PUBLIC SUBMISSION

Received: May 10, 2025
Tracking No. mai-hwe3-np8v
Comments Due: May 28, 2025 **Submission Type:** Web

Docket: NSF-2025-OGC-0001
NITRD_FRDOC_0001

Comment On: NSF-2025-OGC-0001-0001
Request for Information: Development of a 2025 National Artificial Intelligence Research and Development Strategic Plan

Document: NSF-2025-OGC-0001-DRAFT-0071
Comment on FR Doc # 2025-07332

Submitter Information

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General Comment

AI dataservers use a lot of water. This is even more important for data centers located in desert areas where the dry climate is kinder to the electronics. See https://www.forbes.com/sites/cindygordon/2024/02/25/ai-is-accelerating-the-loss-of-our-scarcest-natural-resource-water/
This was usage is due to the need to remove heat in cooling towers. A need exists to remove minerals from cooling tower water in order to increase so called cycles of concentration in order to decrease cooling tower and therefore data center water usage. Capacitive deionization has been used to make cooling towers more water efficient. At present, this technology uses expensive parts in the form of ion exchange membranes, and has a relativelt high pressure drop that causes fouling. A new form of capaciive deionzation does not require this membrane. That is called third genration capacitive dedionization, or 3GCDI. see attachment to compare costs with the only other applicable technologies of reverse osmosis (RO) and ion exchange (IX). RO by itself wastes so muc water as not to be applilcable in this application. With IX it generates salt brine waste. Therefore, new methods applicable to cooling tower water use reduction are needed.

Attachments

Economic Introduction to 3GCDI

Marc Andelman

Mespilus Inc.

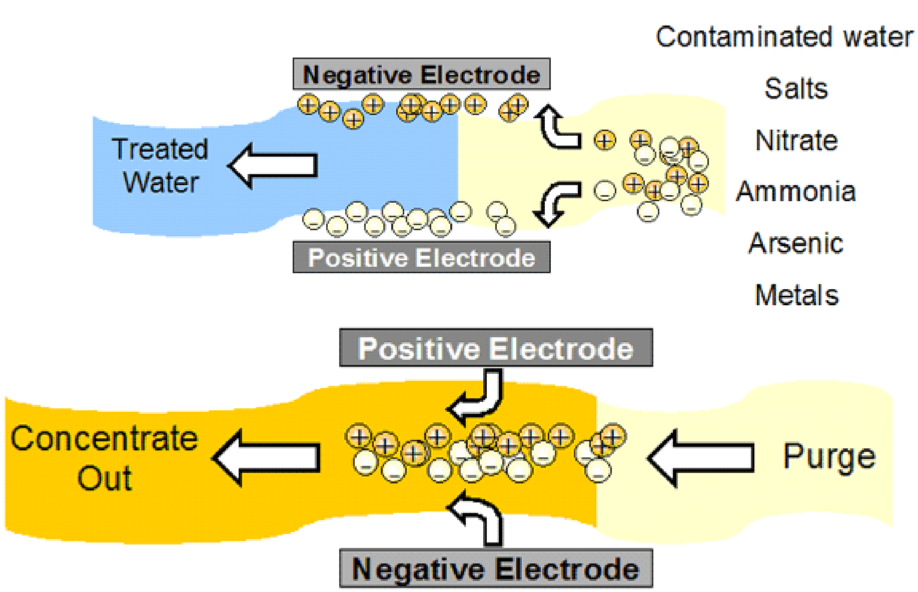
Third Generation Capacitive Deionization (3GCDI)

Who?

Marc Andelman founded the modern field of CDI with inventions from the early 90's, leading to the membrane version currently on the market, and now a 3rd generation membrane-less CDI[i].

What?

3GCDI is the third-generation improvement of the basic capacitive deionization (CDI) water filter idea. In CDI water is purified when dissolved contaminants attract and adsorb onto opposing high surface area carbon electrodes as electronic charges. These contaminants are reversibly removed from the filter in a small quantity of concentrated water upon electronically reversing the voltage. This regenerates the filter allowing it to be used again for successive purification cycles. Therefore, water is purified without chemicals or disposable filters.



CDI applies to total dissolved solids (t.d.s) and some organic ions. However, CDI is a deceptively simple technology and does not work efficiently with only carbon electrodes. That is because the fluid concentrate stored in the electrode pores cannot efficiently be rinsed out and competes with the purification of fluid in the flow spacer. This problem was first recognized and solved by Marc Andelman's invention of membrane capacitive deionization (MCDI), originally called "charge barrier flow through capacitor[ii]. This achieves efficiency by hiding pore solution ions under two kinds of ion exchange membranes.

3rd generation capacitive deionization or 3GCDI is the third iteration of Marc Andelman's capacitive deionization inventions. 3GCDI works without the ion exchange membranes of MCDI. These are the most expensive and troublesome parts of the CDI cell. 3GCDI works by means of derivatized forms of activated carbon (AC). 3GCDI achieves the ability to engineer to low cost because AC is one of the highest volume commodities, already used in water. Other inexpensive parts include inexpensive chemicals used to modify the carbon. For example, electrodes may be modified simply by soaking in surfactants used in food and cosmetics. Other parts include a valve, power supply, controls and electronics. 3GCDI offers robust operation at high water recovery, gravity fed pressure drop, and minimal to no pretreatment needs.

Why the need for better water purification technology for t.d.s.?

Assertion 1. Total dissolved solids (t.d.s) are the rate limiting contaminants in trains of water purification for water recycle, reuse, and remediation. An effective t.d.s remediation method could form the core of improved and broader spectrum water treatments.

Assertion 2. Extremely few t.d.s applicable water purification technologies exist in wide use. Existing widely used technologies to remediate t,d,s in brackish or recycled water are complex and costly[iii]. Complex brackish water purification systems require chemicals, supplies, and personnel to operate and maintain.[iv] These become more costly when employed at small scale (Fig1).

Assertion 3. The way forward to lower costs is a technology that is appliance like in ease and cost of operation. This means a water purification machine with minimal inputs of energy, maintenance, disposables, and chemicals, and with low wastewater. These characteristics will enable scale to smaller as well as larger sizes for distributed use on site.

Assertion 4. Any technology which could reliably recycle or remediate water for operating costs substantially less than the costs of water and sewer would have the benefit of an extremely rapid return on investment, almost independent of capital cost.

Assertion 5. 3rd Generation Capacitive Deionization (3GCDI) is to the best available knowledge the most reasonable approach to the above[v] including low cost of goods sold and low cost of water.[vi]

Assertion 6. Water technology is resistant to change, partly due to reliance upon validated existing technology. Governance, regulatory, and existing contractual issues may contribute to inertia against change. 3GCDI may in this case be employed as a retrofit to make this existing technology work better and more reliably. Because 3GCDI both softens and deionizes water, merely replacing the salt using water softener pretreatment step with 3GCDI will both soften and deionize water without added salt, chemicals, or disposables. This will take the load off of existing downstream components. This will replace the need for much of the ion exchange and RO. That will make the water purification train more reliable, efficient, and smaller.

Assertion 7. Inventors have a role to play. Change comes from the periphery, not the center[vii].

Figure 1 shows how existing technologies become increasingly more expensive at smaller scale.

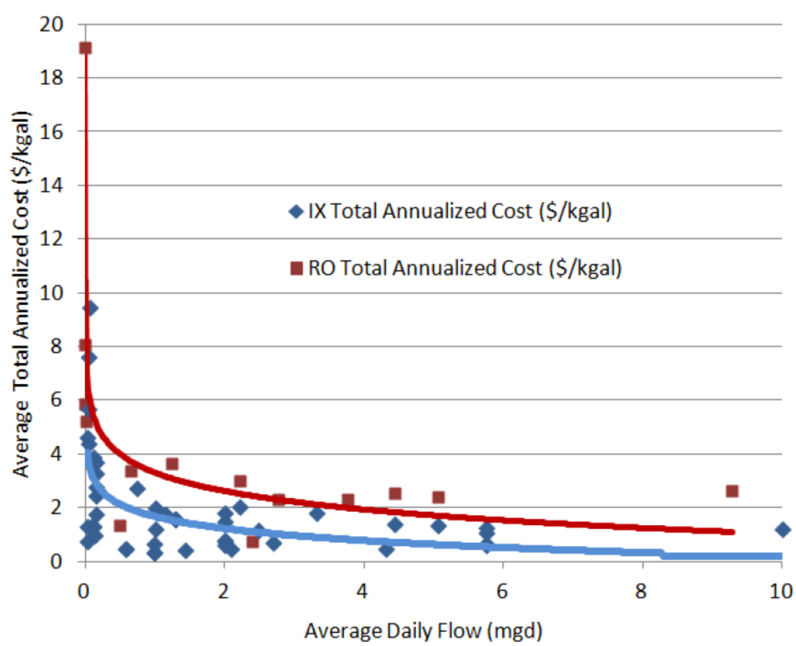


Figure 1. Cost of Ion Exchange (IX) and Reverse Osmosis (RO) by flow rate[viii].

Figure 2 compares estimated cost of 3GCDI water with average all-in cost of water across water purification technologies.

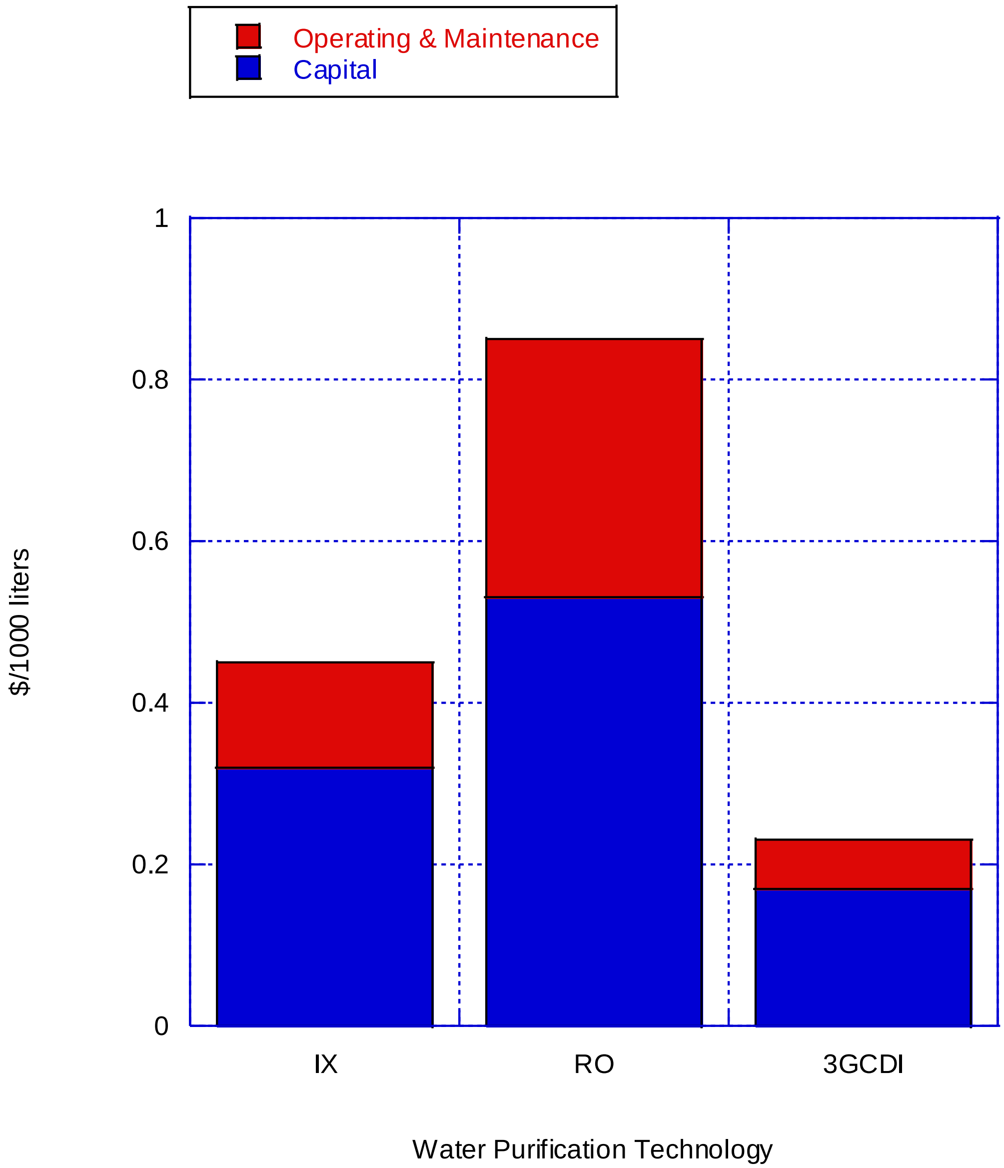


Figure 2. Cost of Water Versus Water Purification Method

Figure 3 shows that actual costs of IX and RO vary a lot and may often be much higher[ix].

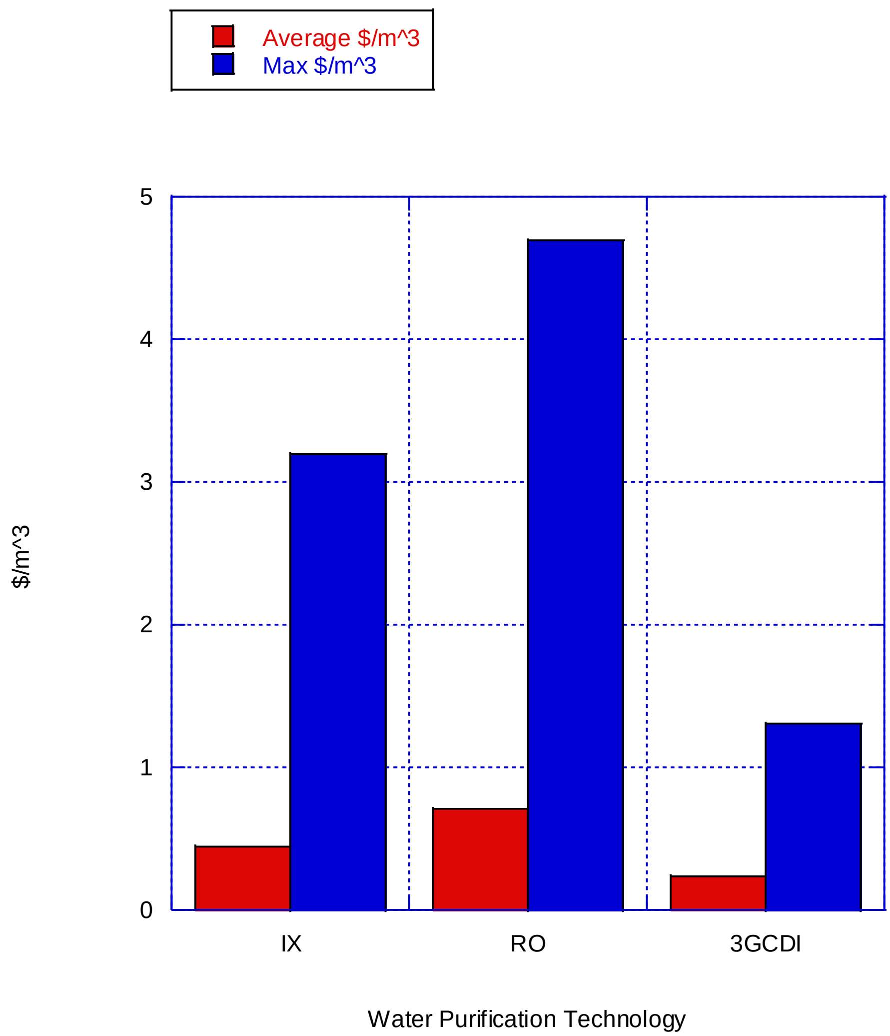


Figure 3. Variation in costs of water produced by water purification method.

Discussion.

This analysis is an apples to apples comparison of prices of the two major technologies applied to total dissolved solids, and one new one, 3rd generation capacitive deionization (3GCDI). 3GCDI costs are predicted to the best of current knowledge[x]. IX and RO costs are exemplified by nitrate contamination from the US Davis report[xi].

Other important costs of water not included are the cost of piping to distribute the water, and the cost of wastewater disposal. Waste disposal cost is related to waste volume. Ion exchange adds salts and chemicals to the wastewater, making it worse in quality and adding disposal cost.

Figure 1 shows that ion exchange and reverse osmosis do not scale down very well. This is likely because these technologies require experienced staff to operate, chemical and disposable supplies. These logistics cause increased costs when operating on a smaller scale and when buying and transporting smaller amounts of supply materials. 3GCDI's chief operating cost is electricity and is expected to operate automatically with minimal supervision and maintenance. 3CDGI does not have costs caused by using, storing, handling, transporting, and disposing of added chemicals or water softener salt. Therefore, 3GCDI costs are expected to be less sensitive to system size. The predecessor membrane CDI technology is well documented to require less energy than RO for up to 3000 ppm[xii]. It is expected 3GCDI will be at least similar. 3GCDI can have high water recovery under many conditions, which means lower wastewater costs.

Much of the real cost of water provided from a central purification grid is in kilometers of water distribution pipes. Smaller, distributed water purification systems will save this cost. Distributed systems that can operate autonomously onsite may be the only economic way to supply upgraded water to small communities and rural customers, such as farms. An onsite 3GCDI system could also take advantage of solar power's low operating cost. Solar power used in this way would need less wiring to distribute electricity. Purification of water itself would also offer a load leveling mechanism for solar.

Current State of Development of 3GCDI. 3CGCI has been granted European patent EP2689438B1 in November 2022, granted US, CN, AU, pending IN. A technical readiness level 6, three bench pilots sold. Recent subject of NSF seed fund grant[xiii].

References

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[i] A selection of Marc's more important CDI inventions is summarized below.

US10294131B2 3GCDI, membrane-less CDI, also known as inverted or i-CDI.
US 6778378 B1 Self-sealing cell design that does not require gaskets.
US6709560B2 The original membrane capacitive deionization (MCDI). This is the first mention of the importance of charge efficiency for a useful device.
US6628505 B1 A true series flow cell with floating electrodes
US5620597 A First description of non-fouling, open flow path spacers in CDI
US5415768 A Many first described cell geometries with flow by electrodes.
US5360540 A Early CDI with first flow-through electrodes
US5196115 A The first modern CDI patent or publication after early attempts died out by the 70s. This contains the first modern design concepts universally employed since. This describes a flow cell with multiple thin, high capacitance, low resistance electrode layers, use of high surface area activated carbon, together with facing, thin low resistance current collectors. Priority date 9-16-1991.

[ii] Charge Barrier Flow Through Capacitor US6709560B2 priority date 10/26/2001
[iii] Webinar by Evoqua on ultrapure. Costs disclosed in Q&A https://www.youtube.com/watch?v=6ppeXSEvebA
[iv] See this excellent US Davis Report https://groundwaternitrate.ucdavis.edu/files/139107.pdf Technical Report 6 Addressing Nitrate in California's Drinking Water With a Focus on Tulare Lake Basin and Salinas Valley Groundwater Report for the State Water Resources Control Board Report to the Legislature Prepared by: Vivian B. Jensen and Jeannie L. Darby of UC Davis, Chad Seidel and Craig Gorman of Jacobs Engineering Group, Inc.

This in part took information from this extensive EPA study required to estimate costs for regulatory purposes. https://www.epa.gov/sdwa/drinking-water-treatment-technology-unit-cost-models

[v] Mespilus information and Pilot studies from third parties
[vi] Mespilus cost of goods sold spreadsheet.
[vii] The March of Folly by Barbara W. Tuchman, March 19, 1984, by Knopf in New York.
[viii] Figure 35 from UC Davis report here https://groundwaternitrate.ucdavis.edu/files/139107.pdf
[ix] Table 24 UC Davis Report
[x] 3CGI is a TRL-6. Three bench pilots sold to third parties. Cost information is from a Mespilus cost of goods sold spreadsheet. This has assumptions that may be varied on materials costs, flow rates, feed concentrations ,etc.. It is available upon request.
[xi] Data on IX and RO from figure 31 of https://groundwaternitrate.ucdavis.edu/files/139107.pdf.
[xii] See figure 7 of R. Zhao, S. Porada, P.M. Biesheuvel, A. van der Wal, Energy consumption in membrane capacitive deionization for different water recoveries and

flow rates, and comparison with reverse osmosis, Desalination, Volume 330,2013, Pages 35-41, https://doi.org/10.1016/j.desal.2013.08.017.

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https://www.nsf.gov/awardsearch/showAward?AWD_ID=2222557&HistoricalAwards=false