

Water From Energy research program

The eight proposed studies address specific decisions in water recovery, reuse and resource recovery. None has established novelty or produced experimental results. The program distinguishes candidate contributions from comparative validation.

Purpose and contribution

The program seeks useful knowledge about water recovery and resource use. Each study must state what prior work already establishes, what decision remains uncertain and what observation would reject the proposed improvement. A successful test can support a bounded contribution; it does not prove that no earlier publication or implementation exists. Scientific novelty, patentability, commercial value and readiness for a particular grant are separate assessments.

Qualification before confirmation

Gate 0 requires a named scientific lead, real feed or climate/service definition, access to the strongest feasible comparator, a precise prior-art difference and an approved residual route. Gate 1 uses development data to qualify measurement uncertainty, reference conditions, independent units, feasible operating limits and a practically important margin. Gate 2 freezes the question, policies, primary endpoint, analysis, planned contrasts and exclusions. Only then may independent confirmation begin. Gate 3 decides advance, revise, adopt the conventional option or stop. A failed novelty gate may leave a useful validation study, but it must be described and funded as validation.

Comparable service and measurement

Define accepted output for an actual intended use. Conductivity alone does not establish broad reuse or drinking-water safety. Record accepted and rejected water, external water, sampling, residual liquid, wet solids and inventory changes. Record thermal energy, auxiliary electricity and cooling separately. Allocate a coproduct credit once and keep mineral sales at zero in research funding estimates. Quantities initially added as reagents cannot be counted as recovered feed constituents. Set mass-balance acceptance from calibrated uncertainty rather than an arbitrary universal closure percentage.

Inference and stopping

Development observations are not confirmation evidence. Freeze policies and hold out entire feed collections, seed histories, trajectories or devices as appropriate. Randomize within practical blocks, record apparatus carryover and use independent quality measurements. Analyze at the independent block or device level; repeated cycles and sensor points do not create more independent replicates. Estimate precision from development variance and the agreed smallest useful effect before confirmation. Proposed sample counts and percentage margins are planning assumptions. Use one primary confirmatory contrast per study, report other comparisons as secondary, account for multiple confirmatory claims if added, and retain failures, nondetects, zero production and downtime. A tie favors the simpler adequate approach.

Portfolio sequence and shared work

A is the first candidate for expert challenge because the project selected brackish-water concentrate recovery as its initial application. F is the alternative when an equipped membrane-distillation host and a useful protection problem are available first. E follows a real brine/product need. B requires representative operating data. C and G share a source/sink feasibility assessment and apparatus planning; C qualifies treatment/material performance, while G assesses cooling and water service. D shares relevant feed assays and finishing work with E only when the feed, target and scope match. H remains a distinct small-supply question. Shared observations cannot be sold as independent replication, and shared staff/equipment cannot be funded twice. Eight standalone estimates are alternatives, not an additive portfolio budget.

Funding and scientific responsibility

Plan the real scope rather than shrinking it to a grant ceiling. Budgets include the established founder coordination input of \$135,200 gross per funded year, qualified scientific staff, laboratory services, institutional costs and reserve under the common model. These are unquoted estimates, not employment offers or spending approvals. Daniel coordinates the program and evidence; the scientific lead owns laboratory methods and approval. A research question alone does not resolve the missing applicant, host, financing or scientific leadership for a submission. Initial physical work uses ordinary water-treatment equipment. Nuclear heat remains a separately bounded modeling scenario without a reactor connection or radiological-safety claim.

Portfolio decisions

Study	Research question	Classification
A	Can separate tests of process liquid and reused gypsum seeds choose corrective actions more economically than calibrated crystallization kinetics and a tuned operating rule?	Candidate decision-method contribution; novelty unresolved
B	Does a consistency check across flow, pressure and salt measurements improve accepted-water operation under unseen faults beyond a tuned normalization-based controller?	Candidate control contribution; novelty unresolved
C	Which qualified membrane and source/sink conditions can deliver the same useful water and cooling service at a lower whole-system burden?	Comparative validation and operating-envelope research
D	For one native feed and one product or removal service, does the proposed recovery route outperform the strongest conventional route after regeneration, material loss and finishing?	Conditional target-specific validation; material novelty not defined
E	Does an impurity- and inventory-aware wash/purge rule reduce total external freshwater use on real concentrate beyond optimized conventional recycled or countercurrent washing?	Candidate operating-rule contribution; novelty unresolved
F	Does a transport-aware routing rule reduce actual off-spec water entering the accepted tank beyond competent early-warning and diversion controls?	Candidate system-control contribution; novelty unresolved
G	When do source interruption, hot sinks and real demand make heat-assisted recovery better or worse than conventional cooling plus water treatment?	Equal-service integration validation with a conditional control question
H	Can a controller that accounts for uncertain forecasts and stored moisture avoid wasted regeneration while delivering more qualifying water than a tuned adaptive controller under the same resource limits?	Candidate constrained-control contribution; novelty unresolved

A — Diagnose the cause of mineral buildup

Can separate tests of process liquid and reused gypsum seeds choose corrective actions more economically than calibrated crystallization kinetics and a tuned operating rule?

Prior work. Antiscalant removal, seeded precipitation, seed reuse, kinetic diagnosis, dual-probe monitoring and seed attrition have precedents. The proposed contribution is the incremental value of a specific crossed assay in an operating decision. [N03](#) [N04](#) [N05](#) [N06](#) [N07](#) [N08](#) [N09](#) [N10](#) [N11](#) [N01](#) [N02](#)

Candidate difference. A crossed liquid-by-seed response informs a frozen action table. Its own water, analysis, delay and handling costs are charged to the proposed policy.

Planning scope. 72 development assay vessels; 36 confirmation campaigns of three decision cycles; 216 diagnostic vessels within the proposed-policy campaigns; 18 downstream RO compatibility runs. 1,368 principal panel equivalents.

Before confirmation. A gypsum-limited brackish RO concentrate, interpretable liquid/seed reference assay, different feasible best actions, and a qualified host are required.

Feed and reference assay

Use one gypsum-limited inland brackish RO concentrate family, rather than pooled seawater and inland feeds. Verify the limiting solids, major ions, alkalinity, additives and competing fouling. Cross matched reference/process liquid with fresh/reused seeds. Match calcium and sulfate activities, major-ion matrix, pH and temperature; reference preparation must not silently alter the causal factor. Measure seed mass, size and effective area. Include unseeded reference/process controls and transfer/carryover checks. A washed seed may lose the surface condition under study. A low growth response is an operational association until validated mechanistic controls distinguish inhibition, aggregation and active-area loss.

Development and decision logic

Use three independently collected development lots and four controlled response families: reference behavior, liquid-associated inhibition, seed-associated deterioration, and their combination. Each family receives four crossed cells and two unseeded controls, giving 72 assay vessels. The perturbations and concentrations are qualified by the host and are not claimed to represent field prevalence. Obtain three chemical panel equivalents per vessel to estimate growth response over a qualified interval. Fit a parsimonious action table using liquid effect, seed effect, interaction and uncertainty. If the assay is indeterminate, fall back to C1. If realistic states favor the same action, or assay uncertainty/delay prevents useful discrimination, stop diagnostic development.

Strongest feasible comparison

Give C0, C1 and T the same permitted actions: continued operation, qualified inhibitor-removal treatment, seed purge/makeup, and feasible conditioning or attrition. Include an action only when the host can implement it safely and compare it fairly. Calibrate C1 against the kinetics and practical seed-management precedents, rather than an arbitrary fixed dose. Make routine sensors and operating limits identical. Only T receives the extra crossed-assay information, and pays its full burden. Attrition is an established alternative to investigate, not an invention claimed by the program.

Independent confirmation and quantities

After freezing all policies, use six later feed collections, two independently established seed histories per collection and three policies: 36 campaigns. Each campaign performs three successive decision cycles, preserving its inventory. Lots are the highest-level blocks; the two seed histories are nested units, not twelve unrelated feeds. Randomize policies/order and reactor assignment within blocks. T has 12 campaigns, and each decision uses four crossed cells plus two unseeded controls: 216 additional diagnostic vessels. Allocate four process panels to each of 108 process cycles, and three to each diagnostic vessel. Finish with 18 separate downstream RO compatibility runs, one per feed-lot/policy combination, with four panels each. Principal capacity is $72 \times 3 + 108 \times 4 + 216 \times 3 + 18 \times 4 = 1,368$. The downstream sample rule is fixed before selection; do not choose only the best campaign.

Endpoints and decision

The primary contrast is T versus C1 in variable operating burden per qualifying treated-concentrate volume at fixed throughput. Record physical amounts and delay alongside cost, including all assay, reagent, seed, energy, sludge, cleaning, reject and downtime burdens. Advance only when uncertainty supports the host-agreed useful margin and all service/residual limits pass. Report C0 secondarily. Report actual and membrane-specific normalized RO flow/salt passage at frozen reference conditions, stage by stage where applicable; do not normalize away a real osmotic-pressure benefit. The public ASTM scope and LG bulletin guide method selection, but do not establish full ASTM compliance. A three-cycle campaign is an initial decision test, not a 30-cycle reuse or lifetime claim.

Resources and work sequence

Use a 12-funded-month planning envelope: months 1–3 qualify feed, references and actions; 4–5 develop policies; 6–9 complete confirmation; 10–11 test downstream compatibility; 12 independent review. Use crossed-assay and conventional seed-management apparatus. Include nine collection events, seed/reference consumables, additional chemical panels and specific assay-qualification work. The scientific lead must revise capacity if reaction times, variance, matrix-specific analyses or apparatus scheduling exceed this ceiling.

B — Make reuse decisions reliable

Does a consistency check across flow, pressure and salt measurements improve accepted-water operation under unseen faults beyond a tuned normalization-based controller?

Prior work. RO normalization, predictive maintenance and automatic quality diversion are established. A prediction score or the use of AI is not the proposed contribution. [N01](#) [N02](#) [N09](#) [N12](#) [N32](#) [N33](#) [S06](#) [S07](#)

Candidate difference. A frozen joint consistency rule decides whether the controller can trust its state estimate or must use a conservative fallback.

Planning scope. 18 development runs and 54 held-out confirmation runs across three controllers, three challenge families and six feed/time blocks; 288 principal panel equivalents.

Before confirmation. A defined reuse service, authorized operating data, independent nonsalt quality methods and representative fault opportunities are required.

Specific intervention

Fit the conventional process model on development data. Compute prespecified residuals between measured and predicted salt/flow/pressure behavior and their uncertainty. T uses their joint consistency, rather than a single alarm, to accept the estimate, continue the qualified policy or abstain to the same safe fallback available to C1. Freeze residual definitions, thresholds, persistence, recovery rules and permitted setpoints. Both C1 and T have the same instruments, quality limits, pressure ceilings and opportunity to tune fault handling. Do not suppress a competent baseline feature simply to create a difference.

Development and confirmation

Use three complete development blocks with six runs each: 18 runs for model/threshold qualification, including matched reference and fault cases. On six later independent feed/time blocks, compare three controllers under three families: routine qualified variation, sensor drift/dropout, and a feed-composition shift that can fool a salt-only proxy. This gives 54 confirmation runs, nominally six hours each. Reset/verify carryover, balance apparatus assignment and randomize within blocks. A hazardous contaminant is not required; use the host-approved safe matrix and analytical challenge. Historical replay can reject a weak policy but is not causal proof of a changed physical plant. Physical confirmation supplies that comparison.

Measurements and analysis

Allocate four principal panels per development/confirmation run: $72 \times 4 = 288$, plus the proposed separate commissioning/blind/QC and nonsalt-method allowances. Choose feed, accepted product and rejected/residual timing during method qualification. Independently measure quality at the delivery boundary and count false acceptance, good-water loss, cleaning, interventions, electricity and calendar downtime. Primary T–C1 comparison is accepted service with no deterioration beyond prespecified absolute quality-risk and resource limits; a lower failure count is not a claim of zero risk. Analyze six blocked contrasts, not sensor samples. Freeze the smallest useful service gain and admissible quality margin with the host; power may require more blocks.

Stop and resource gate

Stop if C1 already provides equivalent qualified service, reference data cannot identify failures, or the joint residual method merely replicates existing practice without a useful unresolved comparison. Use a 12-month staffing and equipment envelope, nine feed/data collection allowances, independent controller audit and feed-specific analytical qualification. No autonomous control of a real production site or certification of reuse water is included.

C — Find when recovered heat earns its place

Which qualified membrane and source/sink conditions can deliver the same useful water and cooling service at a lower whole-system burden?

Prior work. Waste-heat desalination and Janus membrane architectures are established. Combined oil/surfactant exposure also appears in later public research; it is not by itself an originality claim. [N13](#) [N14](#) [N15](#) [N24](#) [S24](#) [N34](#) [S09](#) [S22](#)

Candidate difference. Measure the boundary at which a material's stability, absolute throughput, cleaning burden and cooling demand change the preferred process.

Planning scope. 48 material screens, 72 equal-service comparisons and six 30-cycle endurance campaigns; 972 principal panels.

Before confirmation. Use a measured source/sink envelope, available qualified specimens and a question beyond repeating established material performance.

Contribution and prior-art test

Treat the material screen as qualification/validation. The hypothesis is a condition-dependent process ranking, not a new coating, first waste-heat apparatus or first combined-contaminant challenge. Register a source/sink/service cell where uncertainty could plausibly reverse the choice. If no useful uncertainty remains after the desk model and literature comparison, do not buy a second demonstration rig. A hydrogel-modified PTFE preprint reports a combined synthetic challenge; its selected results and figure were checked, but that does not establish field lifetime, general organic purity or the suitability of its chemistry here.

Methods proposed and bounded

Use the detailed C methods in this protocol: four obtainable architectures, clean/surfactant/oil/combined challenges, three independent preparations, later equal-service feed lots and separate endurance collections. Compare absolute accepted output as well as normalized stability. Select one qualified MD material on development data and freeze it before equal-service confirmation. Six endurance campaigns are a ceiling; if the selected and conventional materials coincide, use the defined narrower branch and make no distinct-material claim. Apply release and cleaning gates before material selection. The proposed >5% modeled cost advantage remains a practical decision margin for host review, not proof of scientific novelty.

Shared work and stop

Share the source/sink feasibility model and, where practical, apparatus qualification with G. Charge shared equipment, founder time and analytical development once in a combined award. Keep C's material/treatment comparison distinct from G's cooling-service study and disclose shared observations. If a conventional treatment delivers equal service as well or better, select it and publish the operating boundary. No laboratory result is converted into a data-center partnership or river-restoration claim.

Implementation: Material qualification

Use four architectures where obtainable: conventional hydrophobic, omniphobic, a hydrophilic surface on a hydrophobic substrate, and a hydrophilic surface on an omniphobic substrate. Obtain commercial or partner-supplied specimens with preparation and composition records; custom membrane synthesis is outside this estimate. Use three independently prepared specimens per architecture/challenge. Four architectures × four challenges × three preparations gives 48 separate screening runs. Randomize run order within preparation and feed blocks. Keep membrane area, hydraulics, feed composition and thermal conditions matched; report thickness and pressure drop. Fix feasible screening temperatures after source/sink commissioning; do not assume the paper's operating point represents a low-grade heat source.

Implementation: Challenges and material gate

Use a clean matrix, surfactant alone, oil alone, and combined oil/surfactant. A synthetic matrix is suitable for mechanism screening; three real development feed lots establish relevance and feasible spike levels. Set concentration ramps and durations during commissioning and lock them before screening comparisons; allow up to ten operating hours per screening run. The paper's challenge concentrations are literature anchors, not environmental exposure claims. Before confirmation, qualify cleaning compatibility and composition-specific leaching, particle release and analytical detection limits. Fluorinated chemistries require an appropriate analyte list, handling and waste route; this is not approval to reproduce the paper's coating recipe. A material that fails the agreed water-contact criteria does not advance.

Implementation: Equal-service confirmation

Select one qualified MD material and the strongest feasible electricity-powered water-treatment baseline using development data. Freeze recovery, accepted-water requirements, source heat availability, cooling duty, return-temperature limits and accounting boundaries. Use source settings of 40, 50 and 65 °C and two sink conditions chosen within the verified apparatus envelope. Three later independent feed lots × two independent apparatus/coupon preparations per lot × three source settings × two sinks × two processes gives 72 six-hour comparison runs, paired within each condition. Count the electric baseline's independent cooling service too. Do not extrapolate an infeasible operating cell: report it as unavailable. Fresh batches and the two processes must supply the same defined service, not merely run for the same duration.

Implementation: Endurance, measurements and inference

Use three additional feed collections in three matched pairs: the selected MD material versus the strongest qualified conventional MD material. Six independently prepared campaigns each receive 30 six-hour operating cycles with a prespecified cleaning, rinse and restart procedure. Record recovery after each cleaning and cumulative accepted water per area and campaign. If the selected material is itself the conventional comparator, run three endurance campaigns and report no distinct-material comparison; the six-campaign budget is a ceiling. This 30-cycle screen does not establish field lifetime. In all stages record absolute flux, normalized flux, independent product conductivity, salt rejection, pressure, temperature, heat, auxiliary electricity, all external water and inventory changes. Report thermal kWh and electric kWh separately. Quality failures do not count as accepted production. Budget three chemistry panels per screening run, four per comparison run and three per endurance cycle: $144 + 288 + 540 = 972$ principal panels. These cover feed/product/residual checks; 48 separate composition-specific release packages are an additional service allowance. Freeze the exact analytes and sampling times with the laboratory.

Implementation: Decision and resources

Advance only if the matched service and quality requirements pass and the modeled full water cost is at least 5% lower than the strongest feasible baseline under the declared assumptions, with uncertainty reported. Assess paired contrasts by independent preparation/feed block; repeated cycles are not independent replicates. Qualify this practical margin and the initial sample sizes with the scientific lead before confirmation. Otherwise report a negative or inconclusive result, or select the established process. Plan 18 funded months: months 1–4 source/sink and methods, 5–8 qualification, 9–13 comparisons, 14–16 endurance, 17–18 independent review. Use an isolated heat emulator with bypass and safe shutdown. No operating data center or reactor connection is included.

D — Choose a useful recovery service

For one native feed and one product or removal service, does the proposed recovery route outperform the strongest conventional route after regeneration, material loss and finishing?

Prior work. Magnetic sorbents, selective resins, boron pretreatment and magnesium precipitation have precedents. No exact new material composition is supplied or presumed. [N16](#) [N17](#) [N29](#) [N30](#) [S23](#) [S13](#) [S14](#)

Candidate difference. A target-specific comparison of cumulative qualifying output and total capture/regeneration/finishing burden, including lost support material.

Planning scope. Up to 24 development runs and six campaigns of up to 100 cycles; 2,202 principal panels at the full ceiling.

Before confirmation. Choose one native target, an obtainable material/process and an accepted service specification; complete an element-level comparison before any invention claim.

Target and contribution gate

Choose magnesium recovery or boron removal from assays and a receiver's requirement; do not fund both as one study. If the candidate is itself conventional and differs only by feed application, classify the result as transfer/validation. For a material claim, disclose the actual composition, support fraction, accessible preparation and regeneration mechanism, then compare each element against the magnetic-particle and resin precedents. No generic magnetic-bead purchase can substitute for that definition. A treatment service may have value without a saleable mineral.

Comparison and proposed methods

Use the detailed D development, paired later-feed campaigns, direct liquid/solid lithium balances and seven analytical checkpoints. Compare recoverable output per initial whole-composite mass as well as surviving material, recording attrition, carryover and replacement. Match acceptable treated volume and product requirements, not merely brine charged or percent removal. Boron pretreatment remains conditional on native chemistry; there is no automatic transfer of salt-lake results to seawater. The eight-panel checkpoint map must include actual incompatible fractions without unvalidated compositing.

Decision and overlap

Test the difference from the conventional route. A positive modeled net value under the proposed lower-value/higher-cost stress case is a commercial screening criterion, not an originality test. Stop a candidate with no attributable difference or no acceptable product/residual path. If E uses the same magnesium/boron development, make D that shared qualification package rather than repeat it as an independent discovery. Preserve six-campaign/100-cycle ceilings only for a justified distinct D question; narrow and recost shared execution before funding.

Implementation: Choose one service and develop the comparator

Collect three independent development feed lots. Measure target and competing species, salinity, suspended material and existing additives. Obtain a proposed customer's dry-product specification or boron-removal requirement, then choose magnesium recovery or boron removal. No customer, feed supplier or sale is secured. For magnesium, screen native feed versus boron-selective-resin pretreatment and NaOH versus lime precipitation: two pretreatment states × two reagent routes × three lots × two independent preparations = 24 development runs. Tune dose, pH, residence time, settling, wash and resin conditioning within the assay-derived chemical envelope. Use appropriate speciation and blanks. If native boron does not justify treatment, omit the resin half and document the 12-run branch. For a boron-removal service, use up to 24 runs to tune the selective-resin benchmark and candidate at matched treated-water specification; do not also conduct the magnesium program.

Implementation: Confirmation and reuse

Freeze one candidate process and the strongest feasible conventional route from development. Use three later independent feed lots, with one independently prepared candidate train and one conventional train for each lot: six campaigns, three per arm. Each campaign follows up to 100 feed/regeneration cycles; preserve and record inventories between cycles. Randomize paired execution order and block by feed lot. Track breakthrough by acceptable treated volume per resin/material volume, rather than counting all charged brine as successfully treated. Match product/service specifications and report residence time, bed volumes and pressure losses. Material replacement or a failed quality gate ends the campaign; do not replace failed runs silently.

Implementation: Direct balances and sampling

Weigh every feed, reagent, recovered liquid, wet cake, wash, regeneration fraction, purge and retained inventory. Measure lithium in liquids and digested solids; wet-minus-dry cake mass is a secondary entrainment estimate, not the lithium balance. Track B, Mg, Ca, Li and introduced material with blanks, validated digestion, matrix spikes and detection limits. Require a commissioning-derived uncertainty budget; unresolved closure outside that interval prevents a recovery claim. Fully assay eight allocated stream/panel equivalents at each of 24 screening runs and at cycles 1, 5, 10, 25, 50, 75 and 100 in each confirmation campaign. Those seven checkpoints replace the routine three-panel set for that cycle. Other cycles receive three panels for feed, treated liquor and regeneration output. At the full ceiling: $24 \times 8 + 6 \times 7 \times 8 + 6 \times 93 \times 3 = 2,202$ principal panels. Full analytical closure is assessed at checkpoints; mass and volume inventories are recorded every cycle. The eight-panel allocation must be mapped to actual fractions and solids before execution; obtain added capacity if separate incompatible fractions require it.

Implementation: Product, water and value

Qualify dry composition and relevant impurities with solid characterization and independent checks. Count all external water: reagent preparation, resin conditioning, acid/alkali regeneration, rinsing, cleaning and retained moisture. Internal recycling is an inventory transfer; usable effluent volume is a separate denominator from feed charged. Evaluate net process value after capture, regeneration, separation, drying, finishing, residual treatment, transport, replacements and water/energy costs. Only constituents originally present in the feed can count as recovered value. Mineral sales remain zero in the research funding model; scenario value is not booked income.

Implementation: Decision and resources

Proceed only when the customer/service requirement is met and modeled net value remains positive with product/service value 30% lower and operating costs 20% higher. Report the candidate's difference from the conventional route and uncertainty; a profitable conventional route can be the preferred outcome. Three independent campaigns per arm are an initial precision allowance, not proof of statistical power. The scientific lead must confirm the decision margin and power before confirmation. Plan 18 funded months, including development and qualification, staged cycle campaigns and independent product/value review. Six collection events, regeneration consumables, 72 solid-characterization samples and 84 special analytical packages are planning allowances. No additional target, resin lifetime beyond 100 cycles, pilot plant or market commitment is included.

E — Control the water cost of mineral washing

Does an impurity- and inventory-aware wash/purge rule reduce total external freshwater use on real concentrate beyond optimized conventional recycled or countercurrent washing?

Prior work. Displacement, recycled-brine and countercurrent washing already exist, including lithium-rich brine patents and industrial practice. Two wash stages alone are not a contribution. [N18](#) [N19](#) [N20](#) [N29](#) [N30](#) [S23](#) [S10](#) [S11](#) [S14](#)

Candidate difference. On a common wash topology, a frozen inventory/impurity rule selects reuse, fresh makeup or purge while meeting the same product and residual limits.

Planning scope. Up to 42 development runs; 24 confirmation campaigns of ten cycles; 2,820 principal panels.

Before confirmation. A real concentrate/product need, measurable native lithium and complete compatible-fraction balances are required.

Separate topology from the candidate rule

Keep the 24-run ceiling for treatment order and justified boron pretreatment. Use the 18 wash-development runs to compare optimized fresh washing, conventional displacement/recycle and established countercurrent washing. All are conventional comparators; choose the strongest feasible topology, then use that same topology for B0 and T. Fit and freeze T's inventory balance, impurity estimate, decision interval, conservative uncertainty bounds and reuse/fresh/purge table using development data. B0 receives competent conventional impurity limits, purge practice and equal sensor access. T must add a useful decision beyond the disclosed conventional washing and recycle rules.

Confirmation and sampling

Use six later lots, two independently prepared trains per arm/lot, 24 campaigns and ten cycles per campaign. Compare the locked policies on fresh aliquots with preserved wash inventory. Hold chemistry, product specification and permitted topology equal. Allocate the same up-to-ten principal panel equivalents per development run/confirmation cycle: $(42+240) \times 10 = 2,820$. Trace the proposed direct lithium, boron, magnesium, calcium, solid and regeneration-fraction map; count reagent dilution, resin conditioning/regeneration, wash, cleaning, purge and retained liquid. An absent stream is unused capacity, not a fabricated sample.

Decision and meaningful failure

The proposed >10% lower-confidence-bound freshwater reduction, $\geq 95\%$ native lithium retained in the designated recoverable liquid, matched product/brine specifications and downstream scale guardrail are proposed decision margins. Validate their measurability before confirmation. Infer paired effects at lot/campaign level. Ten cycles establish only the observed transient horizon; they do not prove steady-state accumulation or stable indefinite recycle. If impurity or water inventory still trends materially at the endpoint, report the transient result and recost a justified extension before a steady-state claim. If B0 is equivalent, keep B0. Keeping lithium is not producing a saleable lithium product.

Implementation: Feed, chemistry and development

Select one real SWRO concentrate source, with three independent development lots and six later confirmation lots. First compare calcium-first versus magnesium-first separation and native feed versus boron-selective-resin pretreatment, all with a common optimized fresh wash. Two orders $\times$ two boron states $\times$ three lots $\times$ two independently prepared trains gives up to 24 chemistry runs. Enable the resin branch only if native boron, speciation and the intended product requirement justify it; otherwise use the 12 native-feed runs. Do not spike confirmation feed to manufacture a boron problem. Select chemistry on qualifying products, lithium retention and total water/reagent/energy burden. Then tune three wash options at that chemistry: optimized fresh wash, a competent conventional displacement/recycled wash, and the established countercurrent wash. Three wash arms $\times$ three lots $\times$ two independent trains gives 18 additional development runs, for a 42-run ceiling.

Implementation: Apparatus and confirmation

Use two controlled stirred precipitation stages, solids separation, weighed rinse reservoirs and a matched downstream scale-challenge loop. Start with a nominal one-litre working batch, qualifying mixing and residence time. Include a small selective-resin column and conditioning/dosing connections only for the justified branch. Freeze chemistry, reagent dosing, resin operating limits, permitted wash-volume ranges, recycle boundaries, policy coefficients and cleaning rules after development. Select the strongest feasible conventional topology from fresh, displacement/recycle and countercurrent washing. Give B0 and T that same topology, chemistry, sensor access and permitted actions. B0 uses a competent conventional wash/purge policy; T adds the frozen inventory/impurity decision rule. Confirm B0 versus the inventory-aware policy on the selected conventional topology on six later lots with two independent trains per arm and lot: 24 campaigns. Each campaign processes ten fresh aliquots while maintaining its wash inventory: 240 repeated cycles. Both arms use the same selected chemistry and boron-treatment state. Cycles and aliquots within a campaign are not independent replicates.

Implementation: Measurements and water accounting

Measure external fresh-water input per litre of feed and per litre of qualifying remaining brine, with inventories corrected at the start and end. Include reagent dilution, resin preconditioning and regeneration, all washes, cleaning, purge and wet-cake water. Meter internal transfers separately and assign no water-saving credit simply for filling a reservoir. Weigh and assay lithium in every relevant liquid and digested solid; report both lithium retained in the designated recoverable liquor and whole-system closure. Measure B, Mg, Ca, introduced materials and product impurities. Report settling/filtration time, bed volumes, breakthrough, electricity and any drying burden. Do not assume a salt-lake resin flow rate works for SWRO concentrate.

Implementation: Analytical allocation

Allow up to ten chemistry panel equivalents for each of 42 development runs and 240 confirmation cycles: 2,820 principal panels. The provisional stream map is feed, remaining brine, two solids, two wash streams, rinse purge, acid regeneration eluate, alkaline conditioning discharge and final neutral rinse. Some fractions occur only at regeneration events; capacity for absent fractions is not a fabricated sample or result. Reagent-input blanks and qualification/QC are additional. Freeze event sampling and compatibility before execution; do not composite incompatible fractions to fit a budget. Obtain a validated solids digestion and an uncertainty-based closure criterion. If native lithium and the validated assay uncertainty cannot resolve the retention criterion, do not claim that it passed. A failure to close the lithium or water balance must be resolved or reported as inconclusive.

Implementation: Decision and scope

Advance only if the lower 95% confidence bound on reduction in total external fresh-water makeup exceeds 10% versus B0, at least 95% of feed lithium remains in the designated recoverable liquid with uncertainty accounted for, and both arms meet the same mineral and treated-brine specifications. The downstream scale endpoint must be no more than 10% worse than B0, or within a prespecified absolute tolerance where B0 is near zero. Use paired feed-lot contrasts and campaign-level inference; test whether the pilot variance supports these margins before confirmation. Report the conventional process as preferred if it performs as well or better. Plan 12 funded months: 1–2 feed/specifications/methods, 3–5 chemistry and wash development, 6–10 confirmation, 11–12 independent review. No mineral income or saleable lithium product is assumed. Capacity, material-release criteria and laboratory quotes must be resolved before testing.

F — Protect delivered water during faults

Does a transport-aware routing rule reduce actual off-spec water entering the accepted tank beyond competent early-warning and diversion controls?

Prior work. Conductive-spacer wetting sensing, threshold alarms, salinometers, dump valves and persistence delays have precedents. Neither early detection nor automatic diversion is new as a broad concept. [N21](#) [N22](#) [N23](#) [N24](#) [N32](#) [N33](#) [S24](#) [N34](#) [S06](#)

Candidate difference. A frozen residence-time and contamination-inventory estimate controls routing and safe recovery on matched hardware.

Planning scope. 12 commissioning runs and 108 confirmation runs; 864 principal plus 96 commissioning panels.

Before confirmation. Independent delivered-water truth, calibrated latency/mixing, an equipped MD host and a nontrivial baseline error or good-water-loss opportunity are required.

Define what T adds

Measure the full residence-time distribution, reference sensor response, valve delay and tank carryover. T propagates contamination-risk inventory through that calibrated flow path, routes conservatively when uncertainty overlaps the acceptance limit, and resumes collection only after its prespecified flushing/recovery condition. A fixed persistence timer or a larger holding tank is not the claimed advance. Give all arms identical sensing, tank volume, valve geometry, membrane and permitted actions; C1 includes competent persistence, hysteresis and fault diversion. Lock the model, thresholds and reset criteria before confirmation.

Adversarial test

Use six challenge families: gradual wetting, abrupt integrity failure, benign feed/temperature variation, sensor drift/dropout, oil-only fouling and combined oil/surfactant exposure. Twelve commissioning runs qualify ranges; six fresh coupons per controller/family give 108 confirmation runs, blocked across later feed and membrane lots. Oil-only is a negative wetting control only if independent truth confirms it. Hold out trajectories. The separate fast reference channel, synchronized logging and chemical sampling in the detailed methods are mandatory. Eight time-point panels per confirmation run are chemistry checks; continuous reference measurements establish the transient endpoint.

Primary contrast and stop

Use T versus C1 as the primary contrast. Predeclare an absolute exposure margin, quality gate and good-water-loss allowance for the selected service. Evaluate both harmful water accepted and unnecessary diversion; a controller that dumps everything cannot win. If baseline bad-water acceptance is effectively zero, report the floor and test a prespecified noninferiority/retention question only if it was chosen before confirmation; otherwise stop or redesign. Twelve commissioning runs are an allowance, not a guarantee that the latency model can be identified. The 2017 material paper's slow sampling cannot validate this controller, and later combined-challenge materials do not prove delivered-water protection.

Implementation: Apparatus and comparators

Use one characterized SWRO concentrate family in a contained direct-contact MD rig, nominal membrane area 0.02 m². Match flow path, active sensor availability, holding volume, valve geometry and membrane/spacer construction across controllers. C0 uses conductivity-triggered routing; C1 uses a tuned early-warning threshold plus conductivity; T adds the proposed transport-delay model and conservative fault diversion. Tune both baselines on the same development access as T. Use 12 commissioning runs, two allocated per challenge family, to qualify ranges, freeze threshold/timing rules and identify feasible exposure trajectories. Qualification may require revising this planning allocation before confirmation; never train on confirmation runs.

Implementation: Six challenge families

Confirmation covers (1) gradual surfactant-driven wetting, (2) abrupt membrane-integrity failure, (3) harmless feed or temperature variation within the qualified envelope, (4) sensor dropout or drift, (5) oil-only fouling, and (6) combined oil/surfactant exposure. Use six independently assigned fresh coupons per controller and family: six families $\times$ three controllers $\times$ six coupons = 108 runs. Block the six coupons across three later feed lots and at least three membrane preparations/lots where available; balance controllers within those blocks. Hold out complete concentration/time trajectories and feed lots from tuning. Set spike levels from the actual feed, apparatus limits and pilot response. If an intended oil-only negative control actually wets, classify it by the independent reference rather than relabeling the result to fit the hypothesis. A combined challenge is a test here, not a demonstrated result from the Janus paper.

Implementation: Independent truth and timing

Use a separate calibrated reference conductivity/quality channel and independently measured flows/tanks, synchronized with early sensors, valves and alarms. The reference must not share the proposed trigger as its truth signal. Before confirmation, measure sensor response time, sample transport delay, mixing, valve actuation and tank carryover using controlled tracer/fault checks. Choose a reference logging interval no greater than the smaller of one second and one tenth of the shortest relevant breakthrough interval; verify actual sensor bandwidth and uncertainty. If response is too slow, enlarge the protected hold interval or redesign before testing. Continuous samples are correlated observations, not replicates. Eight laboratory chemistry time points per confirmation run (864 panels) and per commissioning run (96 panels) verify reference calibration and salt/ion behavior; they do not independently establish subsecond timing.

Implementation: Water quality and endpoints

Freeze accepted-water criteria for the intended use before confirmation; a commissioning alarm such as 100 $\mu\text{S}/\text{cm}$ at 25 $^{\circ}\text{C}$ is not a potable standard. Add oil/organic carryover checks appropriate to the challenge chemistry: 72 targeted packages allow two samples per oil-only or combined confirmation run. Specify analytes and sensitivity during method qualification; conductivity cannot exclude nonsalt contaminants. Compute off-specification water accepted as the time integral of accepted flow times independently determined failure status, with uncertainty and tank assays. Report contaminant mass, absolute bad-water volume, good water diverted, cumulative accepted production and absolute flux. For organic analytes without a validated continuous surrogate, conservatively bound the affected interval between chemical samples; do not claim fine-time resolution for those endpoints.

Implementation: Decision and resources

For prespecified genuine salt-breakthrough families, the lower 95% confidence bound on reduction in bad water accepted must exceed 50% versus C1. Use run-level contrasts with family and feed/material blocks; report every family separately as well as any prespecified pooled estimate. Qualifying water diverted must be no more than 5% during independently confirmed nonfailure periods. The 95th-percentile end-to-end routing latency plus measurement margin must remain below the earliest qualified breakthrough time. If C1 already prevents measurable release, use an absolute detection-limit bound and report no demonstrated percentage advantage. Do not induce a harsher fault merely to rescue that claim. Combined-exposure organic outcomes are separately bounded and cannot establish drinking-water certification. Plan 12 funded months: 1–3 qualification, 4–5 commissioning/freeze, 6–10 confirmation, 11–12 independent audit. These counts require pilot-based precision review and laboratory/equipment quotes; no live water supply is used.

G — Test the full cooling and water balance

When do source interruption, hot sinks and real demand make heat-assisted recovery better or worse than conventional cooling plus water treatment?

Prior work. Data-center heat-driven desalination, telemetry scheduling, RO preheating and seawater cooling have precedents. Building an isolated coupling is a validation task, not a first-invention claim. [N13](#) [N14](#) [N15](#) [N24](#) [S09](#) [S20](#) [S22](#)

Candidate difference. Map failure and benefit boundaries at equal cooling reliability and accepted-water service; advance a new controller only if an explicit difference survives existing scheduling prior art.

Planning scope. 54 six-hour trajectory runs and three paired seven-day campaigns; 288 principal panels across 324 platform hours and 42 configuration-days.

Before confirmation. Actual source/sink and demand traces, feasible host cooling alternatives and an absolute freshwater-saving opportunity are required.

Comparator and scope

Use dry, evaporative/hybrid and isolated seawater-cooling qualification where feasible. Freeze the strongest host-applicable B0 and the simpler B1; a wasteful evaporative baseline is not permitted when a better feasible alternative exists. Specify IT-equivalent load, allowed coolant return, reliability and water demand. Source/sink telemetry-based scheduling alone is already disclosed. T's policy and any claimed incremental feature must be written against that precedent before confirmation. If no distinct rule remains, complete G as comparative validation only.

Methods and decision

Use three later real-feed lots, six trajectories and three configurations, then three paired seven-day B0/T campaigns. Include interruption, hot sink, restart, demand shift and zero-useful-temperature-difference conditions without perfect future knowledge. Keep separate freshwater withdrawal/consumption, saline inputs, exports, returns and source-attributed inventory. Count the emulator's electricity separately from a modeled recovered-heat supply. The proposed >10% freshwater saving and ≤5% auxiliary-electricity increase require uncertainty bounds and matched service. When B0 freshwater use is near zero, declare the savings case absent; do not subtract exported water twice.

Share or stop

Perform the C/G feasibility model once. Share compatible metering and thermal apparatus only after documenting capacity and schedule, with no duplicated costs or independent-evidence claims. If the desk calculation shows no plausible service advantage, stop the MD branch before construction and retain the result. A nominal 2-kW emulator and 42 configuration-days do not establish data-center uptime, intake/discharge acceptability, river benefit or a safe nuclear interface.

H — Collect water when heat and cooling are limited

Can a controller that accounts for uncertain forecasts and stored moisture avoid wasted regeneration while delivering more qualifying water than a tuned adaptive controller under the same resource limits?

Prior work. Weather adaptation, condenser control, forecast-assisted energy management and battery-constrained water generation already appear in research and patents. Adding a forecast or heat budget alone is not a defensible novelty claim. [N25](#) [N26](#) [N27](#) [N35](#) [N36](#)

Candidate difference. A prespecified moisture-inventory and uncertainty-aware run/wait/stop rule is compared on equal hardware and forecast access.

Planning scope. Nine independent beds and 54 chamber bed-days; six paired field units over two 14-day windows, totaling 168 unit-days; 222 principal water panels.

Before confirmation. An actual sorbent and usable heat grade, climate/resource profiles, a strong adaptive baseline and an unresolved forecast/error decision are required.

Exact policy comparison

C1 receives the same forecasts, state sensors and resource ceilings as T and may use competent forecast scheduling and fault fallback. T's candidate addition is a conservative bound on releasable bed moisture and expected condenser capture, with a terminal inventory condition that prevents apparent gains from merely emptying the bed or tank. Freeze the calculation, uncertainty treatment, action thresholds and fallback using development profiles. Both policies pay for sensing/computation and obey the same constraints. The precise added rule must survive full-method comparison with adaptive and forecast-control precedents; otherwise classify the work as validation.

Conditions and independent units

Use the qualified commercial-bed approach and the 54 chamber bed-days across nine independently prepared beds. Allocate the six held-out trajectories to qualified reference weather, heat interruption, hot-sink limitation, forecast timing error, gradual condenser impairment and sensor-invalid/restart conditions. Do not combine several faults and call their effects isolated. Each bed receives repeated profiles in randomized order with validated inventory reset. Empty-device/conditioning runs belong to commissioning. Use three independently assembled C1/T pairs in two contrasting 14-day field windows after the chamber gate. Beds/devices and weather blocks determine inference; 168 unit-days are not 168 independent units.

Energy, water and decision

Measure actual collected liquid, bed/condenser inventory, rejects, external cleaning water, heat and all electricity/cooling. A chamber humidifier is an external water input. Equal starting/final stored moisture and time boundaries prevent borrowing output from another period. Compare the same end-use quality and the proposed >10% lower-confidence-bound daily-output improvement target against C1, subject to host-selected useful volume and resource constraints. Zero-output days remain in the calendar denominator. The proposed 100-cycle retention screen requires its own cycle log and material measurements; it is included in conditioning/bed-life allowances, not extra independent water-production replicates or annual-life evidence.

Prior-art and stop gate

A 2026 primary publisher abstract describes weather forecasting and hierarchical AWH setpoint retrieval for a modeled refrigeration system; a 2022 thesis discusses limited battery power and proposed predictive management. These adjacent systems defeat a broad forecast-control claim but do not validate this sorbent policy. Their headline energy values are not imported. If the selected bed cannot regenerate at the available heat grade, if the conventional policy is equivalent, or if a simpler supply better serves the user, stop this branch. Two field windows do not establish Phoenix annual supply or household self-sufficiency.

Unified preliminary costs

All amounts are USD. Three scenarios apply the same rates, employer costs, analytical pricing, equipment rules, institutional base and reserve across A–H. Each is a complete standalone planning option. Shared execution requires an itemized combined scope; adding the eight totals would double count resources. No mineral revenue, funding award or actual laboratory quote is assumed.

Study	Funded months	Lower	Base	Higher
A	12	\$1,763,996	\$2,079,632	\$2,775,124
B	12	\$1,263,787	\$1,473,068	\$1,889,028
C	18	\$2,275,358	\$2,686,825	\$3,525,225
D	18	\$2,759,221	\$3,266,817	\$4,376,024
E	12	\$2,221,791	\$2,632,286	\$3,607,925
F	12	\$1,563,573	\$1,838,749	\$2,423,266
G	15	\$1,631,277	\$1,917,872	\$2,476,228
H	18	\$1,777,151	\$2,065,165	\$2,649,102

The register has 882 planned rows with different meanings: assay vessels, campaigns, trajectory runs and field windows. They are not an additive count of independent experiments. Confirmation is conditional on an adequate variance/precision calculation. A/B quantities have explicit prospective allocations; C–H retain their detailed conditional capacity. A final sampling method may require more capacity and a revised estimate.

Review before relying on the program

Review the exact closest methods and supplements for the proposed contribution, particularly CESP kinetic/seed management, conductive-spacer sensing and adaptive/forecast AWH control. Confirm reference-assay validity, native analyte detection, compatible fraction sampling, sensor bandwidth, independent units and realistic effect margins. Confirm the real host, feed, end-use specification, available comparator, waste route and quotes before a funding commitment. Check source families and datasets for overlap. Neither the source count nor repeated cycle count establishes independent replication. Full ASTM text and several key methods remain unavailable. The primary A recommendation remains conditional; the proposed no-go presumption for the immediate grant cycle is not overturned by this candidate redesign.

Sources and reading limits

N01

ASTM D4516-19a: Standard Practice for Standardizing Reverse Osmosis Performance Data (2019).

Official public scope and significance/use in indexed ASTM result; direct page intermittently blocked

Full licensed standard and underlying example calculations not obtained; not an experimental dataset.

N02

LG Water Solutions, Technical Service Bulletin 111: Data Logging and Performance Normalization (Undated document; retrieved 2026).

Public 5-page PDF; logging/normalization guidance and equations selected

Manufacturer implementation guidance, not the full ASTM text or evidence of project performance.

N03

McCool, High Recovery Desalination of Brackish Water by Chemically-Enhanced Seeded Precipitation (2012).

Indexed full PDF; selected chapters 4-6, especially printed pp. 92-97, 109-110 and 134-143; references followed

Selected chapters read, not all 239 PDF pages. Local download returned non-PDF HTTP 202. Overlaps the research program in [4-6].

UCLA CESP research program

N04

McCool, Rahardianto and Cohen, Antiscalant removal in accelerated desupersaturation of RO concentrate via chemically-enhanced seeded precipitation (CESP) (2012).

Original abstract and identifiers; DOI 10.1016/j.watres.2012.04.045

Full journal methods not independently obtained; related dissertation [3] supplies selected methods.

UCLA CESP research program

N05

Choi et al., Desupersaturation of RO concentrate and gypsum removal via seeded precipitation in a fluidized bed crystallizer (2021).

Original abstract/highlights and corrigendum checked; DOI 10.1016/j.watres.2020.116766

Full article methods unresolved. Corrigendum DOI 10.1016/j.watres.2021.116943 corrects an affiliation, not a reported process result.

UCLA CESP research program

N06

Lei, A Continuous Process for RO Concentrate Desupersaturation (2016).

Indexed PDF abstract and selected continuous-process/seed-handling passages

Model concentrate pilot; selected reading only. Local PDF download returned non-PDF HTTP 202.

N07

Xu et al., Reverse Osmosis with Intermediate Chemical Demineralization: Scale Inhibitor Selection, Degradation, and Seeded Precipitation (2024).

Existing public-origin PDF copy X02; selected methods/results, pp. 3-10, and references

Model chemistry and short reuse sequence; not a field validation of proposed diagnostic. Preserve distinction between saturation ratio and logarithmic index.

N08

A dual-probe approach for evaluation of gypsum crystallization in response to antiscalant treatment (2004).

Original publisher abstract

Antiscalant ranking via turbidity/calcium signals; full methods not read.

N09

Schwiebert et al., Turbidity-based scaling detection system for batch reverse osmosis combined with gypsum crystal recovery (2024).

Original publisher abstract, highlights and data-availability statement

Synthetic solutions and simulated agricultural runoff; not an independent field-performance guarantee. Data available on request; full methods not audited.

N10

WO2009152148A1: Method and system for high recovery water desalting (2009).

Abstract and selected process description

Disclosure establishes an antecedent, not demonstrated performance or legal clearance.

WO2009152148 family

N11

US10589188B2: System and method for removal of scale forming components (2020; A1 publication 2017).

Description around attrition/seed regeneration; claims 1-9 and family entries

Specific integrated system; exact claim scope and enforceability not assessed. Priority shown 2016-06-27.

US20170368476A1 / US10589188B2; related continuation US11351475B2

N12

US9314742B2: Method and system for reverse osmosis predictive maintenance using normalization data (2016).

Description and claims 1-8 selected

Does not establish all proposed controller logic; defeats a broad assertion that normalized-data maintenance decisions are new.

US9314742 family

N13

US20190233305A1: Using waste heat from a data center cooling system to facilitate low-temperature desalination (2019).

Selected description; claims including 11-20; publication/family entries

Vacuum-evaporation architecture; not proof of MD performance. Priority 2018-01-31, publication 2019-08-01.

US20190233305A1 / US10669164B2; related US10934178B2

N14

Chen et al., Experimental study of a membrane distillation desalination system based on CPU waste heat (2026).

Original Chinese journal metadata and abstract; translated for screening

Abstract-level physical demonstration; full methods, uncertainty and equal-service comparison not independently checked.

N15

Malaguti et al., Waste heat won't make membrane distillation cool: Thermodynamic analysis of cooling and pumping burdens (2026).

Existing public-origin PDF X05; abstract and selected model/discussion, especially journal pp. 6-8

Model is conditional on source, sink, hydraulics and conversion factors; no universal numerical penalty transferred to WFE.

N16

PNNL-35345: Magnetic Nanoparticle Extraction of Lithium from Produced Waters (CRADA 483), Final Project Report (2023).

Existing public-origin PDF X04; selected sections 3.2-4, printed pp. 15-18, plus front matter

Laboratory core/shell uptake and magnetic response; continuous automated cycling still identified as needing improvement.

N17

AU2020289275A1: Polymer-functionalized magnetic particle embodiments for solute separation, and devices and systems for using the same (2022).

Abstract, selected description and claims including particle, jarosite and separation-device embodiments

Material-specific claims; generic magnetic bead is not sufficient for an exact claim comparison. Priority 2019-06-05; this A1 published 2022-01-06.

AU2020289275 / EP3981017 family

N18

Ventimiglia et al., Pilot scale production of Mg(OH)₂ compounds from a real industrial reverse osmosis desalination brine (2025).

Existing public-origin PDF L06; selected methods pp. 4-5, results pp. 7-8 and conclusions p. 13

RO-permeate washing reported. Total wash volume not located in reviewed passages; this is not proof it is absent from all associated data. Mass and cationic purity differ.

N19

US6143260A: Method for removing magnesium from brine to yield lithium carbonate (2000).

Description of displacement washing, limed recycled brine and filtrate recycle; selected examples

Lithium-rich brine process differs from dilute native lithium in SWRO concentrate. Disclosed recycling is not proof of proposed saving.

US6143260 family

N20

SQM, Salar de Atacama Technical Report Summary (2023).

Section 14.1.2 process descriptions, including calcium carbonate separation and lithium hydroxide washing

Operator-reported industrial practice in a different feed/product setting; no cost or capacity assumptions transferred.

N21

McGaughey and Childress, Wetting indicators, modes, and trade-offs in membrane distillation (2022).

Public author manuscript downloaded; selected methods/results, especially section 3.1.2.1 and conclusions

Indicators and mass-balance interpretation do not themselves demonstrate reliable product diversion.

N22

Alpatova et al., In situ conductive spacers for early pore wetting detection in membrane distillation (2022).

Original abstract/indexed publisher material

Full methods not obtained. No numerical lead-time advantage accepted without full methods. Same inventors/research as [23]; not independent replication.

KAUST conductive-spacer research

N23

WO2020165796A1: In situ detection system and method of detecting membrane wetting (2020).

Description paragraphs 0035-0038 and claims 1-18 selected

Conducting spacers, current measurement and threshold alarm; does not on its own establish the proposed quality-protection outcome.

WO2020165796 / US20220143554 / EP3924088 / SA521430030; KAUST research

N24

Alfa Laval AQUA fresh-water generator, operating principle and installation (Undated manufacturer document).

Indexed operating-principle/installation text and salinometer/dump-valve description

Established adjacent thermal desalination hardware, not a controlled comparison of MD controllers.

N25

Almassad et al., Environmentally adaptive MOF-based device enables continuous self-optimizing atmospheric water harvesting (2022).

Original full text surfaced in indexed PMC result; selected adaptive-operation methods, empty-device control, long-term section, data availability and competing interests

Supplementary algorithm/data not independently audited. Claimed year equivalence from cycle count is not accepted as a field year. Related patent [26].

Royal Scientific Society adaptive AWH research

N26

[WO2023007524A1: An atmospheric water generating device and a method of active or adaptive atmospheric water generation \(2023\)](#).

Selected apparatus/method claims, especially 12-17; family records

Priority 2021-07-26. Same underlying invention disclosed by [25], not independent replication.

WO2023007524 / AU2022321035 / US20250012058; PCT/JO2022/050012

N27

[AU2022204740A1: Systems and methods for water extraction control \(2022; parent WO publication 2017\)](#).

Selected condenser/control description and claims; parent/family entries

Controller adaptation and thermal/environmental signals already disclosed. Exact remaining constrained-control claim is undefined.

WO2017201405 / AU2017267967 / AU2022204740 / US10357739; priority 2016-05-20

N28

[Bureau of Reclamation, DWPR Research Reports catalogue \(Living catalogue\)](#).

Catalogue entries selected, including reports 81, 124 and 134

Register-level funding/precedent discovery only; these full reports were not audited and their outcomes are not asserted.

N29

[European Commission, SEA4VALUE results and public deliverables, grant 869703 \(2020-2024 project\)](#).

Original results register, deliverable titles and associated publications

Project description and linked outputs do not prove every technology met a target. Individual deliverables not fully audited.

N30

[European Commission, ZERO BRINE results and public deliverables, grant 730390 \(Project results register\)](#).

Original results register and publication/deliverable titles

Broad resource-recovery and assessment antecedents, not exact duplication of a defined WFE claim.

N31

[USPTO, Patent search strategy \(Current guidance retrieved 2026\)](#).

Official preliminary-search guidance

Used to frame search limits; this review is not an examiner search, legal patentability opinion or freedom-to-operate assessment.

N32

WO2020223210A1: Docking station for mobile deionization trailers and related methods (2020).

Indexed description of conductivity/reactive-silica limits, configurable delay and diversion

Adjacent deionization control, not MD; delay suppresses transients and should not be equated with a transport-compensation model. Claims not read.

WO2020223210 family

N33

US5702582A: Multi-port multi-stream valve apparatus (1997).

Indexed description of conductivity-triggered three-way diversion during electrodialysis reversal

Adjacent-process disclosure, not proof of proposed MD protection. Claims not read.

US5702582 family

S01

USGS PHREEQC: high-salinity speciation and evaporation (date recorded in source).

Official documentation; selected high-ionic-strength example and model documentation read. No project simulation performed.

Database coverage and measured feed chemistry must be checked; equilibrium does not establish deposition rate.

S02

Reverse Osmosis with Intermediate Chemical Demineralization: Scale Inhibitor Selection, Degradation, and Seeded Precipitation (date recorded in source).

Prior project methods review carried forward; current indexed original-method sections checked.

Synthetic calcium-sulfate system and short seed reuse; not a universal mixed-brine protocol.

S03

Turbidity-based scaling detection system for batch reverse osmosis combined with gypsum crystal recovery (date recorded in source).

Original abstract and indexed author-manuscript methods/tables read; complete supplement not audited.

Simulated agricultural runoff; recycled sequences are not independent feed lots.

S04

Wetting indicators, modes, and trade-offs in membrane distillation (date recorded in source).

Current abstract and prior project main-method review used; accessible original retained in watch-sources.

Bench-cell response and averaging do not validate fast product-diversion control.

S05

[In situ conductive spacers for early pore wetting detection in membrane distillation](#) (date recorded in source).

Original abstract/introduction only; full methods and supporting information unavailable.

Sensor architecture precedent only; no verified operating recipe or delivery benefit.

S06

[Membrane technology for water reuse in decentralised non-sewered sanitation systems: comparison of pressure driven \(reverse osmosis\) and thermally driven processes \(membrane distillation and pervaporation\)](#) (date recorded in source).

Original abstract and indexed article sections read; full PDF retrieval returned HTTP 403.

Blackwater matrix and pH-dependent contaminant behavior cannot be transferred directly to seawater.

S07

[EPA: industrial reuse and fit-for-purpose treatment](#) (date recorded in source).

Current official industrial-reuse page and basic reuse guidance read.

Guidance is not a site permit or a complete jurisdiction-specific water specification.

S08

[CDC: cooling-tower water management](#) (date recorded in source).

Official cooling-tower toolkit module, dated 3 January 2025, read.

Health-management guidance; this review does not design or approve a microbial challenge study.

S09

[Waste heat won't make membrane distillation cool: Thermodynamic analysis of cooling and pumping burdens](#) (date recorded in source).

Full original PDF retrieved; selected methods, assumptions, results and conclusions read.

Thermodynamic/model study; illustrative source/sink conditions and ideal permeate are not site measurements.

S10

[The CARMEn project: A sustainable and circular brine treatment chain](#) (date recorded in source).

Full original PDF retrieved; selected process methods, cost boundary, water-balance results and conclusions read.

Lab-informed modeled scale-up; labor, maintenance and waste-disposal costs omitted from preliminary economic model.

S11

[Pilot scale production of Mg\(OH\)₂ compounds from a real industrial reverse osmosis desalination brine](#) (date recorded in source).

Prior project main-method review plus current original washing/settling sections checked.

Short pilot operation; unresolved total wash-water balance, feed-table inconsistency and product-qualification details.

S12

[Magnetic Nanoparticle Extraction of Lithium from Produced Waters \(CRADA 483\) Final Project Report](#) (date recorded in source).

Original report available in project; conclusion checked now, selected methods reviewed previously.

Core-shell architecture precedent; automated continuous operation remained further work.

S13

[Energy-Efficient Seawater Lithium Extraction via a Reversible Redox-Hydrogen Coupled System](#) (date recorded in source).

Original indexed energy-accounting/results sections read; entire supplement and raw data not audited.

Small-cell energy allocations and concentration gain are not whole-plant cost or feed recovery.

S14

[Li-air chemistry inspired electrodialysis for direct lithium carbonate production from seawater](#) (date recorded in source).

Full original HTML retrieved; selected extraction/control and particle-collection methods/results read. Crossmark record inspected.

Small simulated-seawater experiment; fine-particle capture, inventory origin and pressure effects require careful interpretation.

S15

[Solar-powered resource separator for clean water production, electricity generation and critical resource recovery](#) (date recorded in source).

Full original HTML retrieved; selected design, practical tests and methods read; supplement not obtained.

Spiked-feed cycle tests differ from outdoor real-water tests; economic lifetimes and allocation are assumptions.

S16

[Environmentally adaptive MOF-based device enables continuous self-optimizing atmospheric water harvesting](#) (date recorded in source).

Full original HTML retrieved; selected device, control, energy and empty-bed methods read.

Different sorbent and powered cooling; tested conditions are not local annual performance.

S17

[Landfill Leachate Treatment by Using Second-Hand Reverse Osmosis Membranes: Long-Term Case Study in a Full-Scale Operating Facility](#) (date recorded in source).

Original abstract and indexed methods read; complete results and supporting data not audited.

Historical operating comparison is not a randomized matched new-versus-used trial.

S18

[Recycling of end-of-life reverse osmosis membranes: Comparative LCA and cost-effectiveness analysis at pilot scale](#) (date recorded in source).

Original abstract/preview only; full methods unavailable in this review.

Conversion changes membrane duty; historical economics depend on chemical use, energy, permeability and scale.

S19

Pilot-scale removal and recovery of dissolved phosphate from secondary wastewater effluents with reusable ZnFeZr adsorbent @ Fe₃O₄/SiO₂ particles with magnetic harvesting (date recorded in source).

Original institutional abstract and existing project record screened; complete pilot methods not audited.

Target-spiked wastewater and a phosphate-specific sorbent; not validation for all brine minerals.

S20

Pioneering minimum liquid discharge desalination: A pilot study in Lampedusa Island (date recorded in source).

Original institutional abstract and indexed pilot-method sections read; complete integrated operating dataset not audited.

Pilot units with limited operating hours; possible shared project/feed lineage with other brine-recovery papers.

S21

A pilot plant investigation on a real seawater brine valorisation via electrodialysis with bipolar membranes (date recorded in source).

Original publisher preview only; complete methods unavailable.

Pilot chemical-recovery precedent; no verified project-specific reagent purity, water use or energy number.

S22

Analysis of energy, water, land and cost implications of zero and minimal liquid discharge desalination technologies (date recorded in source).

Original selected methods, assumptions and discussion read; code and supplement not reproduced.

Modeled process trains; crystallizer heat recovery and simplified fouling/cost assumptions limit direct transfer.

S23

Boron extraction using selective ion exchange resins enables effective magnesium recovery from lithium rich brines with minimal lithium loss (2021).

Main paper and all main figures reviewed. Supplement not obtained.

S24

Novel Janus Membrane for Membrane Distillation with Simultaneous Fouling and Wetting Resistance (2017).

Main paper, all main figures, and supporting information S1–S5 reviewed.

N34

Ma et al., Hydrogel modified evaporation interface for highly stable membrane distillation (2023).

Public 24-page preprint downloaded; selected results section 2.3, Figure 4 and relevant methods inspected. Not a full supplement or peer-review audit.

Combined synthetic oil/surfactant/salt exposure has precedent. No organic-purity or potable-water conclusion adopted from a Raman non-detection. Published-version status unresolved.

N35

Innovative energy management using time-series forecasting for atmospheric water harvesting in a semi-arid climate, combining a hybrid cascade cycle and AI (2026).

Original publisher indexed abstract and highlights checked; direct full-text retrieval returned 403.

Modeled hybrid refrigeration AWH; not experimental evidence for our sorbent controller. Data stated available on request. No numerical energy performance transferred.

N36

Pavel Soucek, Atmospheric water generator optimization (2022).

Indexed original thesis pp. 47 and related optimization passages screened.

Adjacent limited-battery water-generation optimization; predictive control described as follow-up, not a verified implemented result.