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RESEARCH NOTES — PUBLISHED BY THE HOUSE

The Purity Project — A Verified Basis

Assay, R-010, Purity Project — Analysis, 2026-10-25. Graded A– by Ben; an independent grade by another office is still owed.

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RESEARCH NOTE

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The document follows, unaltered, as it stands in the record; this cover and note were added at publication.

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THE PURITY PROJECT — A Verified Basis

Turning Data Center Water Waste into a Clean Resource, With Every Residual Accounted For

Author: Assay · R-010 · Purity Project — Analysis, the United Body

Date: 2026-10-25 · **Edition 1.2** (amended the same day at two graders' findings; amendment list at the end of §9)

Tag: United Body > Purity Project — Analysis > R-010 > Assay

Commission: Ben, 2026-10-25 — review the graded research with fresh hands; take nothing in the prior paper for credit as it stands; verify the sources; write a new paper that makes no unfounded claim and produces only verifiable, tangible solutions.

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0. The standing of this paper

This paper replaces, for working purposes, *The Purity Project — Review of the Current Edition* (Rowan, Breath 001, 2026-10-17) and its apparatus: the Ledger grade of 2026-10-21 (B+, formally NOT SOURCED) and the every-fact source trackdown of the same date.

The founding corpus does not survive. The Oct 14, 2026 full-scale design edition, Rounds 2–5, the Oct 8 origin report, the energy deep-dive, and the living briefs were searched for on 2026-10-25 — the workspace, the Ark extract, every local archive, and Google Drive by name, by full text, and by folder listing. They are in none of them. Ben's testimony on the loss, recorded as his: the corpus was *likely destroyed*; *so many of the originals were lost in a restore that did not take*. Every claim that rested only on that corpus is therefore unverifiable in principle, and none is carried here.

Method. Every factual claim in this paper was verified on 2026-10-25 against a primary or authoritative source — an agency publication, a statute or permit, a peer-reviewed paper, a municipal or operator record — and is cited at the claim, by source number, to the list in §9. Vendor material is used only where vendor material is all that exists, and is labeled **VENDOR** on its face. Claims that a fresh sweep could not locate are not softened; they are excluded, and the most consequential exclusions are listed in §7 with their reasons. Arithmetic is this author's, recomputed from stated inputs, and is labeled *derived* wherever it appears. Grades used for solutions: **[D]** demonstrated in operation or in a documented demonstration on a comparable feed · **[P]** pilot or bench evidence · **[A]** avenue — a sound route, unproven on this duty.

The charge, unchanged (Ben, 2026-10-17, restated 2026-10-25): (1) what is currently possible to eliminate the problem of data-center water-waste pollution; (2) what has previously been deemed unsolvable; (3) how to utilize contaminated waste into a productive, useful substrate that is nontoxic or permanently contained — with no final effect of the waste system re-entering the environment the data center sits in, and the goal a net positive on the surrounding world.

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1. The problem in numbers

Reference plant (a stated design basis, not a found fact). This paper uses the same reference plant as the prior work, so results compare: a 100 MW evaporative-cooled facility; cooling-tower blowdown of 171,000 gal/d average (647 m³/d) and 250,000 gal/d design (946 m³/d); blowdown feed of 1,000–5,000 mg/L TDS, hardness 500–1,500 mg/L as CaCO■, silica 60–150 mg/L. The basis is a modeling choice; every load below is *derived* from it by arithmetic shown here.

Derived loads (author's recomputation, 2026-10-25):

Stream	Derivation	Load
Dissolved salt	647 m³/d × 1,000–5,000 mg/L	0.65–3.24 t/d; ≈2 t/d nominal; ≈730 t/yr at continuous operation

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Stream	Derivation	Load
Silica	647 m³/d × 60–150 mg/L	39–97 kg/d (14–35 t/yr)
Hardness (pellet ceiling)	647 m³/d × 500–1,500 mg/L as CaCO■	0.32–0.97 t/d if fully precipitated (118–354 t/yr)
Concentrate (after recovery)	647 m³/d × (1 – recovery) at 91–96%	58 m³/d at 91%; 26 m³/d at 96%
Phosphorus	as carried in the prior work from the same basis	≈0.6–1.9 kg/d — small; §4.3 treats it accordingly

The evaporation ceiling (derived, from authoritative relations). US DOE FEMP's cooling-tower balance — Make-Up = Evaporation + Blowdown + Drift, with cycles of concentration ≈ makeup ÷ blowdown [S58] — gives, neglecting drift: at 5 cycles, blowdown is 20% of makeup. Even perfect blowdown recovery therefore cuts intake by about a fifth (plus what higher cycles on cleaner makeup allow). The evaporated fraction is unrecoverable at the treatment level, by physics. Any claim of a water-positive evaporative site from blowdown treatment alone is miscounting. The ceiling is escaped only at the architecture level (§2.4), never at the treatment level.

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2. What is currently possible — verified

2.1 Stop the pollution at the source: the chemical program [D, building scale]

The strongest verified source-elimination result is the US GSA Green Proving Ground programme, assessed by NREL. Its findings sheet for electrochemical tower treatment reports, verbatim in substance: **100% reduction in added chemicals, 99.8% reduction in blowdown, and 31.6% water/sewer savings**, on a 300-ton tower pair (2 × 150 tons) at the Savannah testbed [S1][S2]. The same programme tested an advanced-oxidation system (500 tons; savings estimated 22.7–29.7%; blowdown reduction not measured) and a salt-based system (1,500 tons; 99% blowdown reduction); NREL's guidance notes the non-Savannah testbed carried weaker measurement and verification, so the electrochemical figures are the better-instrumented set [S2][S3]. The honest limit, stated at its size: this is commercial-building scale, independently assessed — not yet a hyperscale data-center tower.

Phosphonate-free chemistry is weaker. Kurita's published bench work names polyaspartic acid polymer and tin as the green inhibitors of choice **if phosphate-free status is mandatory**, at a use cost approximately 30% higher than a phosphate/zinc program, with field testing expressly still required — vendor bench work on carbon steel, labeled as such [S8, **VENDOR**].

The copper gap is named, not dressed. No commercial-scale tower program protecting copper alloys without azoles was located in this sweep. The prior paper's supporting figure — a claim that UFGS 23 25 00 warns ozone-only treatment can increase copper corrosion up to 10× — was checked against the specification's full text: the document contains **no occurrence of "ozone"** and no such figure [S66]. The figure is dropped (§7). The gap itself stands as a finding: azole-free copper protection is the weakest link in source elimination today, and a pilot task (§6).

2.2 Treat blowdown back to makeup at high recovery [D]

The operating proof is institutional: Quincy, Washington. The US EPA's case study states every element: a city-owned, city-operated reuse utility treating data-center cooling blowdown — after the water is cycled four to five times at the data center — through lime softening, ultrafiltration, high-efficiency softening, and reverse osmosis, back to cooling makeup; demand offset **138 million gallons per year**; overall cost **$31 million**, with Microsoft financing all capital and operational costs under a **30-year agreement**; operational June 30, 2021, after about ten years to plan, design, construct, and test [S9]. Quincy's residual fate matters to this project's standard and is stated whole: salts are concentrated in **lined brine ponds** to a solid disposed of so as to prevent entry into state ground or surface waters, with residuals removal expected every two or three years [S9]. Quincy proves the loop — and proves it with containment, not valorization, at the back end. Derived note: $31M divided over 30 years at the stated offset is ≈$7.49 per thousand gallons — an arithmetic annualization of the capital figure, **not a levelized cost** (it excludes financing and all operating costs). The prior paper's ~$14.6/kgal figure does not

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recompute from these numbers and is dropped (§7).

Intel's Ocotillo Brine Reduction Facility, Chandler, Arizona treats fab process water — a different feed from tower blowdown, and labeled so. Intel states the facility's capacity at up to **2.8 million gallons per day** [S11]; the City of Chandler states, in a March 2026 letter to the US Bureau of Reclamation, that the facility **recovers 96% of that water** for return to Intel, while the city's 2023 design agreement says **>94%** — both figures are carried, attributed, not merged [S10]. The same partnership's aquifer-recharge precedent is EPA-documented at **approximately 1 billion gallons** recharged, as of that profile's date [S12].

The pellet-crystallization RO demonstration is one demonstration, and it is vendor-sourced. The prior paper presented a Chile pellet-RO demonstration and an IDE MAXH■O case as two data points. They are the same installation: IDE's MAXH■O Desalter demonstration at ENEL's San Isidro plant, Chile — a 48 m³/d unit on a gas-fired, two-combined-cycle, ~750 MW station [S4][S5]. What IDE's own case study documents: recovery **over 91%** in its results and conclusions; brine silica stabilized at **100–150 mg/L** against a theoretical 630 mg/L; pellets drained to **more than 95% dry solids** with no dewatering step; a permeability dip after a shutdown without flushing, reset by acidic flush [S4]. IDE's brochure reports **up to 94%** in a second phase [S5]. The case study's headline figure of 96% is, in its own results text, a **target** — "the target value of 96% will be reached" in the following month — not a documented result [S4]. Its operating-period framing also conflicts internally (30 days continuous in the introduction; three weeks of presented operation in the results). Carried here as: **[P], vendor-sourced, >91% documented, ~94% second-phase maximum, duration unsettled in the vendor's own tellings.** The further MAXH■O case figures in the prior paper (~95% recovery, permeate silica ~1 mg/L, 24 cycles) were **not located in any source** and are dropped (§7).

Electrocoagulation front-ends are piloted on real blowdown. The Garver/USBR pilot (1.5 gpm train on blowdown from a 600-ton cooling system) reported silica removal of **67–98%** regardless of pH or residence time, and membranes recovering to **within 94% of initial flux** after a permeate flush — flux recovery, not water recovery [S6]. Its vacuum-assisted electro-distillation tail consumed **620–1,750 kWh/kgal (164–462 kWh/m³)** on high-TDS lab feeds [S6] — an energy intensity that disqualifies that tail for this duty on its own numbers. The USBR final report (P2P Report #4, March 2024) exists on the programme's index but was not text-verified in this sweep and is not cited as read [S7].

A peer-reviewed analogue, honestly scoped. A 2025 Technion train — nanofiltration → RO → iron electro-dissolution silica removal → second RO → MVR — attained **>95% recovery at a modelled ~USD 0.70/m³** [S62]. Its feed was Ma'agan Michael brackish **groundwater** (~5,000 mg/L TDS, ~20 mg/L silica), and its MVR step was simulated, not tested. It is an analogue for blowdown, not a blowdown demonstration, and is carried as **[P-analogue]**.

2.3 Potable: the precedent exists, and it is not American, and it is not blowdown [D]

eMalahleni, South Africa treats coal-mine water by ultrafiltration and high-recovery RO to drinking standard and supplies it into a municipality. Confirmed at primary and operator sources: **16 million litres per day** into the municipal system, about **12% of municipal supply** at that reporting [S14]; drinking water for **60,000 people** and **200 tonnes per day of gypsum-based solids used to make bricks** — with the UN's own framing that brick-making had built 66 homes with expansion hoped for, i.e. begun, not a full-tonnage industry [S13]; overall plant recovery **approximately 99%** [S15]. The operator is **Thungela Operations**; Thungela's 2024 reporting states the plant still operated and met **16% of the municipality's daily water demand in 2024** [S16]. The prior paper's higher ranges — 20 ML/d to the municipality, 80,000 people — were **not located at primary sources** (later sources describe 40 ML/d average *total* plant throughput, a different quantity) and are dropped (§7). The institutionally decisive fact survives verification: the municipality is the receiving water authority; industry never became the drinking-water supplier.

No operating facility treating cooling-tower blowdown to potable was located in this sweep; the operating potable-reuse precedents run on municipal wastewater or mine water. The gap is not treatment. It is the applicant category (§3.1).

2.4 The architectural answer to the evaporation ceiling [D — heat recovery as deployed practice; the newest hardware claims in this section are vendor claims and are labeled where they stand]

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Heat recovery is deployed at data-center scale: Ramboll, owner's engineer for the district utility, states Meta's Odense installation delivers **approximately 45 MW** of heat production into the district network [S17]. Annual figures are phase-dependent and must be cited with their phase: 100,000 MWh/yr (initial), 165,000 MWh/yr (post-expansion), 215,000 MWh/yr (Ramboll's full-build figure) [S17]. A site that exports its heat shrinks its evaporative load — contracting the blowdown problem at the source.

Liquid-cooling temperature classes are confirmed at the standard: ASHRAE TC 9.9 lists facility water supply classes **W45 = 45 °C** and **W+ = >45 °C** [S18]. NVIDIA's statement that its Rubin-class servers take coolant in at up to 45 °C and out at roughly 55 °C is the vendor's own claim, about the technology-cooling loop — a different loop from ASHRAE's facility water — and is labeled **[S19, VENDOR]**. The two 45 °C numbers coincide; they do not describe the same water.

Waste-heat desalination at a data center: a null result, stated as a finding. No operating data-center waste-heat-driven membrane-distillation or desalination installation was located in the sources searched. The nearest demonstrated system is a three-month direct-contact MD pilot at a gas-fired **power station** (92.8% recovery, 0.67 m² of membrane) [S61]; data-center applications found are laboratory studies, vendor concepts, or announced pilots. The verified MD economics are from a biogas plant: unit cost **€3.6–4.1/m³ with heat recovery vs €7.6–9.1/m³ without** — a modelled assessment whose specific heat demand was still **80–100 kWh/m³ with recovery** [S60]. Heat is therefore an avenue for the small concentrate tail and for the architecture — not, on present evidence, a rescue for the core process.

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3. What was deemed unsolvable — re-examined on verified evidence

3.1 "A private data center can never produce potable water — no applicant category exists"

The wall is real in the standalone form and has a door written into the newest rules. California's direct potable reuse regulations, **effective October 1, 2024**, define the responsible agency (DiPRRA) as **the public water system** responsible for compliance — and expressly define **Partner Agency** for every other entity in the project [S20]. Arizona's Advanced Water Purification rules, **effective March 4, 2025**, structure applicant pathways (§ R18-9-C813) around National Pretreatment Program applicability, with an Enhanced Source Control program (§ R18-9-E824) expanding pretreatment requirements — an industrial contributor inside a partner's program is contemplated by the pathway structure [S25]. The operating structures agree: at Quincy and eMalahleni the public system holds custody and the permit while industry finances and supplies [S9][S13]. What honestly remains: no precedent of an industrial contributor under Arizona's pathways was located, and no Ohio potable-reuse regulation was located in this sweep — an Ohio potable phase is a rulemaking project measured in years, not a permit project. The potable ambition is a partnership-and-patience problem. It was never a chemistry problem.

3.2 "The tower chemicals are unprovable — no limits, no methods, no MCLs"

The factual core stands: there are still no US drinking-water limits for the common tower additives. What has changed is the evidentiary instrument. California's Recycled Water Policy amendment (adopted December 11, 2018; effective April 8, 2019) requires monitoring for constituents of emerging concern — **including bioanalytical (effect-based) screening tools** against Table 9 monitoring trigger levels — at operating indirect potable reuse facilities [S21]; SCCWRP, the research institute behind the method, describes California as *"the first entity in the world to require the use of bioanalytical screening technology for monitoring recycled water for potable reuse"* — quoted here attributed, at exactly that scope [S22]. The EU has now legislated effect-based judgement as well: Directive (EU) 2026/805, **in force May 11, 2026**, introduces "effect-based trigger values" measured by effect-based monitoring methods into the water framework directives (transposition by December 21, 2027) [S24]. And the field's most recalcitrant tower chemical is now measurable against an adopted rule: the recast Urban Wastewater Directive (2024/3019) names **benzotriazole and the 4-/5-methylbenzotriazole mixture as category 2 indicator substances** for quaternary treatment — with the correction this paper insists on: the directive's **80% is the average removal across at least six measured indicator substances**, not a per-substance mandate [S23].

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Two open items are carried at full size. First, EPA's UCMR 6 — **proposed** July 1, 2026, monitoring 2028–2030 — was checked analyte by analyte: **no benzotriazole, phosphonate, DBNPA, CMIT/MIT, or glutaraldehyde appears on the proposed 30-contaminant list** [S34]. Second, the per-barrier log-removal dataset for tower additives remains unproduced; producing it is a pilot's job (§6). Verdict: "unprovable" is retired. The accurate statement is: provable, to a public sponsor, by an evidentiary method regulators already accept — once someone pays to produce the evidence.

3.3 "Bromate makes ozone unusable on this water"

The prior paper's numbers do not survive. Its figure — ozonation of 1.1–1.3 mg/L bromide water producing 216–422 µg/L bromate, with best suppression of only 33–66% — was **not located in any source** in a fresh sweep; the "422" in the located pilot literature is a **bromide feed concentration (422±20 µg/L)**, not a bromate product. It is dropped (§7), and the correction is stated here because the design conclusion changes with the evidence.

What is verified: the US bromate MCL is **10 µg/L** (EPA National Primary Drinking Water Regulations: 0.010 mg/L, MCLG zero) [S67]. Located pilot studies report preformed monochloramine suppressing bromate formation by an **average of 82%** (3 mg/L NH■Cl-Cl■, at 0.42 mg/L bromide) and **80%** in a second high-bromide pilot — against the old paper's claimed 33–66% ceiling — with the cost stated in the same studies: monochloramine scavenges hydroxyl radicals and measurably inhibits trace-organic oxidation [S55]. And the sequencing avenue is now supported by measurement rather than inference: a peer-reviewed critical review reports **96–97% bromate removal (≈1.4–1.5 log) in pilot- and full-scale RO systems after ozonation** [S56]. The prior paper had rested this step on a bromide-rejection figure doing duty for bromate; that figure traces to vendor nominal tables only. Position ozone before RO, suppress what can be suppressed, and let the membrane carry the measured share — the avenue stands, on better evidence than it had, with the feed-specific measurement still owed (§6).

3.4 "Small-flow economics kill it"

Not overturned — reframed, on verified anchors. Municipal reclaimed water is cheap where it exists; mineral credits at this scale are worth, at most, tens of thousands of dollars a year (the derived loads in §1 make this arithmetic, not opinion). The business case closes, where it closes, on the avoided-cost stack: sewer billed without an evaporation credit — Austin Water's commercial wastewater **volume charge is $11.62/kgal** (rates effective November 1, 2025, plus an $11.26 monthly customer charge and $0.45/kgal of community-benefit adders) [S31]; discharge limits written into individual permits (§5); adopted escalation — Columbus's **11.7% composite** utility increase for 2026 (12.8% outside the city; a composite across water, sewer, and stormwater, not a single service) [S32], Loudoun Water's board-adopted **7.0% per year for 2025, 2026, and 2027** [S33]; and allocation value — Quincy was bought for water-rights headroom and permit compliance, at full price, by the party that needed both [S9]. The Purity purpose does not change the arithmetic; it changes what the plant is for. This plant is bought, not sold.

3.5 "Silica caps recovery; past 95% is marketing"

Verified chemistry, narrower than previously stated: amorphous silica solubility is ≈**100–120 mg/L at 25 °C and neutral pH** (the ~200 mg/L upper end was not located), and the antiscalant ceiling in the located industry/TU Delft literature is **300 mg/L** brine silica (the ~320 figure was not located) [S59]. The route past the ceiling is precipitation inside the loop — the San Isidro pellet loop held brine silica at 100–150 mg/L while running at >91% recovery [S4, **VENDOR**-sourced]. What remains is endurance: the documented run is weeks, not the six months a pilot owes, and it was vendor-documented throughout. An engineering problem with a demonstrated direction and an unproven duration — a different thing from unsolvable, and the distinction is the pilot's whole purpose (§6).

3.6 "The concentrate has nowhere lawful to go"

Verified in-state: **Buckeye Brine, LLC (Coshocton, Ohio)** operates Class I non-hazardous injection wells under Ohio EPA UIC Permit to Operate No. UIC 04-16-017-PTO, capping the combined monthly injection volume at **12,710,700 gallons** at a combined 290 gpm monthly average [S28]. Two prior-paper details are dropped as unlocated: a specific renewal window ("renewed July 2025 to 2030") — injection-well permits carry a five-year term by statute [S29], but no renewal date for this

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facility was located — and any price: Buckeye's price is not published in any source located, so disposition cost is a quote to be obtained, and obtaining it is an outside contact the standing gate reserves (§6). For the final solid, permanent containment has an operating, regulator-approved precedent at far larger scale (§4.5). "Nowhere lawful" is therefore false in Ohio; "unpriced and uncontracted" is the true statement.

3.7 Verdicts this paper will not dress up

- **Evaporated water is unrecoverable** (physics; §1). It dissolves at the architecture level (§2.4), never at the treatment level.
- **Salinity-gradient power from this stream is dead — by measurement.** On Mg²■-bearing multi-ion feeds, reverse electrodialysis power density fell from 3.04 to 1.13 W/m² of membrane pair — 63% in the paper's abstract, 64% in its body text; one paper, both figures stated [S57]. Realistic gross output on real brine is of order 1 W/m² of membrane pair: watts, not a plant output.
- **Biogas from the solids is killed by composition** — stated as design reasoning, not as a sourced figure: the solids this process makes are precipitated minerals (carbonate-class pellets, crystallized salt), not an organic feedstock; there is nothing here for a digester to eat. The prior paper's precise composition figures rested on the lost corpus and are not carried.
- **BMED on raw mixed brine** yields mixed, contaminated acid and caustic — the avenue is sequencing (§4.4), and several of this project's "unsolvables" are, on the verified record, sequencing errors wearing the costume of physical limits.

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4. The waste, converted: a mass-fate design

Design rule, from the charge: **every output of the system is product water, a useful substrate that is nontoxic, or a permanently contained solid.** Nothing from the waste system is discharged to the environment the data center sits in. Fates are graded [D]/[P]/[A] as in §0. All loads are the derived reference-plant loads of §1.

"No environmental re-entry," operationally defined (Edition 1.2). The charge's phrase is a goal, and this paper does not let it masquerade as a physical absolute. A grout monolith in a permitted facility is not isolation under every conceivable condition, and a material that passes one leaching test is not thereby suitable for every use. What this design claims — and what Annex A.4 makes measurable — is **verified containment and verified fitness under specified conditions**: residuals meet stated leaching and leachability criteria, sit in an engineered unit under a permit, and are monitored, with the monitoring part of the claim; recovered products are accepted only for the application their assay supports; product water meets the receiving system's own regulatory criteria. Anywhere this paper says "permanent containment" or "no re-entry," it means exactly that, and nothing stronger.

Transfer risk, stated once for the whole section. Much of the [P] evidence below is bench or pilot work on other matrices — azole pesticides in clean water, a phosphonate in wastewater effluent, bromate in potable-reuse trains. Each case is flagged where it stands, but the aggregate risk is named here so the flags are not the only place it lives: real blowdown is hot, hard, silica-bearing, and chemically mixed in ways none of those studies reproduced, and performance on it is unproven until pilot items 1–5 of §6 run on the real feed. The grades in this section assume nothing across matrices; the pilot program exists precisely to retire this paragraph.

4.1 The pellet stream — the one genuinely clean solid [D for the product class; P for this feed]

Pellet crystallization converts the hardness load into CaCO■-class pellets discharged at **>95% dry solids** with no dewatering plant [S4, **VENDOR** for the blowdown unit]. The product class is established in municipal service: Dutch water companies collectively market softening pellets through their shared service center (Reststoffenunie, now AquaMinerals) into **fertiliser, steel, and construction** industries [S47]. Two corrections ride with this: feed/food use is **prospective**, tied to high-purity calcite pellets, not an established outlet for conventional pellets [S47]; and the life-cycle comparison is Wan et al. (University of Georgia authors, 2011 Georgia Water Resources Conference; the file sits in Georgia Tech's repository) —

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pellet treatment of RO concentrate produced **96% less dewatered solids and 72% less total solid waste** than conventional lime treatment at a 10 MGD conceptual facility, net of 15 ton/day of wasted pellets [S48]. The prior paper's "Georgia Tech LCA" attribution is corrected here.

The blowdown caveat, at full size: pellets from this feed may carry co-precipitated silica and phosphonate-derived phosphate, with possible azole traces and circuit metals. Product status is therefore **not assumed — it is earned** by assaying real pellets against a named buyer's specification (cement raw meal is the most tolerant candidate). Pass: the largest solid stream (derived ceiling 118–354 t/yr) is a substrate. Fail: it joins the containment stream (§4.5) and the design still holds.

4.2 The phosphorus — destroy the antiscalant, precipitate its phosphate [P]

Phosphonates sabotage the design twice: they inhibit the pellet crystallization the plant depends on, and they ride into every solid. The conversion chemistry is verified at bench, with two citation corrections this paper makes in the open:

- An electrochemical cell cleaved NTMP's C–N and C–P bonds at the anode to orthophosphate, and precipitated **calcium phosphate at the cathode** — **89% removal in 24 h in real wastewater-treatment effluent** (Lei et al., *Water Research* 2020) [S39]. The high real-effluent efficiency is attributed to chloride forming chlorine at the anode — a matrix effect, stated so the figure is not over-generalized.
- The HEDP figures (scale-inhibition ratio falling 66% → 34% as ligand removal reached 80%) belong to **UV/chlorine**, not to ozone/UV as the prior paper implied (Huang et al., 2019) [S40]. Ozone cleavage of phosphonates to orthophosphate is separately supported (ATMP ozonation work), with the caveat the sources themselves carry: ozonation **creates bioavailable orthophosphate**, so a capture step must follow [S40].
- Wastewater data give phosphonate "removal" of a **median 96.4%** at the activated-carbon stage (Rott et al., 2020) — but that removal is largely **phase transfer to solids, not destruction** [S41]. This paper pairs every such transfer with its capture step, as the sources do.

At the derived 0.6–1.9 kg P/d, the product is a few kilograms per day of calcium phosphate riding the pellet stream — process hygiene, not a business. **Struvite is corrected, not repeated:** the prior paper ruled it out on mass alone. The literature located contains no minimum-viable-scale threshold, and it contains a counterexample — struvite production at **1.28 kg P/d** from concentrated swine wastewater at $6.56/kg P with a 3.91-year payback [S63]. What rules struvite out *here* is stated as this paper's judgment, not a literature verdict: the phosphorus in blowdown is dilute, largely phosphonate-bound until converted, and magnesium dosing would cost more than the product — and no precedent for viable struvite recovery from a dilute cooling-water stream was located.

4.3 The organics — destroy them in the concentrate, where they are few [P]

At 91–96% recovery the concentrate is **26–58 m³/d** (derived, §1) carrying essentially all the azoles, biocides, and residual phosphonate. Smallness is the opportunity: destruction technologies absurd on 950 m³/d are conceivable on 40.

- **Catalytic wet peroxide oxidation** removed five EU watch-list azoles **completely in <1 h**, with effluents **non-toxic** to *Vibrio fischeri* (López-Aragó et al., *Environmental Technology & Innovation* 2023 — the journal and year are corrected here from the prior paper's citation) [S38]. Real-matrix runs showed a slight rate decrease; the complete-removal figure is the clean-water result, stated as such.
- **Ozone, positioned:** at full scale in wastewater post-ozonation, the ozone-resistant benzotriazole reached **>85% removal at a medium specific ozone dose of ≈0.6 g O■ per g DOC** — a whole-effluent dose at which that removal was observed, not a compound-specific "demand" as the prior paper phrased it (Hollender et al., 2009) [S52]. Ozone's position is pre-RO, under §3.3's bromate discipline.
- **BIT** (benzisothiazolinone): ozonation rendered its zebrafish-embryo toxicity **undetectable** (Li et al., 2016; LC50 6.8 µmol/L before treatment), including in an RO-concentrate matrix [S53].
- **DBNPA's time-course justifies the dark step:** in real cooling-tower water, acute daphnid toxicity **increased after 1 h of illumination** (transformation products) and **decreased by 48 h** (Wagner et al., 2020) [S54]. Design reasoning,

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labeled as such: a dark equalization hold before any UV step lets that decay happen first.

- **SCWO is excluded for this duty.** Its destruction performance is real in the record only in vendor-issued form: the 99.9993% PFAS figure for 374Water's AirSCWO circulates in **the company's own press release** summarizing ERDC report TR-26-19 (July 2026); the report exists and is catalogued, but the figure was not read in ERDC's own text in this sweep [S64, **VENDOR**]. Independently of provenance, heating mostly-water to supercritical conditions for kilogram-scale organics fails the arithmetic the same way digestion did, and salt precipitation is SCWO's classic failure mode. Wrong tool here.

4.4 Then the salt — sequencing, and BMED on the cleaned stream [A, on P-grade components]

Once the additive load is destroyed before crystallization, the mixed NaCl/Na■SO■ salt's contamination argument collapses; what remains is purity and market, not toxicity. **No study located has run this sequence and leach-/tox-tested the resulting salt.** That single experiment is the highest-value item in this paper (§6, item 1): passing it reclassifies the derived ~730 t/yr (continuous operation) from "contaminated waste" to "industrial feedstock candidate."

BMED on the cleaned, pre-purified stream — with the prior paper's most exposed figure corrected in the open:

- **The "99.99% purity" figure is not a primary result.** The primary paper (Chen et al., *Desalination* 2018) reports HCl and NaOH from RO brine at up to ≈2 mol/L with purity ≥**99%**; "nearly 99.99%" appears only in a 2023 review's restatement of that work and in vendor copy [S42]. This paper quotes ≥**99%**.
- The wider verified range, each with its system named: monoprotic acid purities of **93.9–96.1%** (SBMED, simulated seawater) [S43]; **99.2% acid / 96.3% alkali at 3.4/3.3 mol/L** in an industrial BMED plant on pre-treated concentrated seawater (Bohai) [S44]; and an organized-industrial-estate RO-concentrate pilot producing **1.44% HCl / 2% NaOH continuously** — dilute products the authors state cannot be concentrated further under their conditions, suitable for on-site reuse, not merchant chemicals [S45].
- Economics, corrected in form: a 2025/26 pulp-industry ZLD analysis puts evaporation–crystallization (with pEDR) at **$0.43/m³** against a BMED desaturation route at **$0.34/m³, falling to $0.20/m³ with soda valorization** — two scenarios, not a range (Salas et al., 2026) [S46].
- Scale honesty (derived): splitting the full ~2 t/d of salt **as if it were all NaCl** — an upper bound, stated as one — yields ≈1.37 t/d NaOH and ≈1.25 t/d HCl. Internal sinks (pH trim, cleaning, regeneration) plausibly take only a minority; the remainder must export as technical-grade product within short haul or it re-becomes a discharge problem. BMED is cost-avoidance against crystallizer-plus-containment, not revenue.

4.5 The irreducible remainder — permanent containment, on a demonstrated pattern [D]

Whatever survives §§4.1–4.4 — off-spec pellets, the unmarketable salt fraction, treatment residuals — goes to a cementitious grout monolith on the **Savannah River Saltstone** pattern: decontaminated salt solution mixed with cement, slag, and fly ash into monoliths in engineered disposal units [S49]. Verified standing: operating **since 1990**; DOE reported **>30 million gallons** of decontaminated mixture produced by January 2019 [S49]; the site contractor's December 2025 booklet puts cumulative grout at **>56 million gallons** (an operator figure, labeled) [S49]; the state regulator (SC DHEC) issued a **final permit** for the disposal facility under its industrial solid waste landfill regulations, and the units are the final disposal location [S50]. The grout volume increase is ≈1.6×, *derived* from DOE's FY2021 figures (3.1M gal of salt solution → just over 5M gal of grout), not a DOE-stated number [S49]. Scaled here (derived): ~2 t/d of salt becomes roughly 3–5 t/d of grout — a civil-works line item, not a programme.

Two refinements are carried at their true weight, not the prior paper's: DOE's sol-gel/polyceram work **fabricated** forms at 50–70% salt loading; leachability index ≥6.0 was shown on first-generation forms that **failed TCLP**, and TCLP compliance was demonstrated **only at 50% loading, after process modification** [S51]. And the claim that vitrified salt waste "has never failed TCLP and can be delisted as aggregate" was **not located** in any authoritative source — dropped (§7). The design therefore reads: **assume grout monolith, TCLP-verified — landfill is the fallback, not the design.**

4.6 Elements not carried

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The prior paper's on-site hypochlorite loop is not carried as a solution: no source was located for it in this sweep, and it absorbs <1% of the salt mass in any case. It remains available as a design proposal awaiting evidence, and is labeled that, here, once.

4.7 The train's energy and cost — a first-order envelope, with its gaps named

No source located prices or powers this exact train end to end. What follows is an envelope built only from unit figures verified in this paper, arithmetic labeled *derived*, and the gaps stated as gaps. It bounds the question; it does not close it.

Component	Sourced unit figure	Applied to the reference plant (derived)
Post-ozonation step	≈0.035 kWh/m³ for the ozonation step (full-scale wastewater post-ozonation) [S52]	On 647 m³/d of blowdown: ≈23 kWh/d — negligible at plant scale
BMED salt splitting	4.57 kWh per kg NaOH produced (pulp-ZLD BMED step) [S46]	At the §4.4 all-NaCl upper bound of 1.37 t/d NaOH: ≈6.3 MWh/d (≈0.26% of the plant's 2,400 MWh/d) — the train's dominant sourced electrical term, and an upper bound
Whole-train analogue (cost)	Technion brackish train: >95% recovery at a modelled ≈USD 0.70/m³ total cost [S62]	≈$450/d, ≈$165k/yr at 647 m³/d — a modelled analogue on a different feed, carried as an order-of-magnitude anchor only
Pulp-ZLD route comparison (cost)	BMED desaturation $0.34/m³, $0.20/m³ with soda valorization; evaporation–crystallisation $0.43/m³ (both with pEDR) [S46]	Consistent with the analogue above: the concentrate-handling routes price in tenths of a dollar per m³ in the located techno-economic literature
Membrane-distillation tail (if used)	80–100 kWh/m³ **thermal**, even with heat recovery [S60]	On 26–58 m³/d of concentrate: 2.1–5.8 MWh-thermal/d — the reason MD is confined to the tail and to sites with a heat source and a use for the product

Gaps, named: no sourced unit figure was located for (a) RO energy on *this* feed at 91–96% recovery with a pellet front-end, (b) CWPO energy or reagent cost at concentrate scale, or (c) the train's capital cost as a system — the only capital anchor is Quincy's $31M for a multi-plant municipal utility, which does not decompose to this train [S9]. Pellet-softening chemical and seed costs are likewise unsourced here.

What the envelope supports, and no more: on the sourced components, the train's electrical draw is single-digit MWh/d against a 2,400 MWh/d plant — energy is not the objection to this design. "Net positive" on the energy side, however, is **not established by this envelope**: it depends on heat recovery (§8), which depends on a heat sink no Ohio analysis here has established. The energy claim of this paper is therefore: *the treatment train is cheap to run relative to the plant; the net-positive energy case is conditional on a sink.* Anything stronger would be assertion, and this paper does not make it.

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5. The Ohio application — Fairfield siting, on verified ground

- **No data center is located in the City of Fairfield itself.** A fresh sweep of authoritative and trade sources located none operating or announced there; this paper does not write that Fairfield hosts one. The nearest Butler County activity: a Logistix project in neighbouring **Hamilton**, approved November 2024, was **reported dead in September 2026** after a successor developer sought to quadruple capacity [S36]; Prologis and Amazon projects around **Trenton** were announced in 2025–2026 amid a county moratorium and a local ban vote [S37, trade press].
- **The local POTW:** Fairfield's wastewater plant is a **10 MGD** (average design flow) activated-sludge facility serving ~45,000 users, discharging to the Great Miami River, with **no approved pretreatment program**; its NPDES permit (1PD00003) runs to **November 30, 2026** [S35]. Any industrial-contributor structure here starts from that fact, not from an assumed pretreatment framework.
- **The permit path today (verified):** Ohio EPA announced **July 21, 2026** that it had *"decided not to move forward with finalizing"* its draft general NPDES permit for data centers (OHD000001) — the agency's verb; "withdrawn" is the press's

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— and that **individual NPDES permits** continue as the path [S26]. Separately, under **OAC 3745-42-02**, installing or modifying a disposal system requires an Ohio EPA **permit-to-install** or plan approval first; OAC 3745-42-06 lists cooling towers and closed-loop recycling systems among those eligible for a general permit to install [S27]. On-site treatment back to makeup is therefore permittable now, through individual instruments — no new rule needed.

- **The live partner event in this state:** Columbus Water & Power has calculated it could supply **40 MGD** of recycled water from the Southerly plant to nearby data centers, plans to seek proposals in **spring 2027**, and its director has stated on the record that the tech companies must pay for the infrastructure — *"The only way something like this happens is if those tech companies pay for it"* [S30]. The prior paper's "20–40 MGD" range is corrected: the 20 MGD bound was not located; 40 MGD is the reported figure, attributed to the Dispatch's reporting of utility statements, no city primary document having been located.

What this section is, and what it owes. This section is a verified regulatory scan, not a siting analysis, and it does not pretend otherwise. A siting analysis for a Fairfield-area build still owes, none of it done in this paper: a heat-sink survey (the §8 energy line depends on it); haul distance and routing to the Coshocton injection capacity of §3.6; makeup-water supply and pricing at the site; land and interconnection. Those are research tasks with named methods, queued behind this paper — listed here so their absence is a decision on the record, not a gap discovered later.

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6. The pilot kill-order — the experiments that decide, in order

Each item names what it decides. Items requiring contact outside this project's orbit — a buyer's specification negotiation, a disposal quote — are marked **[GATED]**: under Ben's standing ruling they wait for two proofs and two peer reviews, or for his direct word, whichever he gives first.

1. **Oxidize → crystallize → test the salt.** Oxidize real RO concentrate (azole/phosphonate/biocide destruction measured by validated methods, plus bioassay of the treated concentrate), crystallize, then TCLP + bioassay on the salt. *Decides §4.4 — the whole Factor 3 design.*

2. **The evidentiary package.** Transformation-product toxicity through the real train: spike tests at 2–5× worst case, non-target screening, a bioassay battery against a municipal-water control — the California-style package of §3.2. *Decides the potable ambition.*

3. **Bromate across RO, measured on this feed.** The 96–97% figure of §3.3 comes from potable-reuse systems; measure bromate in and out on real blowdown concentrate, with and without monochloramine suppression. *Decides the ozone-first sequence.*

4. **Pellet assay + endurance.** Assay real pellets against a named cement buyer's specification **[GATED — the naming and the approach]**, and run pellet-RO six months at scale, including a tower-chemistry upset and a no-flush shutdown. *Decides §4.1 and §3.5.*

5. **Azole mass balance per barrier**, at ng/L detection; in parallel, a 12-month azole-free copper-protection trial. *Decides §3.2's dataset gap and §2.1's copper gap.*

6. **Disposition in writing.** A Buckeye Brine waste-profile quote **[GATED]**; a grout formulation test on this salt (TCLP + ANSI/ANS 16.1); POTW terms if any stream still seeks one. *Decides §3.6 and §4.5.*

Watch list (events that change verdicts without work of ours): the first DPR/AWP permit actually issued in CA/AZ; the final UCMR 6 analyte list; Columbus Southerly's spring 2027 RFP; renewal of Fairfield's NPDES permit 1PD00003 after November 30, 2026; any operating data-center waste-heat desalination installation (none located as of this paper).

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7. What this paper dropped — the honesty register

Claims carried in the prior paper (or its corpus) that this verification excluded, with the reason. This register is part of the paper, not an appendix of shame: it is how the next breath knows what not to resurrect without new evidence.

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Dropped claim	Reason
BMED acid/base purity "approaching 99.99%"	Not in the primary paper (≥99%, Chen et al. 2018); 99.99% exists only in a 2023 review restatement and vendor copy [S42]
MAXH■O recovery of 96% as an achieved result	IDE's own text: a target to be reached; documented results are >91%, ~94% second phase [S4][S5]
The Chile pellet-RO demo and the MAXH■O case as two data points	One installation — ENEL San Isidro [S4][S5]
MAXH■O case figures (~95%, permeate silica ~1 mg/L, 24 cycles)	Not located in any source
UFGS 23 25 00 "ozone increases copper corrosion up to 10×"	The specification contains no occurrence of "ozone" and no such figure [S66]
Bromate 216–422 µg/L from 1.1–1.3 mg/L bromide; suppression ceiling 33–66%	Not located; "422" is a bromide feed figure in the located literature; located suppression is 80–82% [S55]
Bromate safety resting on bromide rejection ~90–96%	Vendor nominal tables only; replaced by measured bromate RO removal 96–97% [S56]
Quincy capital "~$14.6/kgal"	Does not recompute from the EPA figures ($31M / 30 yr / 138M gal/yr ≈ $7.49/kgal, derived) [S9]
Buckeye Brine "permits renewed July 2025 to 2030"	Not located; permit and 12,710,700 gal/month cap confirmed [S28][S29]
Columbus Southerly "20–40 MGD"	Only 40 MGD located [S30]
eMalahleni "20 ML/d to municipality; 80,000 people"	Not located at primary sources; 16 ML/d and 60,000 confirmed [S13][S14]
Silica solubility "~200 mg/L"; antiscalant ceiling "~320 mg/L"	Not located; located figures are ≈100–120 mg/L and 300 mg/L [S59]
Vitrified salt "never failed TCLP; delisted as aggregate"	Not located in any authoritative source
CCRO ">200 customers at 90–98%" as fleet fact	Sole origin is a DuPont acquisition press release; also restores the dropped "up to" [S65, **VENDOR**]
Salt tonnage "600–700 t/yr"	Implies an unstated ~330-day year; restated as ≈730 t/yr continuous (derived)
"Georgia Tech LCA"	Authors are University of Georgia (Wan et al. 2011); the PDF is hosted in Georgia Tech's repository [S48]
CWPO cited to *J. Environ. Chem. Eng.* 2022	The paper is *Environmental Technology & Innovation* 29 (2023) [S38]
HEDP 66%→34% figures attached to ozone/UV	The figures are UV/chlorine results (Huang et al. 2019) [S40]
Struvite "ruled out on mass" as a literature verdict	No threshold located; a viable 1.28 kg P/d case exists [S63]; §4.2 states this paper's judgment as judgment
RED loss "~64%" as two sources ("RSC Advances / REAPower")	One paper (Tufa et al. 2014): 63% abstract / 64% body [S57]
EU UWWD "80% removal of benzotriazole required"	80% is the average across ≥6 indicator substances [S23]

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Dropped claim	Reason
All corpus-internal claims (the edition's corrections, blocker rankings, round-by-round figures, the reference plant's provenance as a found fact)	The corpus does not survive (§0); the reference plant is carried only as a stated design basis

8. The net-positive ledger — only what verification carries

*Reading rule for this ledger (Edition 1.2): each line is either a benefit **demonstrated at another facility** or a benefit **projected for this design**, and says which. Projected lines are not evidence; they are the pilot program's hypotheses. No line in this ledger has been through a life-cycle assessment, and the ledger as a whole is therefore a statement of where a positive balance would come from — not a proof that it nets positive (see the verdict's third level, and Annex A.5).*

- **Water (projected for this design; the structures are demonstrated [S9][S12]):** intake cut ≈20% at 5 cycles from blowdown recovery alone (derived, §1), more as clean makeup raises cycles; surplus product water delivered **through a public water system** — the Quincy and Chandler structures [S9][S12] — returns water to the public stock. Nothing from the waste system re-enters the local environment; the product enters through the water system.
- **Materials:** assayed pellets displace mined limestone/cement raw meal (§4.1); recovered acid/caustic displaces manufactured chemicals for the minority share consumed on site (§4.4).
- **Energy (a conditional term, not the ledger's foundation):** heat recovery is verified as deployed practice at ≈45 MW thermal into a district network at Odense [S17] — a site *with* a district-heating sink. The Odense figure is that installation's production, not a figure derived for this paper's 100 MW reference plant, and **no heat sink for an Ohio site is established anywhere in this paper** (§5 names the gap). Where a sink exists, recovered heat displaces fossil heat off-site and is plausibly the ledger's largest single term; where none exists, this line is zero and the ledger must close without it. The treatment train's own energy is bounded in §4.7; it is small against the plant's output either way.
- **Not claimed:** the evaporated water (gone); the grout (containment, not enrichment — permanence is its virtue, and calling it enrichment would be the kind of inflation this project exists to refuse); mineral credits as revenue (noise, confirmed twice over).

Verdict — in the three levels the evidence actually supports (structure adopted in Edition 1.2 at the second grader's direction):

- **Demonstrated.** Individual technologies and comparable operating precedents support the key parts: high-recovery blowdown treatment back to makeup in municipal custody (Quincy [S9]); chemical-free tower operation at building scale (GSA [S1]); potable production from a difficult industrial water under a public authority (eMalahleni [S13]); permanent salt-waste containment at scale since 1990 (Saltstone [S49]). The load-bearing precedents stand at primary or official sources; lesser evidence is labeled where it stands — San Isidro on vendor sources, the Columbus figure on news reporting with no city primary document located, the SCWO figure on a vendor release.
- **Plausible but unproven.** The integrated train of §4/Annex A may achieve no liquid discharge and no solid outside verified containment (Annex A.4) on a real 100 MW site — **if** pilot items 1, 3, and 4 of §6 pass (the salt test, the bromate measurement on this feed, the pellet assay and endurance run). Until they pass, the design stands at its own grade: [A] on [P]-grade components.
- **Not yet established.** Net-positive life-cycle performance, full-scale economics, and long-term environmental containment **for the complete system**. No life-cycle assessment and no integrated capital/operating model exists for this design; §4.7 bounds the energy question and Annex A.5 specifies the two studies without pretending they have been done. A founding corpus that no longer exists, a copper gap with no located solution, and a vendor-documented pellet demonstration are named here so the levels above are read with them in view.

That is the strongest honest form of the charge's goal on today's evidence — and it is enough to build the pilot on.

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Annex A — Process definition: flow, mass balance, stage criteria

Added in Edition 1.2 at the second grader's findings. Everything in this annex is either derived from §1's stated basis (labeled derived) or is this paper's engineering proposal (labeled PROPOSED). Acceptance criteria are proposals to be ratified by the pilot program and, where they touch permits, by the regulator — they are not represented as existing requirements unless a source is cited.

A.1 Process flow

Tower blowdown (647 m³/d average, §1) → **Stage 1 — phosphonate conversion sidestream** (electrochemical or UV/chlorine; §4.2) → **Stage 2 — pellet crystallization** (hardness, silica, and converted phosphate out as pellets; §4.1) → **Stage 3 — ozone, pre-RO position** (azole oxidation under §3.3's bromate discipline) → **Stage 4 — RO at 91–96% recovery** (product water to makeup; bromate carried out in the concentrate) → **Stage 5 — CWPO on the concentrate** (residual organics destruction; §4.3) → **Stage 6 — crystallization** (mixed salt out) → **Stage 7 — salt split**: BMED on the cleaned fraction (§4.4) and/or **Stage 8 — grout monolith** for the remainder and all off-spec solids (§4.5) → monitoring (§A.4). Optional tail: membrane distillation on the concentrate, avenue only (§2.4). Tower-side source control (§2.1) operates upstream of the whole chain and shrinks every load below.

A.2 Stream-by-stream mass balance (derived from §1; nominal case TDS 3,000 mg/L, recovery 93% mid-range)

Stream	Flow / load (derived)	Basis
Blowdown in	647 m³/d; salt 1.94 t/d; silica 39–97 kg/d; hardness 0.32–0.97 t/d as CaCO■	§1 loads at the stated feed ranges
Pellets out (Stage 2)	Dry solids within the hardness ceiling, 0.32–0.97 t/d; discharged >95% dry [S4, VENDOR for the unit]	Ceiling is derived; the actual capture fraction is a pilot measurement (§6 item 4)
Product water to makeup (Stage 4)	≈602 m³/d at 93% (range 589–621 m³/d at 91–96%)	647 × recovery
Concentrate (Stage 4 out)	≈45 m³/d at 93% (range 26–58 m³/d) carrying essentially all salt not precipitated, ≈1.9 t/d nominal (0.65–3.24 range)	§1
Organics destroyed (Stages 3, 5)	Mass not quantified in any located source; kg/d scale by the feed's additive dosing — stated as unquantified, not estimated	§4.3 sources report removals, not feed mass
BMED products (Stage 7, if run)	Upper bound ≈1.27 t/d NaOH + ≈1.16 t/d HCl at the nominal salt load (all-NaCl assumption, §4.4 method)	Derived upper bound
Grout out (Stage 8)	≈3–5 t/d for the full salt remainder	Derived from the Saltstone ≈1.6× volume ratio [S49]

A.3 Stage table — status, operating range, failure modes

Status key: **Demonstrated** = operating or documented on a comparable feed · **Extrapolated** = demonstrated elsewhere, transferred to this duty by argument · **Experimental** = bench/pilot only, or never run in this sequence.

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Stage	Status	Operating range (sourced)	Principal failure modes
1. Phosphonate conversion	Experimental on this feed (bench/pilot on other matrices [S39][S40])	NTMP 89%/24 h in WWTP effluent [S39]; HEDP figures are UV/chlorine [S40]	Incomplete conversion leaves the pellet stage inhibited; conversion creates orthophosphate that must be captured (§4.2)
2. Pellet crystallization	Demonstrated as a product class [S47]; pilot on blowdown, vendor-documented [S4]	Brine silica held 100–150 mg/L in the demo [S4]	Phosphonate inhibition of crystallization; silica breakthrough past the ≈120 mg/L solubility behaviour [S59]; off-spec pellets on feed upsets
3. Ozone (pre-RO)	Demonstrated unit operation; placement here is Extrapolated	Benzotriazole >85% at ≈0.6 g O■/g DOC [S52]	Bromate formation — mitigations: monochloramine suppression 80–82% [S55], RO removal 96–97% [S56]; radical-scavenging cost to trace-organic oxidation [S55]
4. RO	Demonstrated on blowdown [S9]; demo-scale for pellet-RO [S4]	91–96% recovery band (§2.2); antiscalant brine-silica ceiling 300 mg/L [S59]	Silica scaling; the documented no-flush-shutdown permeability dip [S4]; flux decline (Garver train recovered to 94% of initial flux [S6])
5. CWPO on concentrate	Experimental on this feed (bench, clean water [S38])	Complete azole removal <1 h, clean-water result [S38]	Rate decrease in real matrices (observed in the source itself); catalyst fouling unmeasured on this feed
6. Crystallization	Demonstrated unit operation generally; Experimental as sequenced after oxidation on this feed	—	The sequence itself is the unrun experiment (§6 item 1); antiscalant carryover reduces salt purity [S59]
7. BMED	Demonstrated industrially on pre-treated seawater [S44]; Extrapolated to this stream	Products ≥99% at ≈2 M [S42]; dilute 1.44%/2% class at pilot [S45]	Hardness fouling without pre-purification (the Bohai plant pre-treats [S44]); product concentration ceiling at pilot scale [S45]
8. Grout monolith	Demonstrated at far larger scale since 1990 [S49][S50]	LI ≥6.0 criterion class [S51]	Volume growth ≈1.6× (derived [S49]); off-spec upstream solids swell this stream
Copper protection, tower-side	**Unresolved gap** — no located commercial azole-free program (§2.1)	—	The gap itself is the failure mode; §6 item 5 is its test

A.4 Acceptance criteria (PROPOSED unless a source is cited)

- **Product water to makeup:** meets the operating chemistry program's makeup specification and the conditions of the site's individual NPDES permit / permit-to-install (§5) [S26][S27]. Any potable step occurs only through a partner public water system under DPR/AWP-class rules, including bioanalytical screening — the criteria there are the regulator's [S20][S21][S25].
- **Pellets as product:** pass a named buyer's specification on assay (composition, moisture — the demo's >95% dry solids is the benchmark [S4]); leaching by TCLP below the regulatory levels of 40 CFR 261.24 for the metals of concern;

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accepted only for the application the assay supports — a pass qualifies the pellets for that use, not for every use.

- **Crystallized salt as feedstock:** TCLP pass **and** a bioassay pass on the post-oxidation salt — the paired test of §6 item 1. Either failure routes the salt to Stage 8.
- **BMED products:** purity at the ≥99% benchmark [S42] for any off-site transfer; dilute pilot-class products (1.44%/2% [S45]) accepted for on-site reuse only.
- **Grout monolith (verified containment under specified conditions):** TCLP pass; leachability index ≥6.0 by ANSI/ANS 16.1 for the salt components — the criterion class DOE's waste-form program set [S51]; placement in an engineered unit under a state permit of the Saltstone class [S50]; groundwater monitoring under that permit, with monitoring results part of the containment claim. This paper claims **verified containment under these specified conditions, monitored** — it does not claim isolation under every conceivable condition, and no honest paper could.
- **Any injected stream:** within the receiving facility's permitted waste profile (Buckeye Brine's Class I permit class [S28]) — profile acceptance is the facility's and the regulator's to give, and obtaining it is **[GATED]** under §6.

A.5 The two studies this paper specifies but does not perform

Named here with their designs fixed, so their absence is a scoped decision and any future breath can execute them without re-deriving the frame. Both were called for by the second grader's findings 1 and 2; neither can be honestly populated from sources located in this paper's sweep (the train's system capital cost, membrane life on this feed, and disposal pricing are unlocated or **[GATED]**).

- **Life-cycle assessment.** Functional unit: 1 m³ of blowdown treated to the §A.4 criteria. Boundary: the Annex A train end to end — electricity, chemical production and transport, membrane manufacture and replacement cycles, residual transport, grout materials, disposal — against avoided burdens (makeup water production, sewer treatment, virgin chemical and limestone production, fossil heat where a sink exists). Baselines: (i) conventional discharge to a POTW/sewer at adopted rates; (ii) a Quincy-structure utility build. Sensitivity on: recovery rate (91/93/96%), heat-sink present/absent, BMED run/not run. Benefits demonstrated at other facilities and benefits projected for this design reported in separate columns, never summed into one figure.
- **Capital and operating cost model.** Low/central/high scenarios built only from sourced anchors until quotes exist: concentrate-handling routes at $0.20/$0.34/$0.43 per m³ [S46]; whole-train analogue ≈$0.70/m³ modelled [S62]; avoided sewer at $11.62/kgal class rates [S31]; disposal and buyer terms **[GATED]** (§6 item 6). Outputs: cost per m³ of recovered water and annual net cost against the conventional baseline. Capital enters as a stated range with its source named, or not at all — the Quincy $31M is a utility-scale anchor and is not decomposed into this train (§2.2 note).

Annex B — Evidence matrix (major claims)

Added in Edition 1.2. Confidence uses this paper's grades. "Access" for every entry: 2026-10-25. The full verification record behind each row is in the research archive uploaded with this paper (§9 closing note).

Claim	Source	Type	Conditions / basis	Limitation	Confidence
Electrochemical tower treatment: 100% chemicals eliminated, blowdown −99.8%, savings 31.6%	S1–S3	Agency (GSA/NREL)	300-ton towers, Savannah testbed	Building scale, not hyperscale; non-Savannah testbeds weaker M&V	Demonstrated (at that scale)
Blowdown → makeup utility, 138M gal/yr, $31M, 30-yr	S9	Agency case study (EPA)	Quincy, WA; lime/UF/HES/RO; brine ponds for residuals	Residual fate is containment, not valorization	Demonstrated

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Claim	Source	Type	Conditions / basis	Limitation	Confidence
Ocotillo brine facility 2.8 MGD; 96% recovery	S10, S11	Municipal letter; company	Fab process water, not tower blowdown; city design doc says >94%	Two figures, both carried attributed	Demonstrated (feed differs)
Pellet-RO on blowdown: >91%, ~94% phase 2; silica 100–150 mg/L; pellets >95% dry	S4, S5	**VENDOR** (IDE)	48 m³/d demo, ENEL San Isidro	96% is a target; duration framing conflicts internally; no independent confirmation	Pilot, vendor-grade
EC front-end: silica 67–98%; flux recovery 94%	S6	Project team, trade press	1.5 gpm pilot, real blowdown	USBR final report not text-verified (S7); VAED tail energy disqualifying	Pilot
Technion train >95% at ≈$0.70/m³	S62	Peer-reviewed	Brackish groundwater, ~20 mg/L silica; MVR simulated	Analogue, not a blowdown result	Pilot-analogue
eMalahleni: 16 ML/d, 60,000 people, 200 t/d gypsum to bricks, ~99% recovery	S13–S16	UN agency; operator	Mine water to potable, municipal custody	Brick use begun, not full-tonnage; SANS 241 numbering rests on vendor/conference material	Demonstrated
Odense heat ≈45 MW	S17	Owner's engineer	District-heating sink present	Annual MWh phase-dependent; no Ohio sink established	Demonstrated (there)
DPR partner-agency door; AZ AWP pathways	S20, S25	Statute/agency	CA eff. 2024-10-01; AZ eff. 2025-03-04	No industrial-contributor precedent located under AZ pathways	Demonstrated (as rules)
Bioanalytical screening required (CA); EU effect-based trigger values	S21, S22, S24	Agency; institute; EU directive	CA policy eff. 2019; EU 2026/805 in force 2026-05-11	"First in the world" is SCCWRP's phrasing, attributed	Demonstrated (as rules)
Benzotriazole = EU indicator; 80% is an average across ≥6 substances	S23	EU directive	Quaternary treatment, phased to 2045	Not a per-substance mandate	Demonstrated (as rule)
Bromate: suppression 80–82%; RO removal 96–97%; MCL 10 µg/L	S55, S56, S67	Peer-reviewed pilots; critical review; EPA	Potable-reuse conditions, not blowdown	Feed-specific measurement still owed (§6 item 3)	Pilot

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Claim	Source	Type	Conditions / basis	Limitation	Confidence
Phosphonate conversion: NTMP 89%/24 h; HEDP UV/chlorine figures	S39, S40	Peer-reviewed	WWTP effluent; RO antiscalant studies	Matrix effects; conversion creates orthophosphate needing capture	Pilot
BMED purities ≥99% (≈2 M); named-system range 93.9–99.2%; OIE pilot 1.44%/2%	S42–S45	Peer-reviewed; industrial report	Pre-purified/pre-treated brines	99.99% excluded (§7); dilute pilot products are a ceiling under their conditions	Pilot–Demonstrated (by system)
Saltstone containment since 1990; >56M gal grout (Dec 2025)	S49, S50	DOE; state regulator; operator	Nuclear salt waste, cementitious grout	56M figure is operator-reported; ≈1.6× ratio is derived	Demonstrated
Buckeye Brine Class I cap 12,710,700 gal/month	S28, S29	State permit; statute	Coshocton, OH	Renewal dates and price not located	Demonstrated (permit); price unknown
Ohio path: individual NPDES + PTI; no DC in Fairfield located	S26, S27, S35	Agency; code; agency fact sheet	As of 2026-10-25 sweep	Southerly 40 MGD is news-reported (S30), no city primary doc	Demonstrated (as rules/record)
Waste-heat MD at a data center	S60, S61	Peer-reviewed TEA; pilot	Biogas digestate; power-station pilot	**Null result:** no operating DC installation located	Not established

9. Sources

Every source below was located in the verification sweep of 2026-10-25 and checked against the claim it is cited for; a source's presence certifies nothing beyond that claim. Two exceptions stand on their face and are repeated here so the list does not overclaim: **S7** was verified at the programme's index only — the report text was not read; **S64**'s figure was read in the vendor's press release, not in the ERDC report's own text. Vendor sources are marked.

- **S1** US GSA, Green Proving Ground — *AWT: Electrochemical Water Treatment, Findings 038* — source
  [https://origin-www.gsa.gov/system/files/038-Electrochemical%20for%20Cooling%20Towers-Findings-508.pdf]
- **S2** US GSA, Green Proving Ground — *Alternative Water Treatments for Cooling Towers* (summary report) — source
  [https://www.gsa.gov/system/files/18-Alternative%20Water%20Treatments%20for%20Cooling%20Towers.pdf]
- **S3** NREL for GSA — *GSA Guidance for Alternative Water Treatment Systems for Cooling Towers* — source
  [https://docs.nrel.gov/docs/fy20osti/73940.pdf]
- **S4** Water Tech Online (authored by IDE Technologies' Director of Water Treatment Process) — *Case Study: 96% Recovery of Power Plant's Cooling Tower Blowdown with an Advanced Reverse Osmosis Demonstration Plant* (2023) — **VENDOR-authored** — source
  [https://www.watertechonline.com/water-reuse/article/14298234/case-study-96-recovery-of-power-plants-cooling-tower-blowdown-with-an-advanced-reverse-osmosis-demonstration-plant]
- **S5** IDE Technologies — *MAXH2O Desalter for Brine Minimization and Effluent Treatment* (brochure) — **VENDOR** — source [https://ide-tech.com/wp-content/uploads/2025/03/MAXH2O-Desalter-digital.pdf]
- **S6** POWER Magazine (Garver project lead) — *A Model for ZLD Treatment of Blowdown from Cooling Towers—Even the Big Ones* (2023) — source [https://www.powermag.com/a-model-for-zld-treatment-of-blowdown-from-cooling-towers-even-the-big-ones/]

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- **S7** US Bureau of Reclamation, DWPR — *Pitch-to-Pilot Research Reports* (index; Report #4 existence confirmed, text not verified) — source [https://www.usbr.gov/research/dwpr/P2P_Reports.html]
- **S8** Kurita America — *The Pursuit of a Green Corrosion Inhibitor, Part 1* — **VENDOR** — source [https://www.kuritaamerica.com/the-splash/the-pursuit-of-a-green-carbon-steel-corrosion-inhibitor-laying-the-groundwork-part-1]
- **S9** US EPA — *Water Reuse Case Study: Quincy, Washington* — source [https://www.epa.gov/waterreuse/water-reuse-case-study-quincy-washington]
- **S10** City of Chandler — comment letter to US Bureau of Reclamation (March 2, 2026) — source [https://www.usbr.gov/ColoradoRiverBasin/post2026/draft-eis/docs/PublicComments/Local/CityofChandler-008067.pdf] ; and City of Chandler professional services agreement (Jan 2023) — source [https://public.destinyhosted.com/chanddocs/2023/CC/20230123_672/3432_WW2001.203_READY_3.pdf]
- **S11** Intel — *Intel's Ocotillo Campus Honored for Water Stewardship* (2023) — source [https://download.intel.com/newsroom/archive/2025/en-us-2023-07-11-intels-ocotillo-campus-honored-for-water-stewardship.pdf]
- **S12** US EPA, Performance Track — *Intel's Successful Water Conservation Program at Ocotillo* — source [https://nepis.epa.gov/Exe/ZyPURL.cgi?Dockey=P1006NZ0.TXT]
- **S13** UNFCCC, Momentum for Change — *eMalahleni Water Reclamation Plant* — source [https://unfccc.int/climate-action/momentum-for-change/lighthouse-activities/emalahleni-water-reclamation-plant]
- **S14** Anglo American South Africa — *Anglo American demonstrates a solution to the looming water crisis in South Africa* (2015) — source [https://southafrica.angloamerican.com/media/press-releases/2015/26-08-2015]
- **S15** Water360 / International Water Association — *eMalahleni Water Reclamation Plant case study* — source [https://water360.com.au/case-study/e-malahleni-south-africa-emalahleni-water-reclamation-plant/]
- **S16** Thungela Resources — 2024 ESG/annual reporting (operator statements on the eMalahleni plant) — source [https://thungela-reports.co.za/esg-2023/approach-to-esg.php]
- **S17** Ramboll (Owner's Engineer) — *Meta: surplus heat to district heating* — source [https://www.ramboll.com/en-us/projects/energy/meta-surplus-heat-to-district-heating]
- **S18** ASHRAE TC 9.9 — *2021 Thermal Guidelines for Liquid Cooling, Table 3.1* (5th-edition reference card) — source [https://www.ashrae.org/File%20Library/Technical%20Resources/Bookstore/Supplemental%20Files/Therm-Gdlns-5th-R-E-RefCard.pdf]
- **S19** NVIDIA Blog — *Hotter Than a Hot Tub: The 45°C Breakthrough to Cool AI's Biggest Machines* (2026) — **VENDOR** — source [https://blogs.nvidia.com/blog/liquid-cooling-ai-factories/]
- **S20** California State Water Resources Control Board — DPR regulations page, and 22 CCR § 64669.05 (DiPRRA and Partner Agency definitions) — source [https://www.waterboards.ca.gov/recycledwater/] ; source [https://www.law.cornell.edu/regulations/california/22-CCR-64669.05]
- **S21** California State Water Resources Control Board — *Water Quality Control Policy for Recycled Water* (2018 amendment), with US EPA's summary of California's IPR guideline (Table 9 MTLs) — source [https://www.waterboards.ca.gov/water_issues/programs/recycled_water/policy.html] ; source [https://www.epa.gov/waterreuse/summary-californias-water-reuse-guideline-or-regulation-indirect-potable-water-reuse]
- **S22** SCCWRP — *California's experiences with bioanalytical screening included in new international guidance documents* (2022) — source [https://www.sccwrp.org/news/californias-experiences-with-bioanalytical-screening-included-in-new-international-guidance-documents/]
- **S23** Directive (EU) 2024/3019 (recast Urban Wastewater Treatment Directive), Annex I Table 3 and Note 2 — EUR-Lex — source [https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32024L3019]
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- **S25** Arizona DEQ — *Advanced Water Purification (AWP) Approved* (March 5, 2025), with US EPA's summary of Arizona's DPR regulation (§ R18-9-C813, § R18-9-E824) — source [http://azdeq.gov/pr/awp_approved] ; source [https://www.epa.gov/waterreuse/summary-arizonas-water-reuse-guideline-or-regulation-direct-potable-water-reuse]

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- **S26** Ohio EPA release of July 21, 2026 (verbatim reproduction, The Clermont Sun, July 22, 2026), corroborated by Columbus Dispatch and Farm and Dairy reporting of the same date — source [https://www.clermontsun.com/2026/07/22/ohio-epa-will-not-finalize-proposed-data-center-general-permit]
- **S27** Ohio Administrative Code 3745-42-02 (permit-to-install) and 3745-42-06 (general PTI eligibility) — source [https://codes.ohio.gov/ohio-administrative-code/rule-3745-42-02]
- **S28** Ohio EPA — *UIC Permit to Operate, Class I Non-Hazardous, Buckeye Brine LLC, No. UIC 04-16-017-PTO* — source [https://edocpub.epa.ohio.gov/publicportal/ViewDocument.aspx?docid=3428989]
- **S29** Ohio Revised Code § 6111.043 (five-year injection-well permit term) — source [https://codes.ohio.gov/ohio-revised-code/section-6111.043]
- **S30** The Columbus Dispatch — *Columbus-area data centers used 1.2 billion gallons of water in a year* (July 6, 2026) — source [https://www.dispatch.com/story/news/local/2026/07/06/columbus-area-data-centers-used-1-2-billion-gallons-of-water-in-a-year/90664392007/]
- **S31** Austin Water — *Commercial Public Rates 2026* (rates effective November 1, 2025) — source [https://austin.widen.net/content/aqqaszp2rc/original/CommercialPublicRates_2026.pdf]
- **S32** The Columbus Dispatch (Nov 11, 2025) and Columbus Monthly (Oct 6, 2026) — Columbus composite rate increases — source [https://www.dispatch.com/story/news/local/2025/11/11/columbus-city-council-to-vote-on-water-bill-increases-for-city-suburbs/87194716007/]
- **S33** Loudoun Water — *Information on Rate Changes* (7.0%/yr adopted Dec 12, 2024, for 2025–2027) — source [https://www.loudounwater.org/information-rate-changes]
- **S34** US EPA — *Proposed Sixth Unregulated Contaminant Monitoring Rule (UCMR 6)*, 91 FR 39952 (July 1, 2026) — source [https://www.epa.gov/dwucmr/proposed-sixth-unregulated-contaminant-monitoring-rule] ; source [https://www.govinfo.gov/content/pkg/FR-2026-07-01/pdf/2026-13263.pdf]
- **S35** Ohio EPA — *Fact Sheet for NPDES Permit Renewal, Fairfield WWTP (1PD00003)* — source [https://dam.assets.ohio.gov/image/upload/epa.ohio.gov/Portals/35/permits/doc/1PD00003.fs.pdf]
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- **S37** Data Center Dynamics — Prologis Trenton and Amazon Butler County coverage (2025–2026) — trade press — source [https://www.datacenterdynamics.com/en/news/prologis-details-plans-for-data-center-campus-outside-cincinnati-ohio/]
- **S38** López-Aragó et al. — *Insights on the removal of the azole pesticides included in the EU Watch List by Catalytic Wet Peroxide Oxidation*, Environmental Technology & Innovation 29 (2023), DOI 10.1016/j.eti.2022.103004 — source [https://www.sciencedirect.com/science/article/pii/S2352186422004278]
- **S39** Lei, Saakes, van der Weijden & Buisman — *Electrochemically mediated calcium phosphate precipitation from phosphonates*, Water Research 169 (2020) 115206 — source [https://zenodo.org/records/3625981]
- **S40** Huang et al. — *UV/chlorine oxidation of the phosphonate antiscalant HEDP*, Journal of Environmental Management 237 (2019) — source [https://www.sciencedirect.com/science/article/abs/pii/S0301479719302063] ; and ATMP ozonation study, Chemosphere — source [https://www.sciencedirect.com/science/article/abs/pii/S0045653521034998]
- **S41** Rott, Happel, Armbruster & Minke — *Behavior of PBTC, HEDP, and Aminophosphonates in the Process of Wastewater Treatment*, Water 12(1) (2020) 53 — source [https://puma.ub.uni-stuttgart.de/bibtex/2c972be255d3cedc6ae25b9ace294bbb4/eduardrott]
- **S42** Chen, Jiang, Wang, Fu, Liu & Xu — *Selectrodialysis with bipolar membrane for the reclamation of concentrated brine from RO plant*, Desalination 442 (2018) — source [https://www.sciencedirect.com/science/article/abs/pii/S0011916418302510] ; the "nearly 99.99%" restatement: Membranes 13(6) (2023) 605 — source [https://www.mdpi.com/2077-0375/13/6/605/htm]
- **S43** Yan et al. — *In-Situ Combination of Bipolar Membrane Electrodialysis with Monovalent Selective Anion-Exchange Membrane…*, Membranes (2020) — source [https://pmc.ncbi.nlm.nih.gov/articles/PMC7345200/]
- **S44** *Bipolar membrane electrodialysis for producing acid and alkali from concentrated seawater: Industrial application in Bohai Sea, China*, Journal of Water Process Engineering (2025) — source [https://www.sciencedirect.com/science/article/abs/pii/S2214714425013388]

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- **S45** Gazigil, Er, Kestioglu & Yonar — *Pilot-Scale Test Results of Electrodialysis Bipolar Membrane for Reverse-Osmosis Concentrate Recovery*, Membranes 12(1) (2022) 83 — source [https://www.mdpi.com/2077-0375/12/1/83/pdf]
- **S46** Salas, Schwarz & Gonzalez-Vogel — *Desaturation and chemical recovery from desalination concentrates using ion exchange and bipolar membrane electrodialysis as a zero liquid discharge process*, Environmental Science: Water Research & Technology 12 (2026), DOI 10.1039/D5EW00977D — source [https://pubs.rsc.org/en/content/articlehtml/2026/ew/d5ew00977d]
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- **S49** US DOE — *Savannah River Site Facility Produces 30 Million Gallons of Decontaminated Mixture* (Jan 2019); *Fiscal 2021 Saltstone Production Surpasses Past Five Years Combined*; Savannah River Mission Completion, site facilities booklet (Dec 2025) — source [https://www.energy.gov/srs/articles/savannah-river-site-facility-produces-30-million-gallons-decontaminated-mixture] ; source [https://www.savannahrivermissioncompletion.com/_files/ugd/bb0c50_1ac70b793cf74027a4cf6f923bdcb651.pdf]
- **S50** South Carolina DHEC — modified permit, SRS Z-Area Saltstone Disposal Facility, No. 025500-1603 (2011, hosted by US NRC) — source [https://www.nrc.gov/docs/ML2020/ML20206L011.pdf]
- **S51** US DOE — *Stabilize High Salt Content Waste Using Sol Gel Process*, Innovative Technology Summary Report DOE/EM-0473 (1999) — source [https://www.osti.gov/biblio/1246966]
- **S52** Hollender et al. — *Elimination of organic micropollutants in a municipal wastewater treatment plant upgraded with a full-scale post-ozonation…*, Science of the Total Environment 407 (2009) — via MDPI Processes 9(6) (2021) 1013 — source [https://www.mdpi.com/2227-9717/9/6/1013]
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- **S61** Dow et al. — pilot trial of direct-contact membrane distillation driven by low-grade waste heat at a gas-fired power station, Desalination — source [https://www.sciencedirect.com/science/article/pii/S0011916416300224]
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- **S64** 374Water Inc. — press release, *U.S. Army Corps of Engineers Validates 374Water's AirSCWO Technology at 99.9993% PFAS Destruction* (July 23, 2026) — **VENDOR**; the underlying report is ERDC TR-26-19 (catalogued, ERDC Library) — source [https://internationalorganizations.einnews.com/pr_news/929141516/us-army-corps-of-engineers-validates-374water-s-airscwo-technology-at-99-9993-pfas-destruction-in-afff-treatment-report]
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End of paper. The verification record behind it — five cluster reports and the independent recomputation — is uploaded with this paper in the same Drive folder ("04 — Purity Project") as `PURITY-ANALYSIS-RESEARCH-2026-10-25.zip`, so any reader of this paper can re-run the checks.

Edition note: Edition 1.1 (2026-10-25) amended Edition 1.0 at the first grader's findings — §8's verdict made conditional on pilot items 1, 3, and 4; the §8 evidence sentence restated tier by tier; the heat line in §8 rewritten (no magnitude asserted; the Ohio heat-sink gap named); §4.7 added (first-order energy envelope, gaps named); a transfer-risk paragraph added at the head of §4; §2.4's heading grade separated; §5 closed with its own owed-work statement; this sources preamble corrected. ***Edition 1.2 (2026-10-25)*** *amends 1.1 at a second, independent evaluation (A–, 91/100; preserved with the research archive): §8's verdict restructured into the evaluator's three levels (Demonstrated / Plausible but unproven / Not yet established) and its ledger given a reading rule separating demonstrated-elsewhere benefits from projected ones; the Quincy $7.49/kgal figure relabeled an arithmetic annualization, not a levelized cost; "no environmental re-entry" operationally defined in §4 as verified containment under specified conditions;* ***Annex A*** *added (process flow, stream-by-stream mass balance, stage table with status/operating ranges/failure modes, PROPOSED acceptance criteria, and the specified-but-unperformed LCA and cost-model designs);* ***Annex B*** *added (evidence matrix). No verified claim changed in either edition.*