	0.34[2]	1.29	$ 0.11/kgal

* Assuming $0.08/kWh

([1] - Data from "Desalination role scheduled for Aerogel", *Chemical Engineering*, 2/97, pg. 23)
([2] – With no energy recovery; that is, all of the energy is dissipated during regeneration.)

Pilot Test
Saskatchewan, Canada

Softening Results

	As Received Water	Single Pass Water	Continuous Recycle
Ca Hardness	450 ppm	270 ppm	280 ppm
Total Hardness	970 ppm	470 ppm	590 ppm
TDS*	1980 mg/L	732 mg/L	1160 mg/L

Average power consumption for each test 0.6 Whr/L

•Saskatchewan Provincial Drinking Water Standards: Max. of 1,500 mg/L TDS

Reticle Carbon

Remove everything but the “wet” from water!