Pilot demo location - Spain

Capacitive Deionization (CDI) – Overview

About Aquas Technologies Corp.

About Aquas Tech

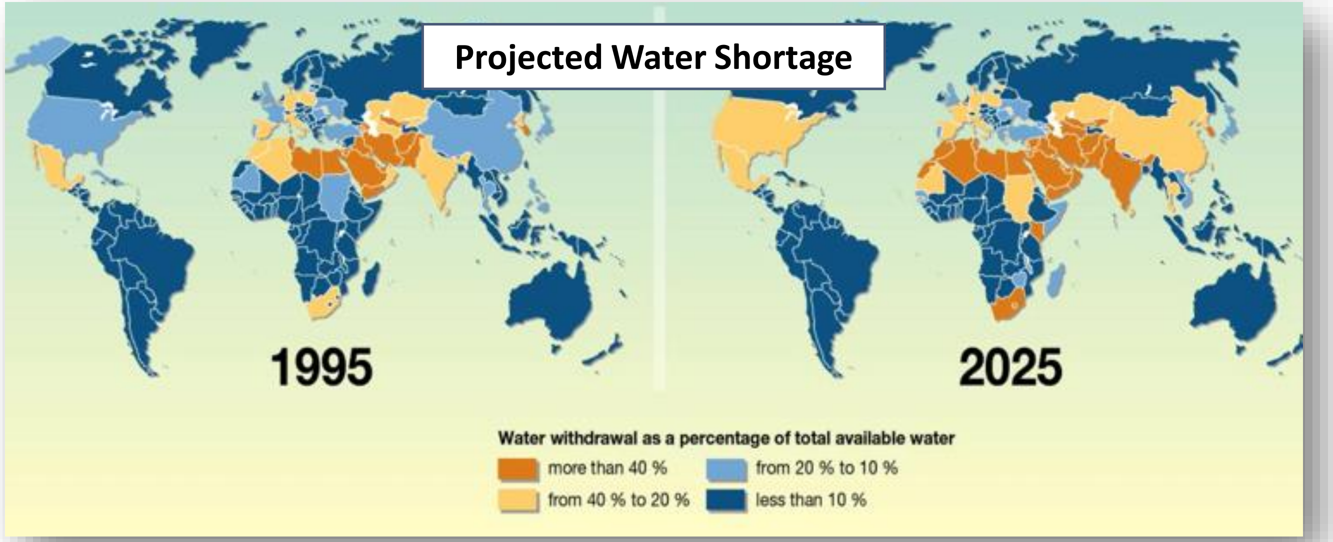
- Founded in 2010, Aquas’ CDI product is **highly energy efficient** and modular - serves small to large utility scale systems
- We are a **licensee with exclusive rights** to commercialize capacitive de-ionization (CDI) patented technologies including carbon aerogel materials from US Dept. of Energy’s Lawrence Livermore National Laboratory (LLNL) for water treatment
- With this strategic license, Aquas is leveraging **over $40 Million spent** by LLNL/DOE in developing CDI technologies in the past 20 years to accelerate our product roadmap
- We are actively engaged in the ongoing CDI research and materials development at

- Capacitive deionization (CDI) is a rapidly growing technology for removal of ions/salt from water to make potable water using electricity and supercapacitors
- **First new technology in 25 years that can truly disrupt the water treatment markets**

Water Stress & response

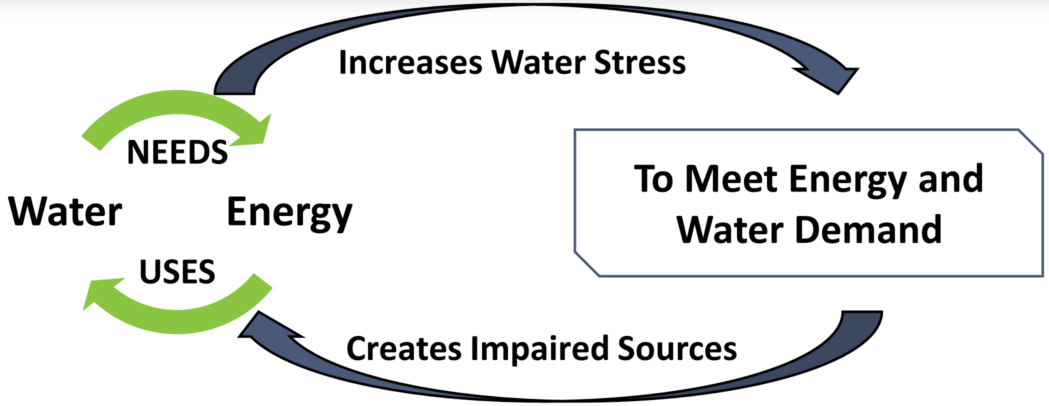
US DOE 2014 Report, "Water-Energy Nexus: Challenges and Opportunities"

- **Brackish water treatment to reduce water stress** caused by climate change
- **Government response to drought** (such as $7.5B fund in California)
- **Stricter government regulation & policies** on pollution and sewage discharge is also encouraging water recycling and re-use
- Industrialization and improved standard of living in developing countries – **citizen's demand for clean water**



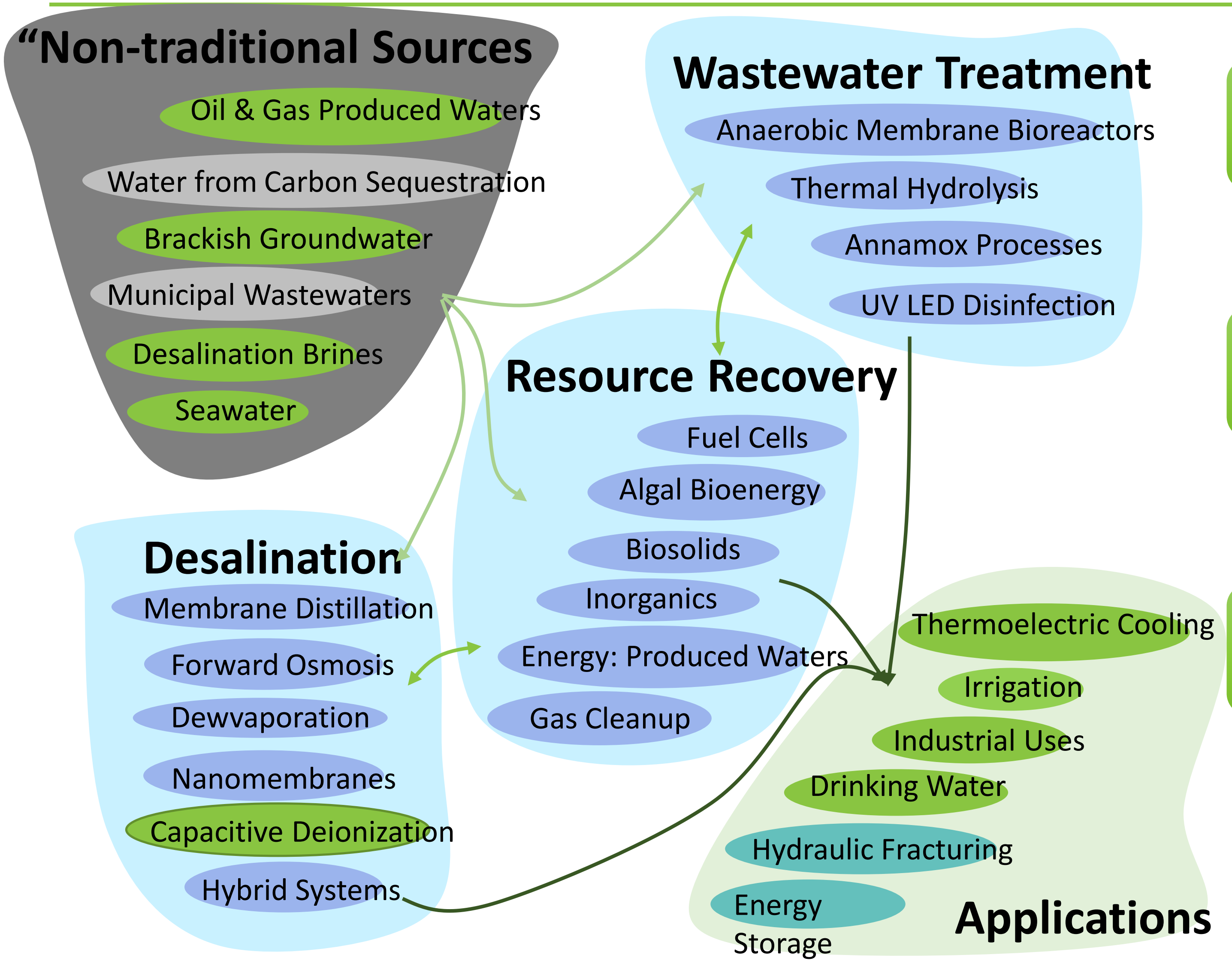
Energy-Water Nexus:

- Thirst for power – re-use of water for energy generation - **Urgent need for energy efficient water treatment solutions**
- Diverse water treatment market with varied desalination needs
- **Energy intensive reverse osmosis not viable in long term**



Treating Non-Traditional Water Resources To Alleviate Water Stress

Desalination is most-promising technology – very energy intensive



Water Supply and Recharge

- Convert local, existing impaired sources; control pollution and sewage policies

Water Resiliency

- Local recycling and reuse, promote efficient use of water – reduce energy cost due to treatment and transport

Water National Security

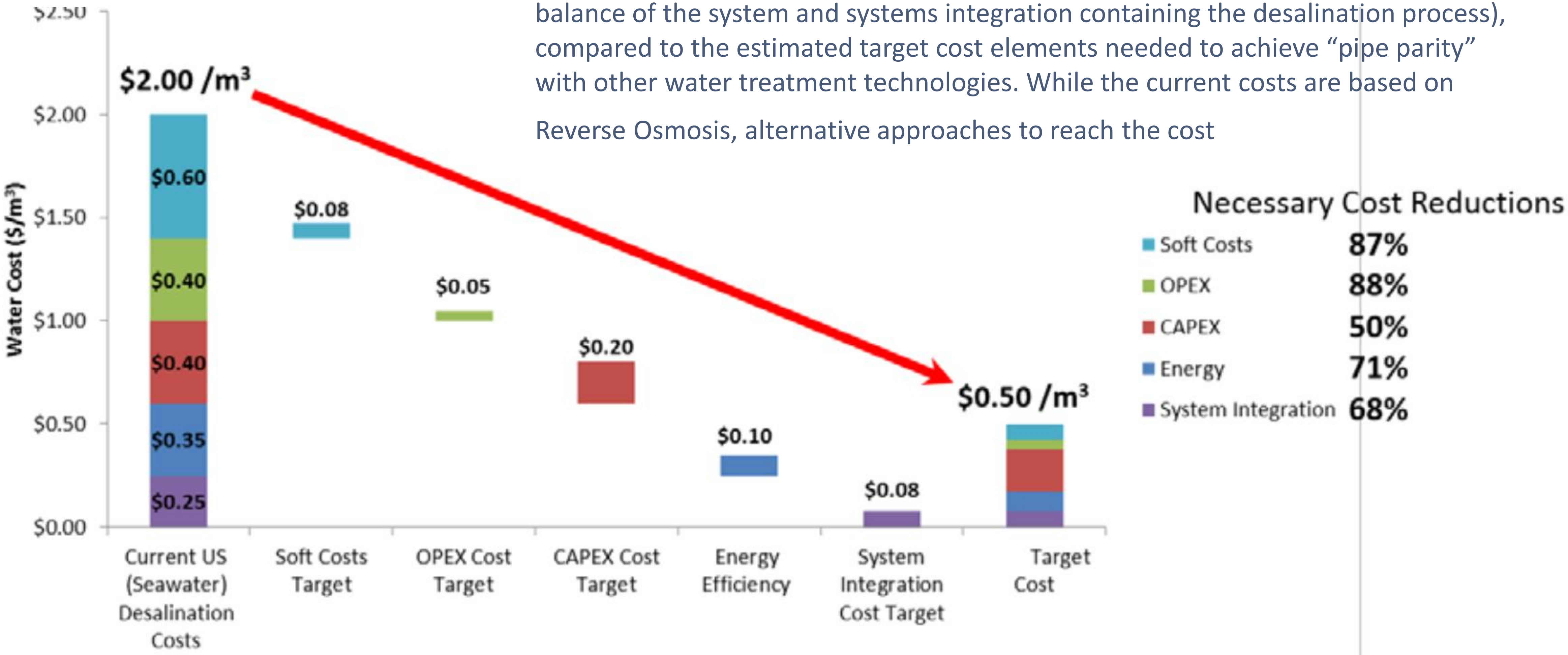
- New Technologies and Monitoring Solutions to prevent bio-terrorism, health epidemics, and toxic industrial pollution such as Mercury, Lead, Arsenic, etc.

Source: US DOE 2014 Report, “Water-Energy Nexus: Challenges and Opportunities”

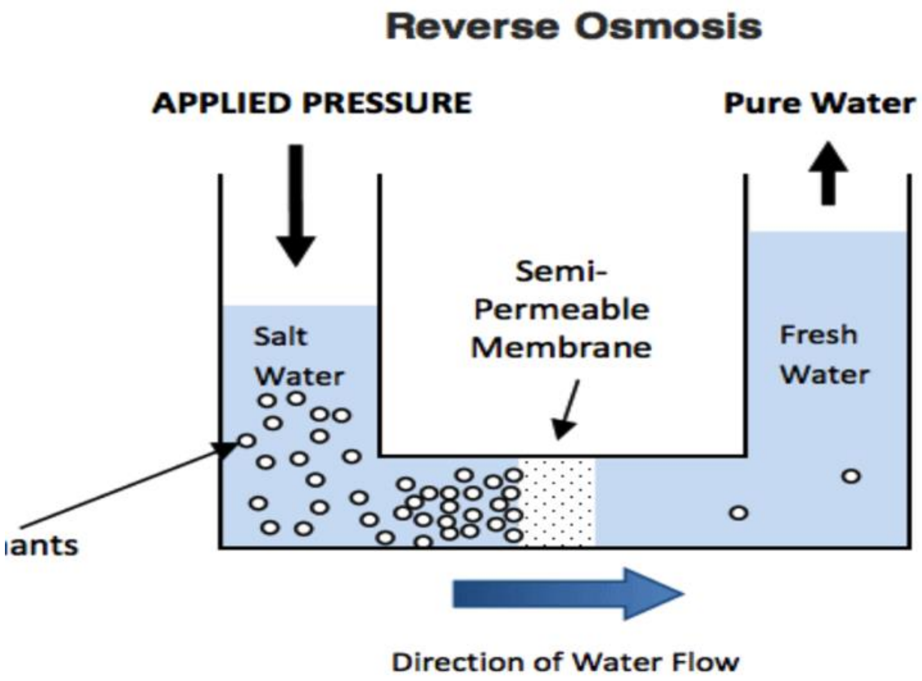
US DOE: RO CAPEX Reduction Goals and Pipe Parity

Estimated current cost elements for desalination of seawater (including capital expenses (CAPEX), operating expenses (OPEX), energy costs, and costs for the balance of the system and systems integration containing the desalination process), compared to the estimated target cost elements needed to achieve "pipe parity" with other water treatment technologies. While the current costs are based on

Reverse Osmosis, alternative approaches to reach the cost



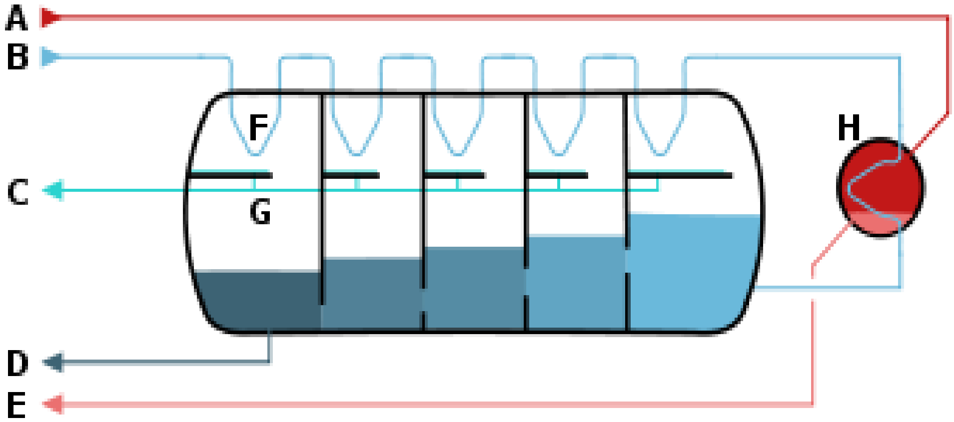
Brief Review of 2 most widely adopted Sea Water Desal Methods
Reverse Osmosis(RO)-Membrane



Reverse osmosis (RO) is a water purification technology that uses a ***semipermeable membrane*****.** In general, ***RO*** systems apply pressure against semipermeable membrane, where the membrane is preamble only to the water molecules.

Energy Consumption per **TON** of Sea Water input: 4 kWh

Brief Review of 2 most widely adopted Sea Water Desal Methods
Multi-stage Flash Distillation / Multi-effect Distillation-Thermal



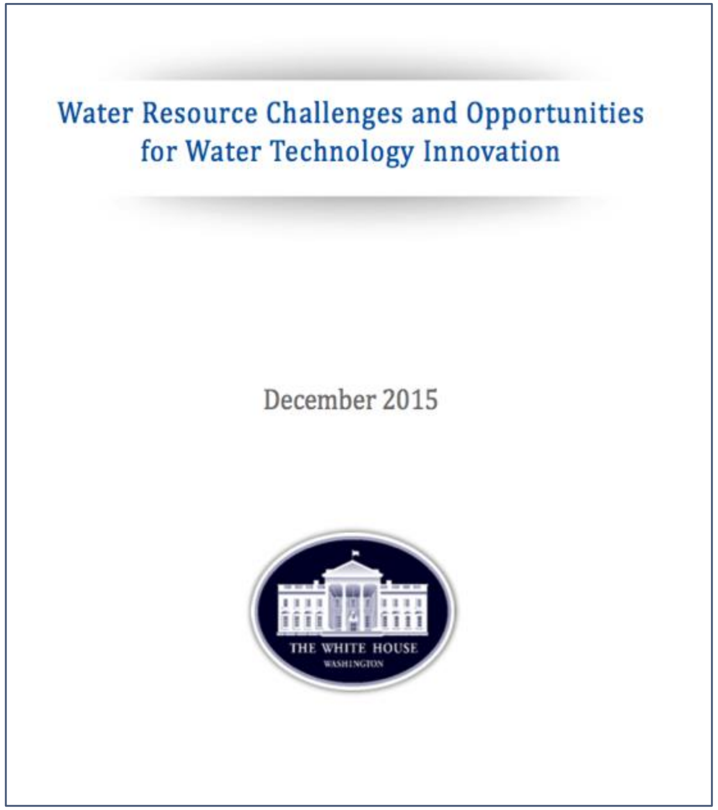
Multi-stage flash distillation (MSF) is a water desalination process that distills sea water by flashing (low pressure evaporation) a portion of the water into steam in multiple stages of what are essentially countercurrent heat exchangers.

Multi-stage flash distillation plants produce about 60% of all desalinated water in the world*

Energy Consumption per **TON** of Sea Water input: 23 to 27 kWh**

Image Source: https://en.wikipedia.org/wiki/Multi-stage_flash_distillation
**Source: https://en.wikipedia.org/wiki/Multi-stage_flash_distillation*
***Source: http://www.iags.org/n0813043.htm*

White House Report on Water Challenges and New Tech


Water Resource Challenges and Opportunities for Water Technology Innovation

December 2015

…Technologies such as forward osmosis, [...] freeze separation, and ***capacitive deionization potentially can be used in commercial desalination of both brackish and sea-water….***

[Source: "Water Resource Challenges and Opportunities for Water Technology Innovation", 2015]

Capacitive Deionization	ambient	0.11kWh$_e$/m^3

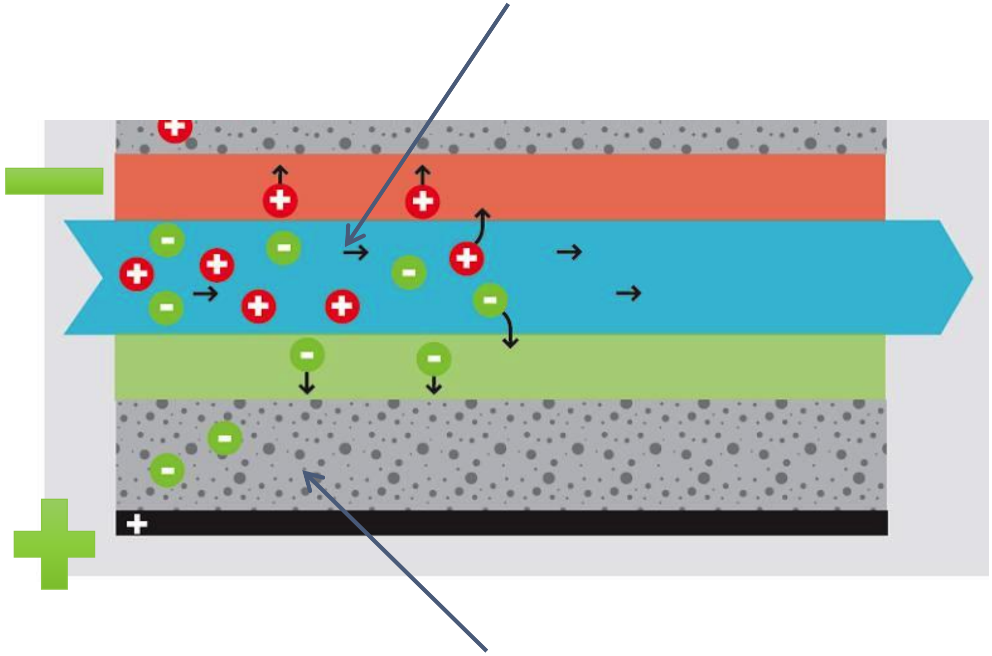
4X LESS ENERGY THAN EXISTING PRODUCTS

CDI IS LOW PRESSURE & LOW TEMPERATURE TECHNOLOGY

Basic Concept of CDI

- Water flows **between** high surface area electrode pairs having a potential difference of 1.3 Volts
- Ions and other charged particles are attracted to and held on the electrode of opposite charge while desalination process and rejected into a low salinity brine during

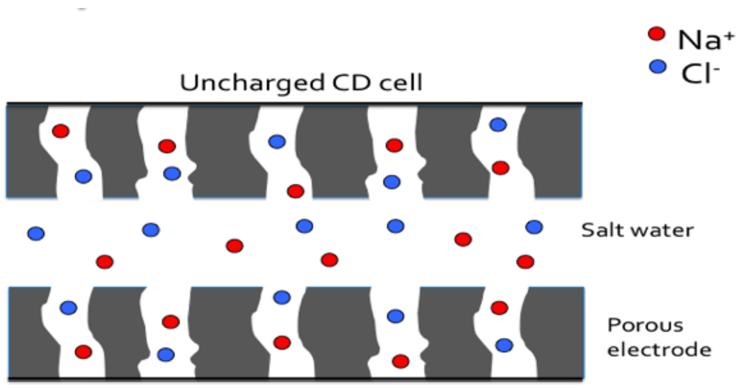
Negative electrode attracts positively charged ions (cations) like Sodium (Na), Calcium (Ca), Magnesium (Mg)



Positive electrode attracts negatively charged ions (anions) like Chloride (Cl), Nitrate (NO_3), Carbonate (CO_3), Silica (SiO_2)

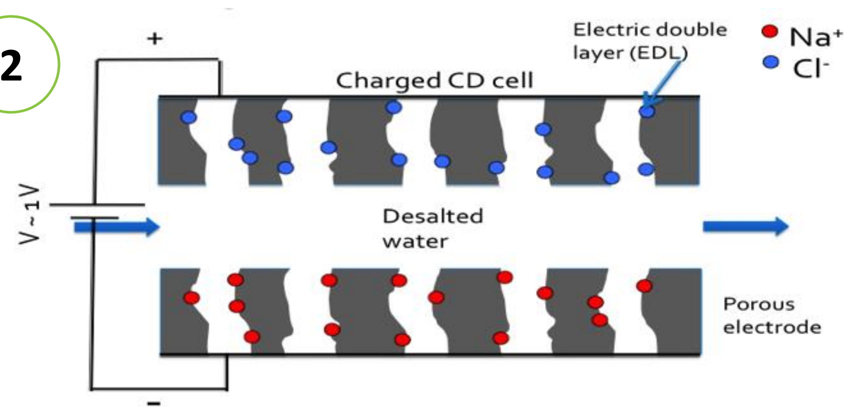
Basic Concept of CDI

1



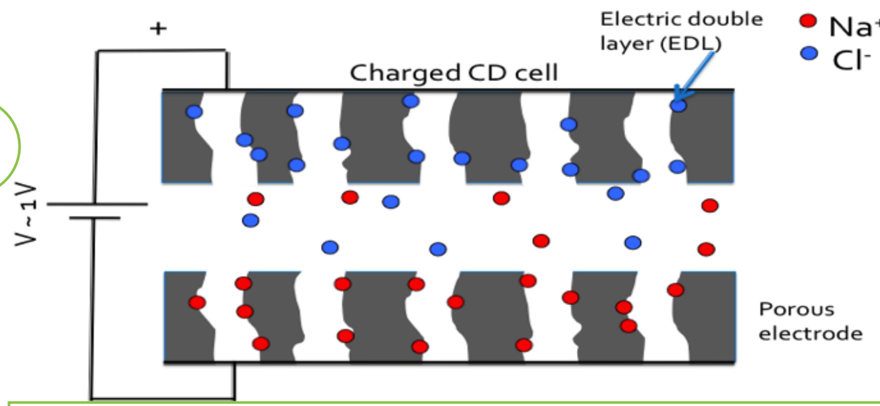
Salt in water exists as ions (Na+, Cl-)

2



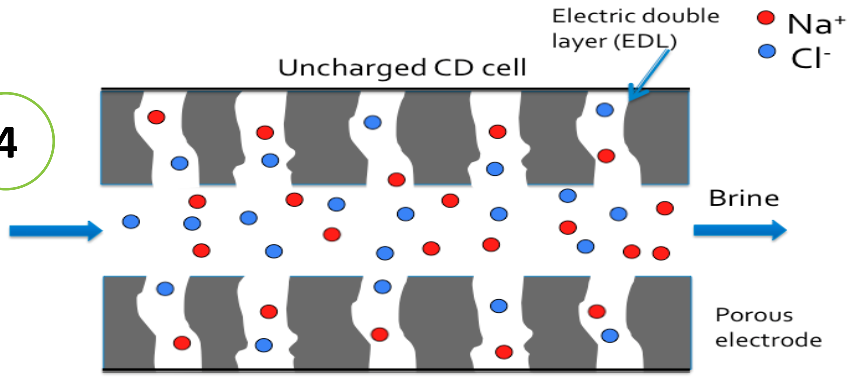
As water flows, Toxic Chemical ions are adsorbed and trapped

3



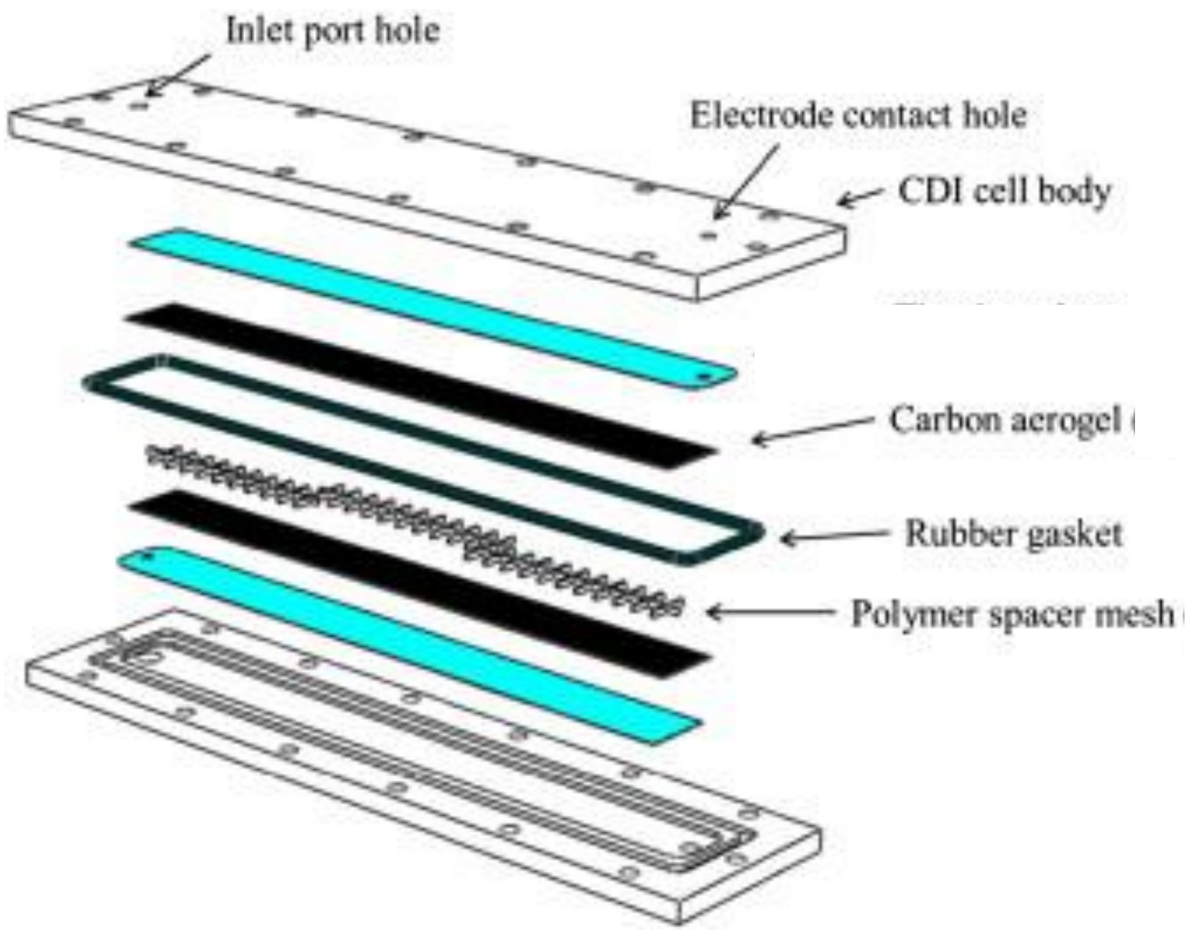
Fully Charged Cell ready for regeneration cycle

4



Cell discharge releases adsorbed ion in Brine Stream, energy is recovered during discharge for use in next cycle

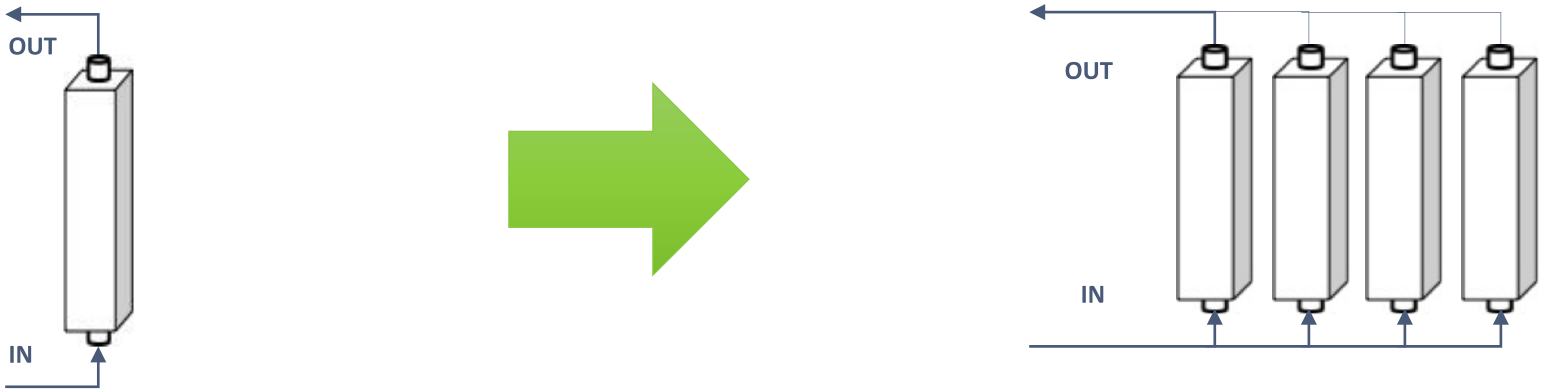
CDI Cell Assembly



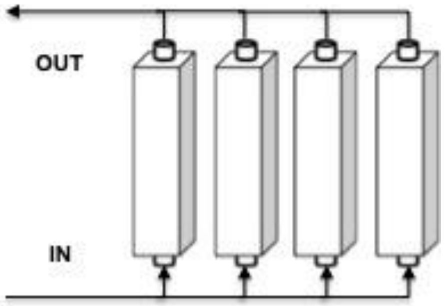
Typical Cell Technical Data

- Cell Dimension: 4.5 in x5 in x25 in
- Capacitance : 50kF
- Water Capacity: 1-3 lpm
- Operating Voltage: 1.6V (2V Max) DC
- Operating Pressure(psi) : 40psi
- Energy Consumed : 0.06-0.25(kWh/m3)

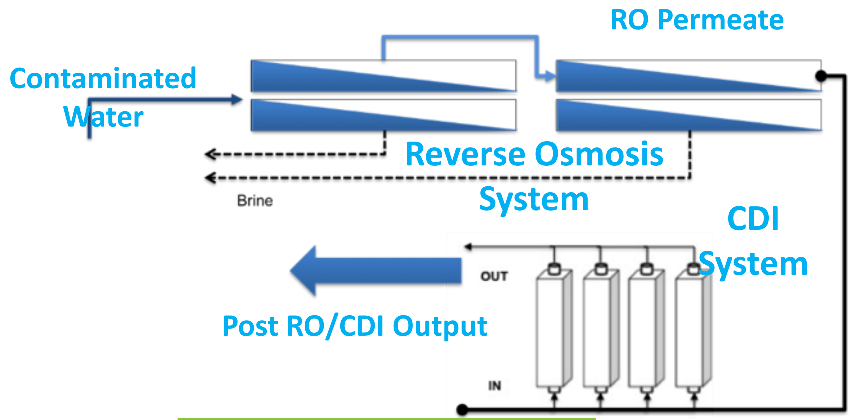
Scalable and Modular Systems



Modular design for linear scalability – CDI cell Arrays



STAND ALONE

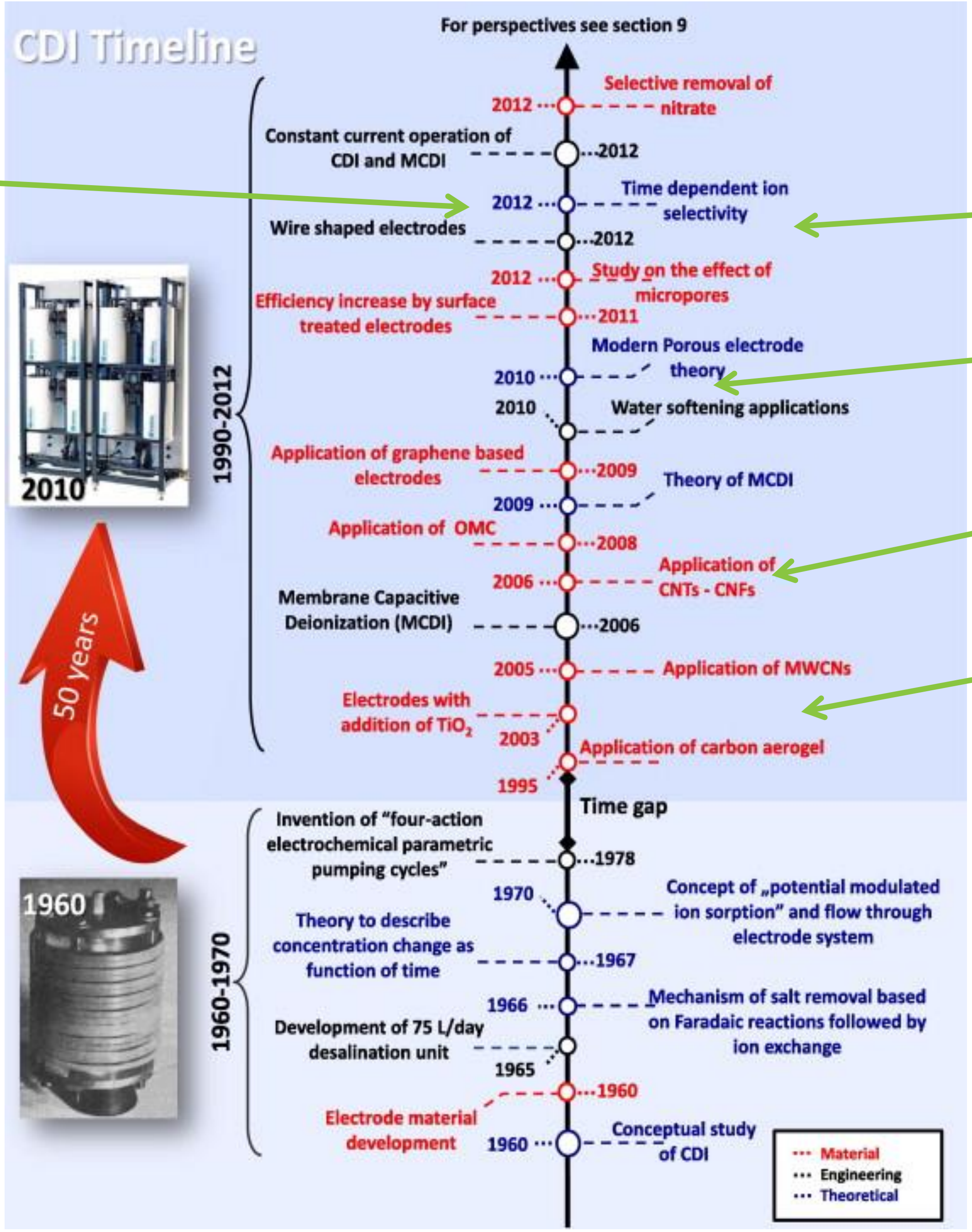


RO+CDI / Hybrid System

Technology Development History

- **Established Technology:**
  - Principles known since 1960’s as a way to remove ions, bacteria, and other toxins from water and other liquids. Already in use commercially as Electro De-ionization
- **Early Break-Through:**
  - Creation of high surface area aerogels in early 1990’s
  - Over $40 million invested by LLNL in Advanced Carbon Materials R&D and Capacitive Deionization (CDI) systems for use by US DOE and DOD
- **CDI 2.0:**
  - LLNL scientists developed metal oxide doped aerogels which can be used for enhancing ion-selectivity
  - Aquas Tech has exclusive license agreement for using these “advanced” materials for water treatment

Aquas partnered with Stanford



Aquas acquired 3rd generation material

Aquas acquired rights from LLNL

LLNL tested Industrial Scale System

LLNL started work carbon aerogel

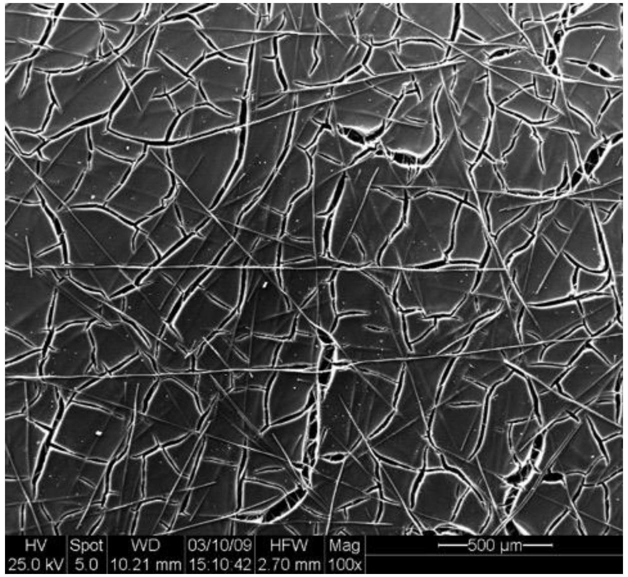
Stanford- Stanford University
LLNL- Lawrence Livermore National Laboratory

Advanced Carbon Materials

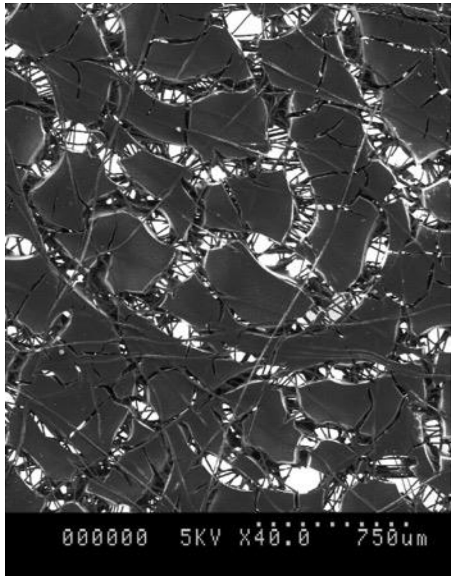
Activated Carbon	High Surface Area
	Can be made from commodity carbonaceous materials like coconut shells, sugars, etc.
	Cannot control porosity or tune the characteristics for functionalization and doping
	Commoditized materials with varying degree of efficiency, high quality AC are expensive to make
Carbon Aerogel	High Surface Area which can be controlled and tuned for specific applications
	Ideally suited for doping and functionalization
	Consistent quality, easy to control and reproduce
	Inexpensive to scale up, widely available at present not commoditized
Carbon Nanotube	Highly engineered nano materials with tunable surface area
	Excellent electrical, mechanical, and electrical characteristics
	Good for water and energy applications
	Expensive and difficult to mass produce

Carbon Aerogel Electrode Specs

Sample	BET Surface Area (m^2/g)	Total Pore Vol (cm^3/g)	Material Density (grams/cm^3)	Avg Pore Size (nm)	Specific Capacitance (F/gram)	Sorbent Type
Type 1	451	0.31	0.8214	4	36.91	Meso/Microporous
Type 2	418	0.75	0.4556	10	26.36	Mesoporous
Type 3	497	0.61	0.4437	8	24.67	Mesoporous
Courtesy of Theodore F. Bauman, LLNL						



- Tunable Porosity
- Tunable Density
- Optionally, dope with Metals Oxides, Graphene, CNTs, etc.



Materials Performance

Material	Specific Surface Area (m^2/gram)	Current Scale of Cell/ Technology tested	Ion Removal Capacity (mg of Cl^- /g of Carbon)	Price Performance ($/$m^3$ processed)*
Activated Carbon	2000 – 3000	Lab Scale	4	1,000
Activated Carbon Aerogel	3000	Lab Scale	10	10,000
Carbon Aerogel (Gen 1) [Aquas]	600	Lab Scale	3	2,500
	400– 600	Full Scale	2.7-3.5	1,000
Functionalized Carbon Aerogel [Aquas 2015+]	**1100**	**Prototype Scale**	**9**	**300**
PACMM	800	Lab Scale	4-5	10,000

CDI is more than Desalination. It can remove most of the impurities.

Radioactive elements are highlighted in red

atomic # → | atomic symbol → | English element name → | 29 Cu copper 63.55 +2,1 | ← ions commonly formed | ← atomic mass (rounded)

Removable | Potentially Removable | Not removable

Period		1 I A	2 II A		3 III B	4 IV B	5 V B	6 VI B	7 VII B	8 VIII B	9 VIII B	10 VIII B	11 I B	12 II B		13 III A	14 IV A	15 V A	16 VI A	17 VII A	18 VIII A
1	1s	1 H hydrogen 1.008 ±1																			2 He helium 4.003
2	2s	3 Li lithium 6.941 +1	4 Be beryllium 9.012 +2												2p	5 B boron 10.81 +3	6 C carbon 12.01 −4	7 N nitrogen 14.01 −3	8 O oxygen 16.00 −2	9 F fluorine 19.00 −1	10 Ne neon 20.18
3	3s	11 Na sodium 22.99 +1	12 Mg magnesium 24.31 +2												3p	13 Al aluminum 26.98 +3	14 Si silicon 28.09 −4	15 P phosphorus 30.97 −3	16 S sulfur 32.07 −2	17 Cl chlorine 35.45 −1	18 Ar argon 39.95
4	4s	19 K potassium 39.10 +1	20 Ca calcium 40.08 +2	3d	21 Sc scandium 44.96 +3	22 Ti titanium 47.87 +4,3,2	23 V vanadium 50.94 +5,2,3,4	24 Cr chromium 52.00 +3,2,6	25 Mn manganese 54.94 +2,3,4,6,7	26 Fe iron 55.85 +3,2	27 Co cobalt 58.93 +2,3	28 Ni nickel 58.69 +2,3	29 Cu copper 63.55 +2,1	30 Zn zinc 65.41 +2	4p	31 Ga gallium 69.72 +3	32 Ge germanium 72.64 +4,2	33 As arsenic 74.92 −3	34 Se selenium 78.96 −2	35 Br bromine 79.90 −1	36 Kr krypton 83.80
5	5s	37 Rb rubidium 85.47 +1	38 Sr strontium 87.62 +2	4d	39 Y yttrium 88.91 +3	40 Zr zirconium 91.22 +4	41 Nb niobium 92.91 +5,3	42 Mo molybdenum 95.94 +6,3,5	43 Tc technetium 98 +7,4,6	44 Ru ruthenium 101.1 +4,3,6,8	45 Rh rhodium 102.9 +3,4,6	46 Pd palladium 106.4 +2,4	47 Ag silver 107.9 +1	48 Cd cadmium 112.4 +2	5p	49 In indium 114.8 +3	50 Sn tin 118.7 +4,2	51 Sb antimony 121.8 +3,5	52 Te tellurium 127.6 −2	53 I iodine 126.9 −1	54 Xe xenon 131.3
6	6s	55 Cs cesium 132.9 +1	56 Ba barium 137.3 +2	† 5d	71 Lu lutetium 175.0 +3	72 Hf hafnium 178.5 +4	73 Ta tantalum 180.9 +5	74 W tungsten 183.8 +6,4	75 Re rhenium 186.2 +7,4,6	76 Os osmium 190.2 +4,6,8	77 Ir iridium 192.2 +4,3,6	78 Pt platinum 195.1 +4,2	79 Au gold 197.0 +3,1	80 Hg mercury 200.6 +2,1	6p	81 Tl thallium 204.4 +1,3	82 Pb lead 207.2 +2,4	83 Bi bismuth 209.0 +3,5	84 Po polonium 209 +4,2	85 At astatine 210	86 Rn radon 222
7	7s	87 Fr francium 223 +1	88 Ra radium 226 +2	‡ 6d	## Lr lawrencium 262 +3	## Rf rutherfordium 261 +4	## Db dubnium 262	## Sg seaborgium 266	## Bh bohrium 264	## Hs hassium 277	## Mt meitnerium 268	## Ds darmstadtium 281	## Rg roentgentium 272	## Cn copernicum 285	7p	## Uut ununtrium 284	## Fl flerovium 289	## Uup ununpentium 288	## Lv livermorium 292	## Uus ununseptium 293	## ununoctium 294

lanthanides (rare earth metals)	† 4f	57 La lanthanum 138.9 +3	58 Ce cerium 140.1 +3,4	59 Pr praseodymium 140.9 +3,4	60 Nd neodymium 144.2 +3	61 Pm promethium 145 +3	62 Sm samarium 150.4 +3,2	63 Eu europium 152.0 +3,2	64 Gd gadolinium 157.3 +3	65 Tb terbium 158.9 +3,4	66 Dy dysprosium 162.5 +3	67 Ho holmium 164.9 +3	68 Er erbium 167.3 +3	69 Tm thulium 168.9 +3,2	70 Yb ytterbium 173.0 +3,2
actinides	‡ 5f	89 Ac actinium 227 +3	90 Th thorium 232.0 +4	91 Pa protactinium 231.0 +5,4	92 U uranium 238.0 +6,3,4,5	93 Np neptunium 237 +5,3,4,6	94 Pu plutonium 239 +4,3,5,6	95 Am americium 243 +3,4,5,6	96 Cm curium 247 +3	97 Bk berkelium 247 +3,4	98 Cf californium 251 +3	99 Es einsteinium 252 +3	100 Fm fermium 257 +3	101 Md mendelevium 258 +3,2	102 No nobelium 259 +2,3

Technology Comparison

APPENDIX

After extensive industry and research community interaction DOE has come up with potential technology advances

Overview of technical metrics and potential for technological advances for selected desalination technologies. (Source: Department of Energy, 2015)

Technology	Current Operating Temperature Range	Current Power Consumption	Current State of the Art Costs	Potential 'Game-Changing' Technology Advances
Reverse Osmosis (RO)	ambient	~3 kWh/m^3	$2.00/$m^3$	• Long-lifetime membranes (high-durability, low-fouling) • Integration with renewable primary energy sources
Multi-effect Distillation / Multi-stage Flash Distillation (MED/MSF)	70 – 110 °C	• 15 – 20 kWh_t/m^3 • 1 – 2kWh_e additional	$2 – $3/$m^3$	• Low-cost, high-flux heat exchanger materials • Integration with waste/renewable sources of heat
Forward Osmosis (FO)	• Thermal FO: 80 – 100 °C • Non-thermally-driven FO is also being explored	• 0.5 – 1.5 kWh_e/m^3 • Thermal FO: additional 10 – 16 kWh_t/m^3	No commer-cial data	• New membranes designed for FO (currently using RO membranes) • Materials discovery for draw solutes
Membrane Distillation (MD)	40 – 100 °C	• 1 – 30 kWh_t/m^3 • Current wide range due to no large-scale projects	No current commercial data	• Thermally insulating membranes that preserve selectivity • Low-cost, high-flux heat exchanger materials
Dewvapora-tion	120 °C	6 kWh_e/m^3 – 407 kWh_t/m^3	$80/$m^3$	• Low-cost, high-flux heat exchanger materials • Integration with waste/renewable sources of heat • Optimized system configuration
Capacitive Deionization	ambient	0.11kWh_e/m^3	No current commercial data	• Hybridization with other desal technologies • Novel electrode materials

$0.50-$1.0/m^3

Technology Comparison

Cost per gallon	Capacitive Deionization	Reverse Osmosis	Multi-Stage Flash / Multi-Effect Distillation	Electro-dialysis
Capital Expenditure	Medium	High	Medium	Medium
Operation & Maintenance	Low	Medium	Medium	Medium
Pre/post-treatment requirements	Low	High	Medium	High
Energy Usage	Low	Medium	High	Medium
Water Recovery	High	Medium	High	Medium

Advantages of CDI system

- No use of chemicals & low maintanance
- High Recovery/Low discharge
- Low Energy Consumption
- Removal of multiple contaminants
- Long life of cells (10 years)
- Scalable & Modular: from home use to utility scale.

Applications of CDI

- Ideal for Brackish water desalination (ground water)
- Hybrid system for sea water desalination
- Removal of Boron from Desalinated water
- Removal of Fluoride, Arsenic, Nitrate, Phosphate, Chromium, Lead, Perchlorates, Cadmium and more
- Ultrapure water for Industrial, laboratory use
- Use in Heavy Metal Detection System

Is CDI ready for the market?

Current state if CDI Technology

- Few companies introduced small size systems
- Biggest CDI plant running in China for water recycling
- Lot of traction from Government Agencies from USA, Europe, Australia and China
- Novel material is going to make a difference
- Technology is ready for marker roll out for small and mid size systems
- It will need Industry support to get in to mainstream

Aquas CDI System

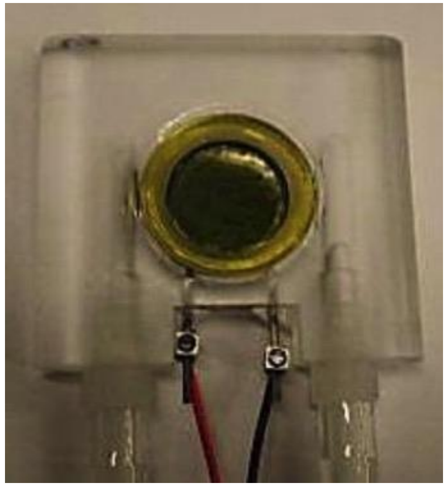
2016 Full scale product at customer test site in CA

2015 Full scale product at customer test site in Spain

CDI System using Solar Power

CDI also used in heavy metal testing

Carbon Nanomaterial Pre-concentrator

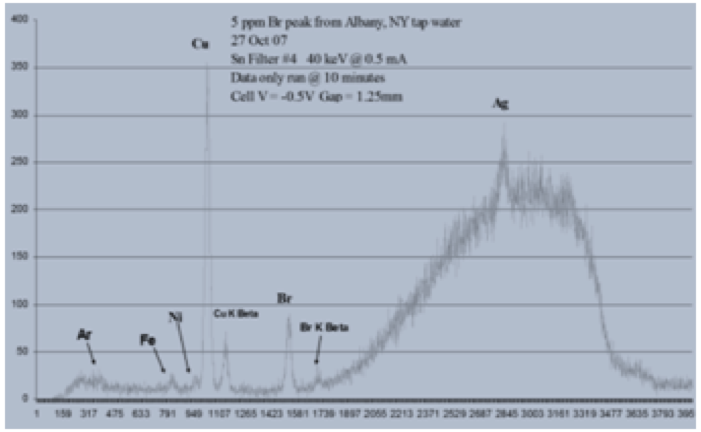


Detector & Analyzer

UV-VIS/ NEAR IR
XRF Spectroscopy
TDS, pH, DO/COD etc.

1. Integrated Sensors Array
2. PLC Controlled
3. Low Consumables
4. Remotely configurable LOD and Sensitivity

Onboard, analytics, cloud Integration



Pre-concentrator → Detector & Analyzer → Data processor → Transmitter

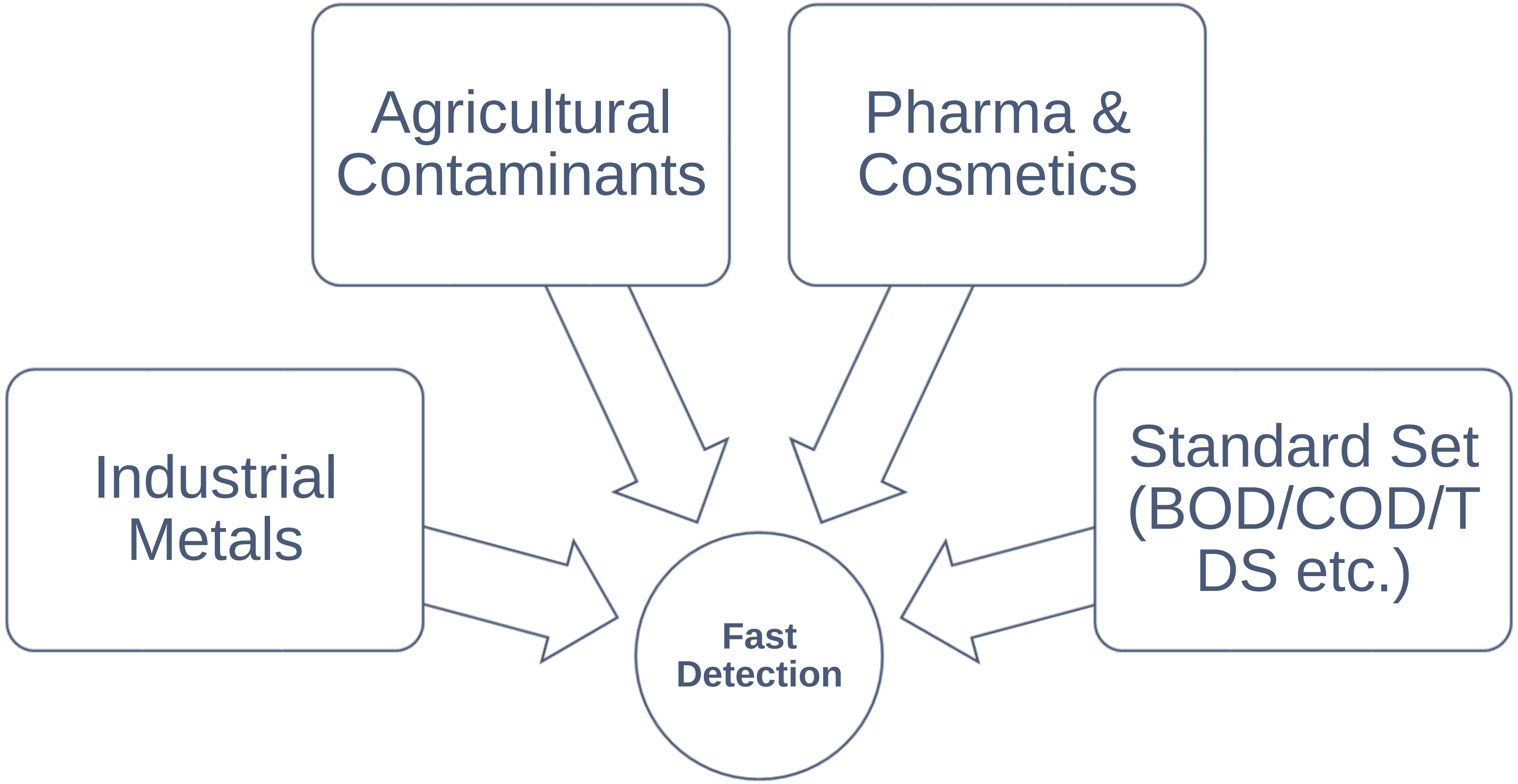
- **Pre-concentrator is the KEY innovation that enables this 24x7, on-site, parts per-billion (ppb) level measurements**
- **Self-calibrating system**
- **LOD and LOQ is increased many folds due to unique pre-concentrating and proprietary correlation algorithms**

Portable Smart Water Monitoring Solution for Ganga River

World's first system that can do on-site measurement of heavy metals (like Lead, Arsenic, etc.), drugs (antibiotics, hormones, etc) without expensive labs, in **Real-Time** , with **High Sensitivity**, **Integrated GIS** updates for autonomous monitoring Ganga Water Quality

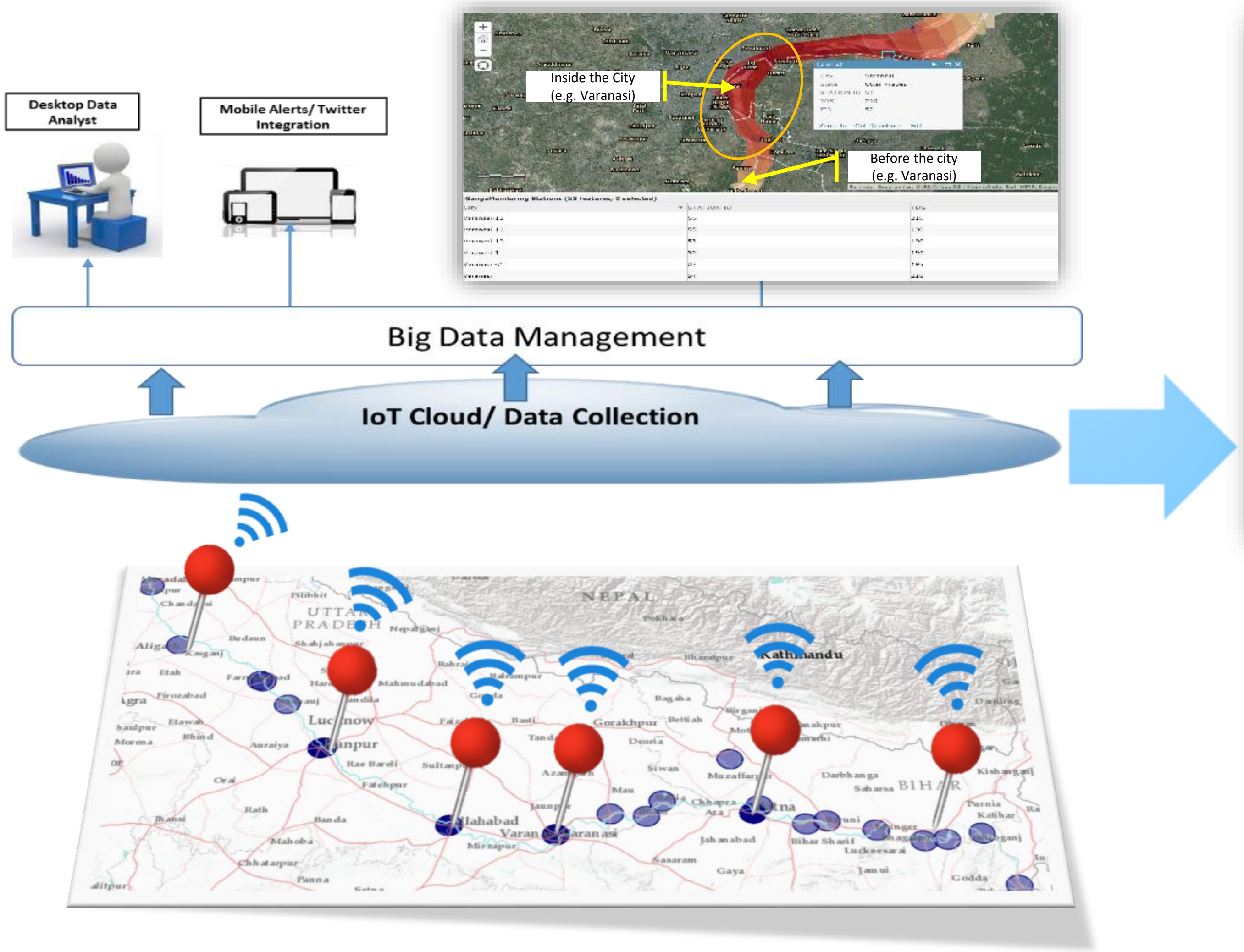
1. Product deployed and tested by government/ military, and water departments in Wisconsin and California States
2. Primarily targeted for military and remote use to quickly analyze water samples
3. Take up to 100 measurements per day as opposed to 1 per fortnight!

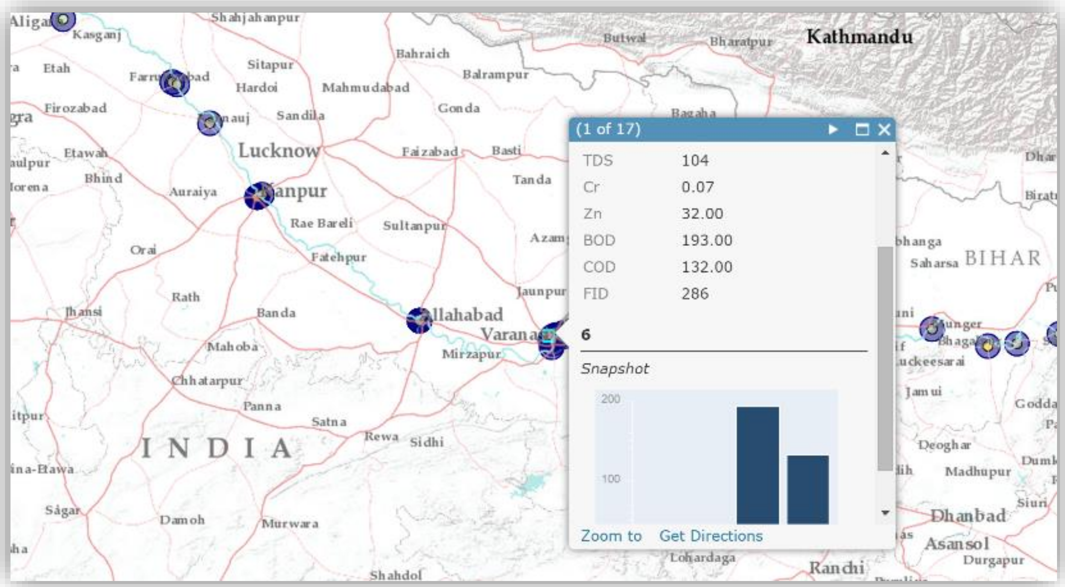
Sensor Integration System can measure a wide range of pollutants



End to End Solution for Automated System Operations

Live GIS, Alerts, Reporting, Big Data, and Crowd-sourcing

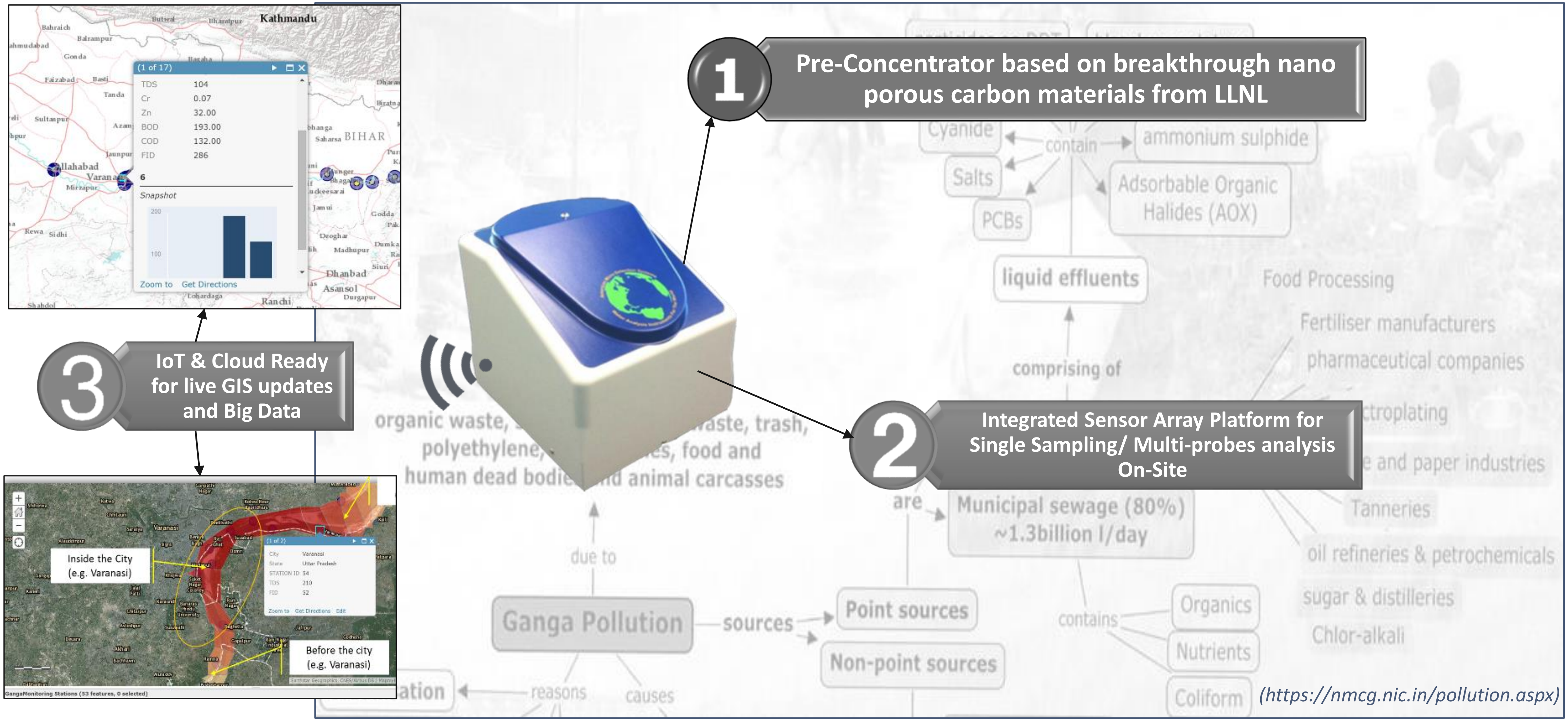




GIS Integration

- Live Updates
- Mobile App
- Spatial & Time Lapse Analysis
- Extrapolation and Triangulation

Water Quality Monitoring



(https://nmcg.nic.in/pollution.aspx)

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AQUAS TECHNOLOGIES

Aquas' Capacitive Deionization (CDI) System

Ideal solution for non-traditional water sources

- Ideally suited for brackish water treatment
- TRL 7+ readiness: Already tested in field
- Programmable, for removal of multiple contaminants*
- 90%+ water recovery & 90% lower energy consumption
- Ultra low waste/ brine discharge
- Solar Power integration WITHOUT adding significant cost

*Contaminants Removed:

- Nitrate
- Phosphates
- Chromium
- Arsenic
- Fluoride
- Lead
- Perchlorates
- Cadmium
- and more

Current State of CDI technology

Traditional CDI

- Usually uses high surface area Activated Carbon, Porous or Mesoporous Carbon Aerogel
- Most common designs use stack of electrodes making channels for water to flow between
- Typically consists of an Ion Exchange membrane to service as a charge barrier
- Contains a spacer element

Limitations of Traditional Design

- No enhanced ion-selective targeting – removes dominant bulk ions more than trace contaminants (such as Boron etc.)
- Primary mechanism for charge separation is double-layer formation
- Low Capacitance, Activated Carbon is not very conductive
- Effective efficiency (mg of ion removed per sq.ft. of cell area) of removal of trace contaminants is much lower
- Ion Exchange membrane is expensive

Aquas CDI Solution addresses current limitations

- Functionalized Carbon Aerogel: Targets specific ions. *5x to 10 x increase in effective removal efficiency of "trace contaminant of interest"*
- Metal Doped Carbon Aerogel exhibits additional pseudo-capacitance. *Nearly 10x increase in capacitance of the CDI cell*
- No Ion Exchange membrane is required. *Cost reduction by elimination of expensive component*
- Flexible design options to meet high through-put requirements. *Allows entry into mining, Oil & Gas (SAGD) market and more*
  - Flow across design
  - Amorphous and Fluidized electrodes

What can be monitored?

Standard Set:

- pH, TDS, Turbidity, etc.
- Oxygen (DO, COD, BOD) (20 parameters)
- Perchlorates, Nitrogen, Phosphates, etc.

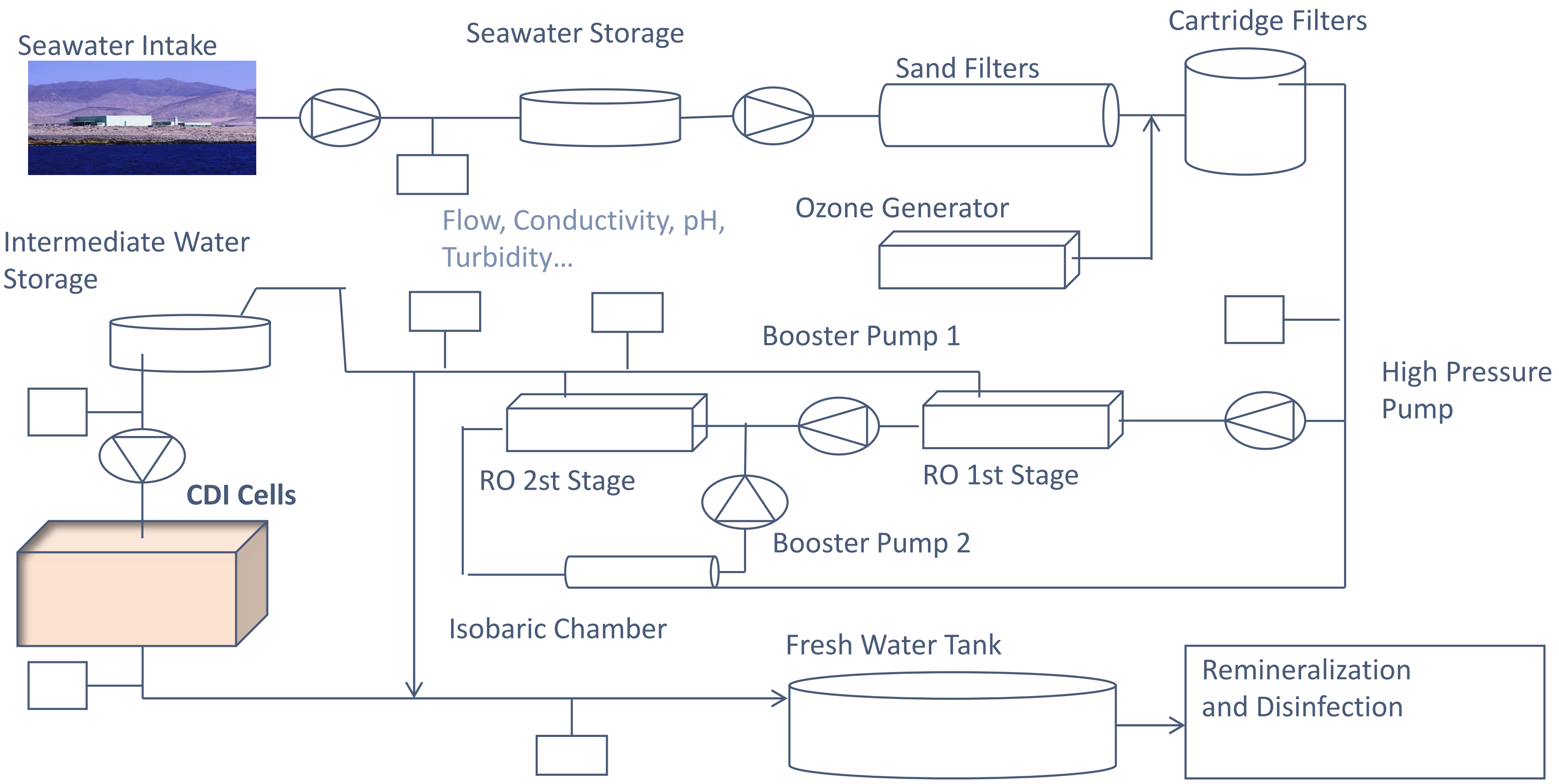
Heavy Metals and Industrial Pollution:

- Chromium, Arsenic, Lead, and other heavy metals (50+)
- Radio Active contaminants
- Toxins, Pharmaceutical, drugs, antibiotics, etc.

Endocrine Disruptors, sources of estrogen, testosterone etc.

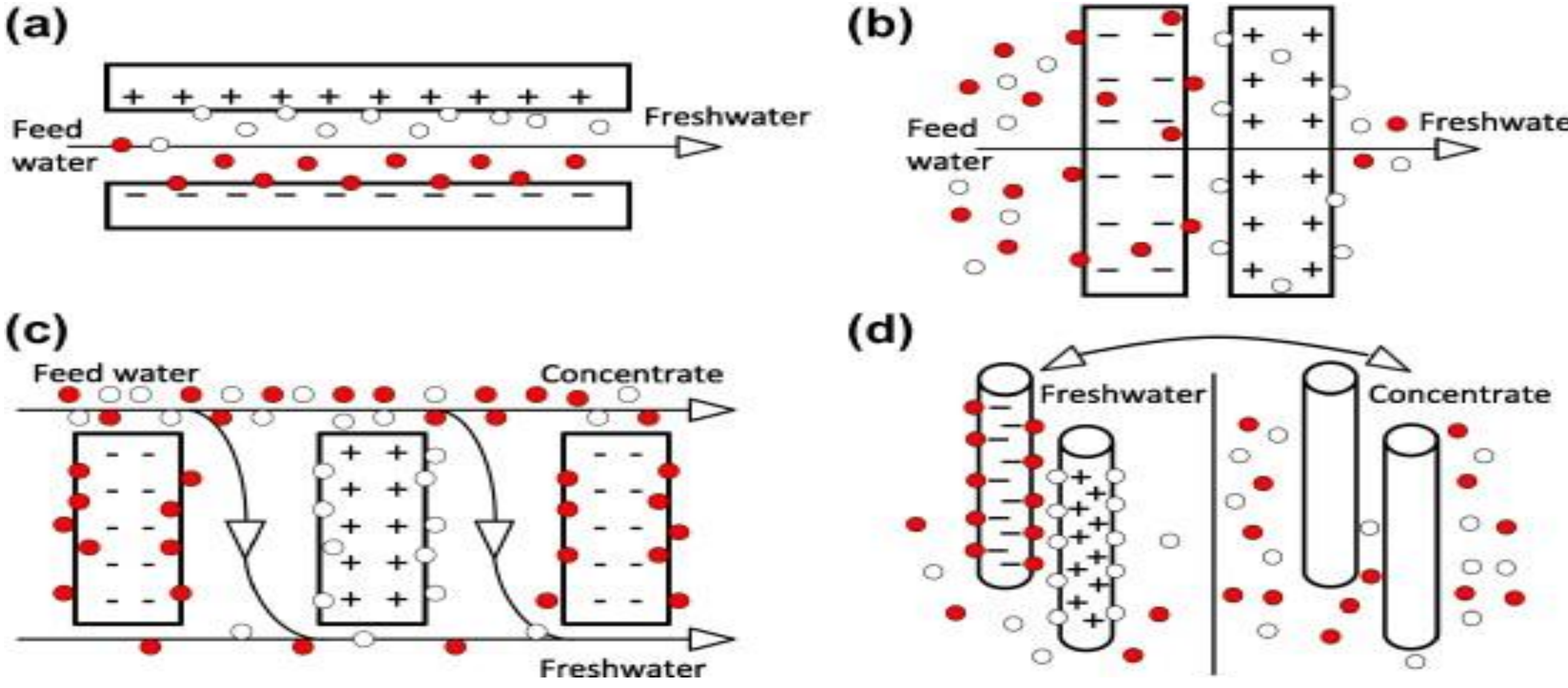
- Typically found in cosmetics, and personal effects
- Usually flushed into toilets and drains, waste water treatment and recycling doesn’t eliminate it completely

CDI-4-EEDSAL ES-USA project: the first hybrid CDI System for ENERGY EFFICIENT DESALINATION



CDI system geometries

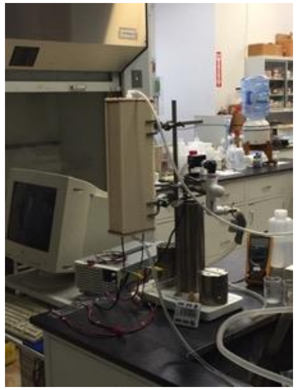
. (a) Flow-by mode, (b) flow-through mode, (c) electrostatic ion pumping, and d) desalination with wires.



http://dx.doi.org/10.1016/j.pmatsci.2013.03.005

Timeline of Aquas CDI Cell

Product Development and Demonstration



<u>2013</u>
Stanford University test cell

<u>2014</u> Cell assembly and testing facility

<u>2015</u> Full scale product at customer test site in Spain

Relative Ion Removal Capacity of Carbon Aerogel

Bromide (Br)	mg/L	0.52	0.35	0.67	2.8
Chloride (Cl)	mg/L	169	149	0.88	1
Fluoride (F)	mg/L	0.07	< 0.05		
Nitrate (NO_3)	mg/L	18.64	6.47	0.35	5.5
Sulfate (SO_4)	mg/L	135	113	0.84	1.4
Sodium (Na)	mg/L	103	102	0.99	0.08
Potassium (K)	mg/L	2.5	2.7	1.08	
Arsenic (As)	µg/L	2.0	1.2	0.60	3.4
Barium (Ba)	µg/L	120	43	0.36	5.4
Chromium (Total Cr)	µg/L	9.8	< 1.0	< 0.10	> 7.6
Cobalt (Co)	µg/L	106	5.2	0.05	8.0
Nickel (Ni)	µg/L	3.3	2.8	0.85	1.3
Selenium (Se)	µg/L	9.5	5.2	0.55	3.8
Strontium (Sr)	µg/L	960	620	0.65	3.0
Vanadium (V)	µg/L	5.2	< 2.0	< 0.38	> 5.2
Uranium (U)	µg/L	5.1	< 1.0	< 0.20	> 6.8

- CDI is highly selective to ionic impurities (Strontium confirmed, cesium test planned), and suitable for removing hazardous ions out of potable water

- : treated to untreated molar fraction for species
- Ions with are removed preferentially (marked with yellow in table)
- : reduction in concentration of species divided by reduction in concentration of chloride after treatment

- For example, while chloride ion concentration decreased from 169 to 149 mg/L (~12% reduction), cobalt changed from 106 to 5.2 µg/L (95% reduction). It means CDI is 8 times more selective to cobalt comparing to chloride, or
- Note that chloride itself is removed with 5-10x more selectivity comparing to sodium

Data from: Lawrence Livermore National Laboratory (LLNL), 2013 on New Carbon Aerogel materials (unfunctionalized)

Typical process for making Carbon Aerogels and Foams

- Mix water-based reagents
- Curing / Polymerization at low temperature
- Drying / Supercritical Drying to remove water
- Pyrolysis to carbon – burn off at high temperature under inert atmosphere