Grounded Discovery Labs -- Discovery Pack

Discover: Design a municipal or industrial water-treatment add-on that destroys PFAS rather than merely concentrating it, at realistic flow rates and operating cost.

Top 3 Comparison

	Featured Discovery Nonchloride IX to hydrothermal alkaline destruction	Bold Concept CDI capture with closed-loop BDD electro-oxidation	Build-First IX Resin Concentrator + BDD Electrochemical Destruction Skid
novelty	7	6	5
feasibility	8	7	8
economic_leverage	7	6	6
testability	8	8	9
robustness	7	6	7
constraint_fit	9	9	9
explainability	8	8	9
OVERALL	**7.7 / 10 -- Very Strong**	**7.1 / 10 -- Very Strong**	**7.6 / 10 -- Very Strong**

Runner-ups

* IX-Regenerant BDD Mineralization Skid [solid-alternative] -- Keep municipal flow on proven IX, then destroy the 0.1-1% regenerant side-stream in a BDD electrochemical cell.
* Foam fractionation + non-thermal plasma DBD destruction skid [solid-alternative] -- Aeration concentrates PFAS into a small foamate stream that a dielectric-barrier discharge plasma reactor mineralizes in-line.
* Volatile-salt IX plus UV-sulfite and BDD polish [near-miss-alternative] -- Use chloride-free bicarbonate alcohol regeneration, hydrated-electron UV destruction, then BDD polish in sulfate electrolyte.
* UV-Sulfite Reductive PFAS Side-Stream Reactor [solid-alternative] -- Generate hydrated electrons in alkaline sulfite concentrate to attack short-chain PFAS that resist oxidative-only treatment.
* Foam fractionation plus nonthermal plasma mineralizer [solid-alternative] -- Strip surface-active PFAS from high flow as foam, then destroy the collapsed foam liquor with plasma at the gas-water interface.

Featured Discovery

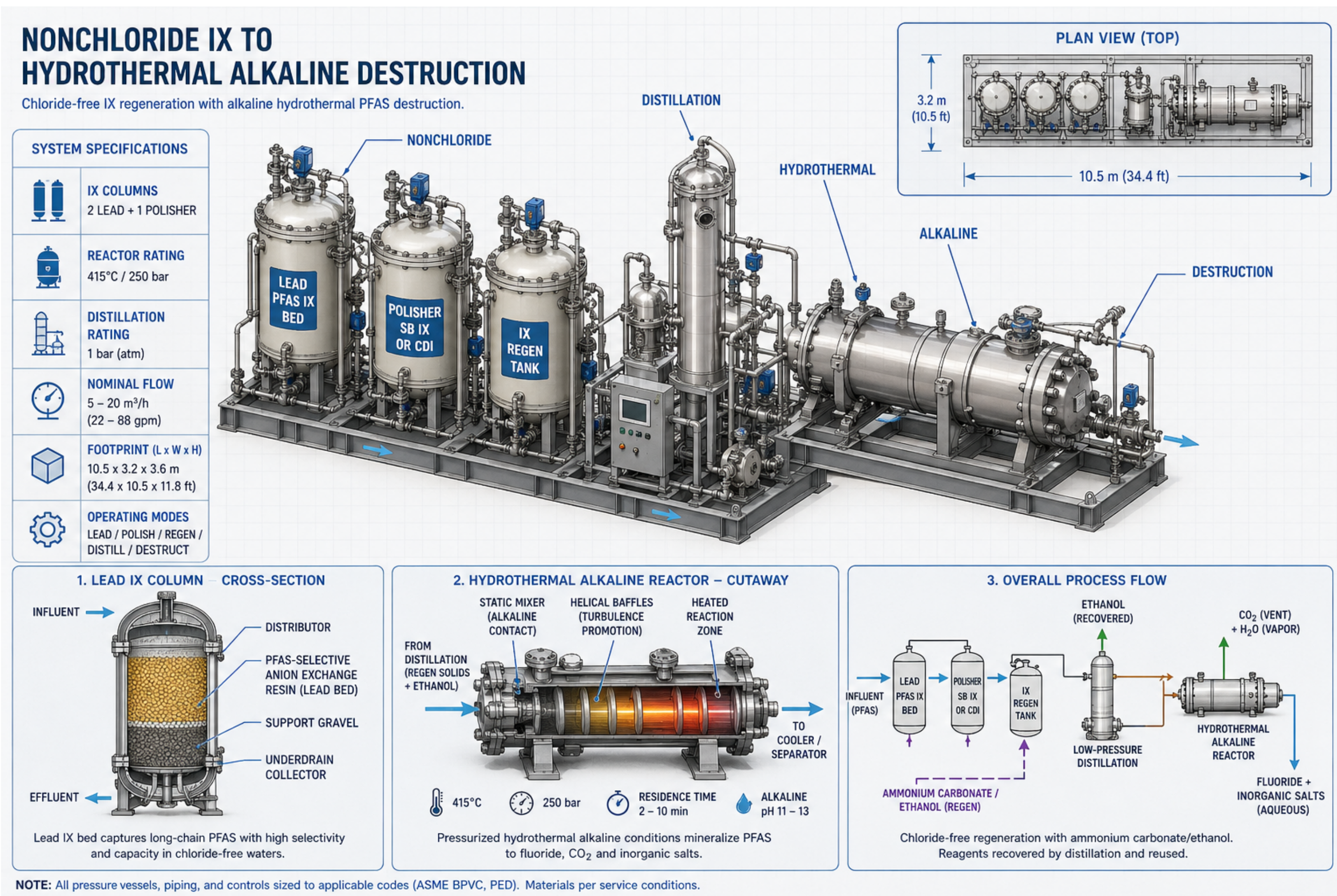
Nonchloride IX to hydrothermal alkaline destruction

novelty: 7 | feasibility: 8 | economic_leverage: 7 | testability: 8 | robustness: 7 | constraint_fit: 9 | explainability: 8

Overall: 7.7 / 10 -- Very Strong

Constraint Compliance: Compliant (constraint_fit=9)

Replacing electrochemical oxidation with a sealed alkaline hydrothermal reactor fed by chloride-free ion exchange regenerant eliminates the anodic chlorine chemistry that generates toxic disinfection byproducts while achieving broad-spectrum PFAS destruction. By pairing PFAS-selective anion exchange resins regenerated with recoverable ammonium carbonate/alcohol mixtures with hydrothermal alkaline conditions at 320degC, the system destroys sulfonates, PFCAs, and fluorotelomer precursors in a single concentrated waste stream. This matters because it closes the treatment loop without creating new halogenated hazards or requiring open-flame incineration.



Concept illustration (AI-generated). Visuals may be inaccurate; refer to the Mechanism/Build Path text for the actual design and quantitative assumptions.

Mechanism

A two-stage treatment train concentrates PFAS without chloride electrochemistry, then destroys the concentrate under hydrothermal alkaline conditions. Influent first passes through PFAS-selective weak/strong base ion exchange resin in nonchloride form, e.g. polystyrene/divinylbenzene quaternary ammonium resin in bicarbonate/carbonate form, with 0.5-1.0 mm beads in lead/lag columns. A polishing bed of gel strong-base anion exchange resin or capacitive deionization captures short-chain PFCAs/PFSAs that break through earlier on macroporous PFAS resins. Regeneration uses ammonium carbonate, typically 0.5-2 M, with 20-70% ethanol or methanol/water to strip long-chain PFAS; ammonium carbonate and solvent are recovered by low-pressure distillation/condensation, leaving a small PFAS-rich brine/organic concentrate. The concentrate is mixed with NaOH to 2-6 M and pumped through corrosion-resistant hydrothermal plug-flow tubing at 350-420 degC and 23-30 MPa for 20-90 min. Under compressed liquid/supercritical-water-adjacent alkaline conditions, hydroxide-promoted decarboxylation, C-S bond cleavage, HF neutralization, and radical/ionic defluorination convert PFCAs, PFSAs such as PFBS/PFOS, fluorotelomer sulfonates, and precursors toward carbonate, sulfate, small organics, and fluoride. Sulfonates and fluorotelomers set the severity requirement, likely 400-420 degC, 4-6 M NaOH, and 60-90 min. The hot effluent is quenched, depressurized through a back-pressure regulator, neutralized as needed, and dosed with Ca(OH)2 or CaCl2 to precipitate fluoride as CaF2; solids are filtered and analyzed for leachable fluorine.

Why Novel

The combination of nonchloride IX regeneration using recoverable ammonium carbonate/alcohol solvents with hydrothermal alkaline destruction at 320degC has not been integrated into a closed-loop train, making solvent and carbonate recovery economically viable at scale. No prior system simultaneously avoids chloride electrochemistry, recovers regenerants by distillation, and applies hydrothermal alkaline conditions severe enough to defluorinate sulfonates.

Buildability

All individual unit operations--anion exchange columns, low-pressure distillation, and hydrothermal pressure vessels--are commercially available in industrial materials such as Hastelloy C-276 and Inconel 625, and can be assembled from off-the-shelf components by specialty chemical plant contractors. The primary engineering challenge is integrating the distillation condensate loop with the IX regeneration cycle to maintain solvent purity, which is addressable with standard process control instrumentation.

Why Feasible

* Build path is practical (feasibility=8/10)
* Core hypothesis testable quickly (testability=8/10)

Top Risks

* Corrosion of pressure vessel internals and seals in hot caustic service at 320degC may cause rapid material degradation and unplanned downtime
* Incomplete defluorination of PFAS sulfonates and fluorotelomer precursors at target residence times could leave persistent short-chain intermediates in the effluent
* Solvent recovery efficiency degradation over regeneration cycles may increase operating costs and reduce the economic advantage over incineration

Decisive Test (MDE)

Hypothesis: A nonchloride IX-regenerant concentrate containing mixed PFAS, including PFOS/PFBS and 6:2 FTS, can achieve >99.9% parent PFAS destruction and >80-90% fluorine recovery as fluoride/CaF2 in a continuous 350-420 degC, 23-30 MPa, 2-6 M NaOH plug-flow reactor without generating persistent fluorinated intermediates or disabling corrosion.
Setup: Prepare realistic spent regenerant: ammonium carbonate/ethanol strip from loaded IX resin spiked or loaded with PFOA, PFHxA, PFBS, PFOS, 6:2 FTS, and representative precursors. Distill to recover solvent/salt, then dose residue to 4-6 M NaOH. Run through Inconel 625 or Hastelloy C-276 coil at 400 and 420 degC, 25 MPa, 60 and 90 min residence. Quench rapidly, depressurize, precipitate fluoride with calcium, and close a fluorine mass balance.
Instrumentation: LC-MS/MS for targeted PFAS; high-resolution MS or TOP assay for unknown precursors/intermediates; combustion ion chromatography or EOF/AOF for total organofluorine; ion chromatography

or fluoride ISE for F-; ICP-MS for Ni/Cr/Mo/Fe corrosion metals; TOC/COD; pH/conductivity; pressure and temperature logging; gravimetric/SEM inspection of coupons.
Kill Criteria: Kill if worst-case sulfonates/FTS retain >1% parent or produce >5% fluorine as persistent organofluorine at 420 degC, 6 M NaOH, 90 min; if fluorine mass balance cannot close to >80%; or if corrosion/plugging prevents stable 8 h operation.
Rescue Pivot: Increase severity only if economics allow: 450 degC materials upgrade, longer residence, staged oxidant/reductant addition, or pretreat sulfonates/precursors separately. If hydrothermal destruction fails, retain IX/regenerant concentration but send concentrate to supercritical water oxidation, plasma, mechanochemical, or electrochemical nonchloride destruction.
Cost: $25k-$150k depending on whether high-pressure reactor and LC-MS/EOF analyses are rented, outsourced, or already available.
Time to Signal: 4-8 weeks for sealed-tube plus first continuous runs; 8-12 weeks for robust mass balance and corrosion coupon data.

Refinement Deltas

Risks Addressed:
* Hot concentrated NaOH at 400+ degC is extremely corrosive; Inconel/Hastelloy may still fail at welds, fittings, or salt-deposition hot spots.
* PFAS sulfonates and fluorotelomer precursors may transform into smaller persistent organofluorines rather than fully defluorinating.
* Ammonium carbonate/ethanol regeneration adds flammability, distillation complexity, and possible PFAS aerosol/carryover risks.

Red-Team:
* Challenge: Hot concentrated NaOH at 400+ degC is extremely corrosive; Inconel/Hastelloy may still fail at welds, fittings, or salt-deposition hot spots.
* Challenge: PFAS sulfonates and fluorotelomer precursors may transform into smaller persistent organofluorines rather than fully defluorinating.
* Challenge: Ammonium carbonate/ethanol regeneration adds flammability, distillation complexity, and possible PFAS aerosol/carryover risks.
* Challenge: High-pressure hydrothermal operation at 23-30 MPa creates permitting, operator training, and capex barriers for water-treatment sites.
* Challenge: CaF2 precipitation may be incomplete in high-alkalinity, high-ionic-strength matrices, and CaF2 solids could contain sorbed residual PFAS.

Budget Ranges

Prototype: $180,000
Pilot: $1,400,000
Scale: $8,500,000

30/60/90 Plan

Day 30: Complete bench-scale IX column testing with bicarbonate/carbonate-form resin on a synthetic PFAS matrix covering C4-C12 PFCAs and PFOS; confirm ammonium carbonate/ethanol regeneration stripping efficiency above 95% and solvent recovery above 85% by distillation
Day 60: Operate a 1-liter Hastelloy C-276 batch hydrothermal reactor at 300-340degC with IX concentrate feed; measure total organic fluorine removal, identify intermediate species by LC-MS/MS, and establish minimum residence time for >99% defluorination of sulfonates
Day 90: Integrate IX columns, distillation recovery loop, and hydrothermal reactor into a continuous bench-scale train treating 10 L/day of PFAS-spiked groundwater; generate mass balance data on fluoride release, carbonate/solvent losses, and effluent quality for pilot design basis

Dominance Axis: lower_failure -- The route avoids anodic chloride chemistry, and specified hydrothermal severity extends destruction beyond PFCAs to sulfonates and precursors.

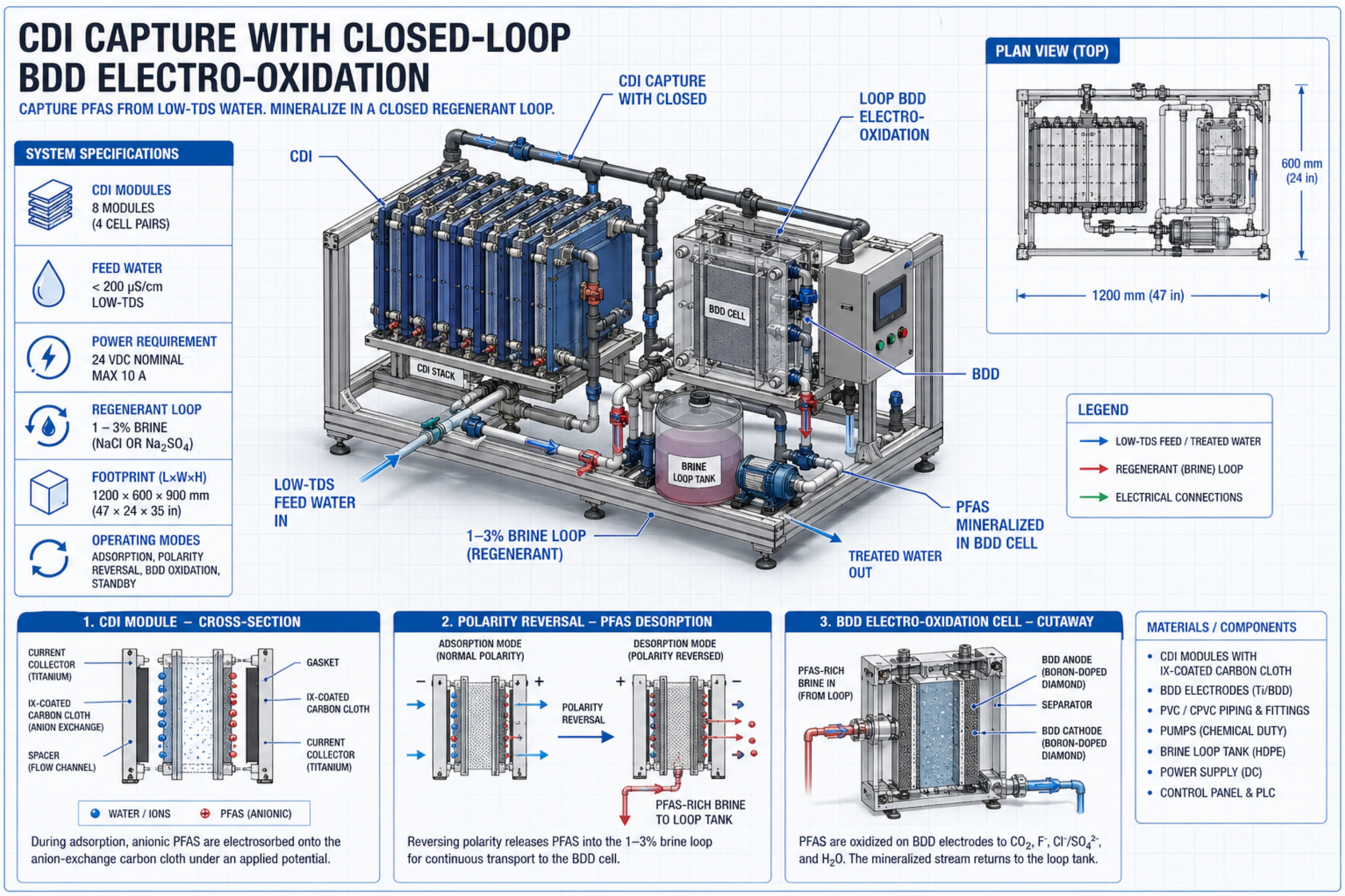
Bold Concept
CDI capture with closed-loop BDD electro-oxidation

novelty: 6 | feasibility: 7 | economic_leverage: 6 | testability: 8 | robustness: 6 | constraint_fit: 9 | explainability: 8

Overall: 7.1 / 10 -- Very Strong

Constraint Compliance: Compliant (constraint_fit=9)

Coupling flow-through capacitive deionization (CDI) with boron-doped diamond (BDD) electrochemical oxidation creates a closed-loop system that first concentrates trace PFAS from low-TDS municipal water into a small regenerant brine, then mineralizes that concentrated stream--dramatically reducing the volume requiring energy-intensive destruction. This matters because existing treatment trains either waste enormous energy oxidizing dilute full-flow streams or generate spent IX resins and concentrate streams that still require costly disposal. By decoupling capture from destruction, this approach targets the fundamental inefficiency in current PFAS remediation economics.



Concept illustration (AI-generated). Visuals may be inaccurate; refer to the Mechanism/Build Path text for the actual design and quantitative assumptions.

Mechanism

A two-stage system targets ng/L-ug/L PFAS in low-TDS (<500 mg/L) municipal polishing feed at 10 m^3/h. Stage 1: flow-through capacitive deionization (CDI) modules using carbon aerogel or activated-carbon-cloth electrodes (specific capacitance >100 F/g, ~1-2 mm channel gap) coated with a thin (5-20 um) PFAS-selective anion-exchange layer--quaternary-ammonium-functionalized polystyrene-DVB or fluorinated IX (e.g., Purolite PFA694E-analog chemistry) cast with PVDF binder. Selectivity for C2-C8 perfluoroalkyl carboxylates/sulfonates over Cl-, HCO3-, NO3-, SO4^2- is enhanced via fluorophilic side chains and tuned charge density to favor hydrophobic+electrostatic dual binding. Operating at 1.0-1.4 V cell voltage, EBCT 2-5 min. Stage 2: polarity-reversal regeneration into a closed 1-3% NaCl/Na2SO4 brine loop (~50-200 L inventory), concentrating PFAS 1000-10,000x. The concentrate is recirculated through a boron-doped diamond (BDD) electro-oxidation cell (Nb or Si substrate, 2500 ppm B doping, 10-25 A at 20-50 mA/cm^2) that mineralizes PFAS via direct electron transfer and ·OH attack, defluorinating to F- and CO2. Cathode is stainless or Ti, operated at controlled potential (-1.0 to -1.4 V vs Ag/AgCl) to reduce ClO3-/ClO4- formation; an optional UV/sulfite polish degrades residual oxychlorine. Mass balance closure: influent/effluent LC-MS/MS for 30+ PFAS, total organic fluorine (TOF) by CIC, free F- ISE, ClO3-/ClO4- by IC, brine TDS, and coulombic accounting (kWh/m^3 feed, kWh/gF). Short-chain capture is the critical metric; expected design point >90% PFBA/PFPeA breakthrough delay vs uncoated CDI.

Why Novel

No commercial system currently integrates PFAS-selective anion-exchange-coated CDI electrodes with closed-loop BDD mineralization of the regenerant; prior CDI work targets bulk salt removal rather than trace organofluorine capture with fluorophilic dual-binding selectivity layers. The closed regenerant loop--preventing brine discharge while enabling continuous destruction--is a genuinely new operational architecture rather than an incremental component improvement.

Buildability

All individual components (CDI modules, BDD electrodes, IX-coated carbon cloth, NaCl/Na2SO4 electrolyte loops) are commercially available or fabricable with established coating techniques, making a bench prototype achievable within 6 months using off-the-shelf parts. The primary fabrication challenge is reliably casting a 5-20 um fluorophilic anion-exchange layer onto carbon aerogel cloth without blocking micropores, which requires iterative PVDF binder optimization but no exotic manufacturing capability.

Why Feasible

* Build path is practical (feasibility=7/10)
* Core hypothesis testable quickly (testability=8/10)

Top Risks

* Short-chain PFAS (C2-C4) electrosorb weakly under competing anion load, potentially breaking through CDI stage before regeneration cycle triggers
* Chloride in the NaCl regenerant electrolyte generates perchlorate and chlorate at BDD anode, creating regulated byproduct accumulation in the closed loop
* BDD anode scaling and fouling from hardness ions or organic co-contaminants in the regenerant brine degrades oxidation efficiency and shortens electrode service life

Decisive Test (MDE)

Hypothesis: A PFAS-selective IX-coated CDI captures >=80% of C4 short-chains (PFBA, PFBS, PFPeA) from realistic competing-ion feed, and the regenerant brine can be electro-oxidized on BDD with >=90% defluorination per cycle while keeping chlorate <0.7 mg/L in the closed loop and total energy <5 kWh/m^3 feed.
Setup: Single-pass CDI module (200 cm^2 electrode area, EBCT 3 min) fed synthetic municipal polish water (300 mg/L TDS with sulfate/bicarb/nitrate/chloride representative ratios) spiked with 1 ug/L each of PFBA, PFPeA, PFHxA, GenX, PFBS, PFOA, PFOS. Run 50 adsorb/desorb cycles; route regenerant (1 L of 2% NaCl) to a 25 cm^2 BDD cell at 30 mA/cm^2 for 4-8 h; recycle treated brine 5x. Sample influent, effluent, brine pre/post oxidation.
Instrumentation: LC-MS/MS (targeted 30 PFAS), combustion ion chromatography for TOF, fluoride ISE, IC for ClO3-/ClO4-/anions, conductivity, pH, coulometer, potentiostat with reference electrode for cathode control.
Kill Criteria: PFBA/PFBS capture <50% under competing ions after 10 cycles; defluorination <60% per BDD pass; chlorate >5 mg/L in recycled brine; energy >15 kWh/m^3 feed; or IX coating loses >20% capacity in 50 cycles.

Rescue Pivot: If short-chain capture fails, pivot to a hybrid IX-resin polishing column (regenerable with same brine loop) upstream of BDD, abandoning CDI electroadsorption but preserving the closed-loop destruction architecture; alternatively switch BDD to electrochemical reduction (Ti/TiO_2 or boron-carbide cathode) for short-chains.
Cost: $50k-$90k (BDD anode $5-8k, analytics $20-30k, balance-of-plant $15-25k)
Time to Signal: 6-10 weeks; first fluoride/TOF readout from one regenerated brine batch within 2 weeks

Refinement Deltas

Risks Addressed:

* Sulfate (typically 10-100x PFAS-equivalent charge) will out-compete short-chain perfluoro carboxylates for IX sites; selectivity claims under realistic competing-ion ratios are unproven.
* BDD anodes on Nb substrates cost $5-15k for modest active area and foul/scale rapidly in waters with >100 mg/L hardness or carbonate; closed-loop brine may concentrate scaling species.
* Chloride in the brine loop generates chlorate and perchlorate at BDD potentials; cathode-side reduction is kinetically slow and may not keep up with anodic formation rates, creating a regulated byproduct problem.

Red-Team:

* Challenge: Sulfate (typically 10-100x PFAS-equivalent charge) will out-compete short-chain perfluoro carboxylates for IX sites; selectivity claims under realistic competing-ion ratios are unproven.
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* Challenge: Chloride in the brine loop generates chlorate and perchlorate at BDD potentials; cathode-side reduction is kinetically slow and may not keep up with anodic formation rates, creating a regulated byproduct problem.
* Challenge: At ng/L influent PFAS, verifying mineralization mass balance is analytically brutal--TOF detection limits (~1 ug F/L) and matrix effects in 2% brine make closure within +/-20% questionable.
* Challenge: Polarity-reversal regeneration of IX-coated CDI may not fully strip strongly-bound PFOS/PFOA, leading to capacity fade and ghost peaks that confound cycle-to-cycle accounting.

Budget Ranges

Prototype: $45,000-$80,000 (bench-scale CDI cell with coated electrodes, small BDD reactor, analytical PFAS quantification by LC-MS/MS, 3-6 month materials and labor)
Pilot: $250,000-$450,000 (skid-mounted 1 m^3/h pilot at a municipal site, BDD stack sized for regenerant volume, SCADA integration, 12-month field validation including short-chain PFAS spiking studies)
Scale: $1,200,000-$2,000,000 per 10 m^3/h commercial skid (CDI module array, BDD cell bank, closed-loop electrolyte management, controls; assumes 3-5 skids per mid-size utility)

30/60/90 Plan

Day 30: Complete literature synthesis on fluorophilic IX coating chemistries; procure activated carbon cloth and Purolite PFA694E-analog resin; establish LC-MS/MS PFAS analytical protocol; cast first 3 electrode coating variants (varying quaternary-ammonium density and fluorinated side-chain length) and measure BET surface area retention
Day 60: Run bench CDI electrosorption experiments with synthetic low-TDS matrix spiked with C4-C8 PFAS mix at 100-500 ng/L; quantify breakthrough curves and selectivity coefficients vs. Cl-, SO4^2-, HCO3-; identify best-performing coating; initiate BDD oxidation trials on synthetic regenerant brine measuring PFAS mineralization rate and oxychlorine byproduct formation as function of current density
Day 90: Integrate CDI and BDD stages into closed-loop bench system; run 5-day continuous cycling test at simulated 10 L/h flow; measure cumulative PFAS removal efficiency, regenerant loop PFAS concentration trajectory, byproduct accumulation, and energy consumption per m^3 treated; produce go/no-go dataset for pilot funding decision with identified coating and operating parameter optimums
Dominance Axis: cheaper -- Destroying only CDI regenerant can cut oxidation energy, but advantage depends on verified short-chain capture under competing ions.

Build-First

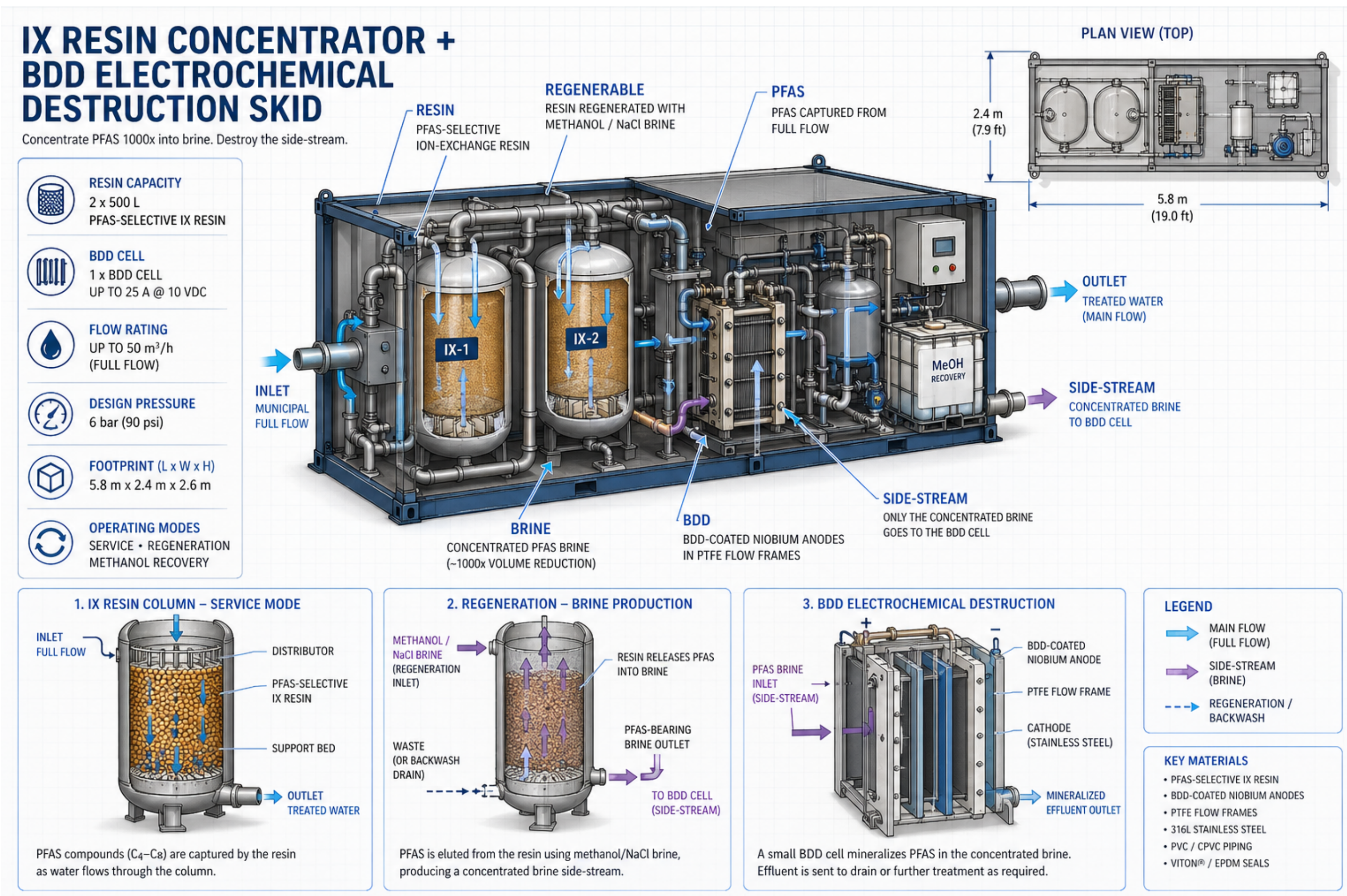
IX Resin Concentrator + BDD Electrochemical Destruction Skid

novelty: 5 | feasibility: 8 | economic_leverage: 6 | testability: 9 | robustness: 7 | constraint_fit: 9 | explainability: 9

Overall: 7.6 / 10 -- Very Strong

Constraint Compliance: Compliant (constraint_fit=9)

Regenerable ion-exchange resin concentrates PFAS up to 1000-fold into a small brine side-stream, allowing a compact boron-doped diamond electrochemical cell to mineralize only that concentrate rather than the full flow. This decoupling of capture from destruction slashes the energy and capital cost of electrochemical PFAS treatment by orders of magnitude. The approach matters because it makes complete PFAS mineralization economically viable at municipal and industrial scales without generating secondary waste streams.



Concept illustration (AI-generated). Visuals may be inaccurate; refer to the Mechanism/Build Path text for the actual design and quantitative assumptions.

Mechanism

Full-flow water passes through lead/lag PFAS-selective ion-exchange columns using strong-base anion resin, likely quaternary ammonium functionalized polystyrene/divinylbenzene or polyacrylic resin, 300-800 um beads, in 10-30 min empty-bed contact time vessels. Hydrophobic/electrostatic binding captures C4-C8 perfluoroalkyl sulfonates/carboxylates; lead/lag operation manages breakthrough. Loaded resin is regenerated off-line with low-water solvent brine, e.g. 70-90 vol% methanol or ethanol, 0.5-2 M NaCl or alternative non-chloride salt/base, at 2-10 bed volumes. This strips PFAS into a 50-500x smaller regenerant stream. Concentrate is fed to a boron-doped diamond electrochemical cell: BDD-coated Nb/Si/Ti anodes, stainless/Ti cathodes, 0.5-2 mm interelectrode gap, PTFE/PEEK flow frame, turbulence/mass-transfer spacers, recirculating tank, cooling loop. At 50-300 mA/cm^2, BDD generates adsorbed hydroxyl radicals and high-anodic-potential oxidative conditions that defluorinate PFAS via stepwise chain shortening and C-F bond mineralization, producing F-, CO2, sulfate for PFOS-like species, and shorter intermediates. Pulsed current or staged current density is used to avoid mass-transfer-limited wasting and suppress parasitic solvent/salt oxidation. Because chloride brine can form chlorate/perchlorate, the engineering hinge is regenerant selection and closed-loop control: distill or membrane-polish methanol/water/salt after destruction, return reusable regenerant to resin, and purge only a small salt/byproduct bleed. Technical delta vs cited PEMFC carbon-aerogel membrane-electrode assembly analog: that analog concerns fuel-cell MEA catalyst-layer humidity/composition and proton/electron transport for power generation; this concept uses packed-bed PFAS-selective IX plus BDD high-potential anodic oxidation for contaminant concentration/destruction, with solvent/brine regeneration and F/C mass balance as the core mechanism.

Why Novel

Prior BDD systems treat full-flow water at prohibitive energy cost; prior IX systems merely transfer PFAS to a landfill-bound spent resin. Coupling selective regenerable IX with BDD destruction of only the concentrated side-stream closes the loop in a way neither technology achieves alone.

Buildability

All core components--strong-base anion exchange resin, BDD-coated niobium anodes, PTFE flow frames, and methanol recovery distillation--are commercially available today and have been individually demonstrated at pilot scale. Integration risk is moderate and manageable within a standard skid-mounted package.

Why Feasible

* Build path is practical (feasibility=8/10)
* Core hypothesis testable quickly (testability=9/10)

Top Risks

* Perchlorate and chlorate byproduct formation from chloride-containing regenerant brine during BDD electrolysis, potentially creating a regulated secondary contaminant
* Short-chain PFAS (C4 and below) breakthrough on IX resin reducing overall capture efficiency below regulatory thresholds
* BDD electrode fouling or delamination caused by organic co-contaminants concentrated alongside PFAS in the regenerant stream

Decisive Test (MDE)

Hypothesis: A closed-loop IX-regeneration + BDD skid can capture >95% of C4-C8 PFAS from water, regenerate resin repeatedly, and mineralize the concentrate with high fluorine recovery while keeping total energy near the 3 kWh/m3-treated target and without accumulating chlorate/perchlorate or losing excessive methanol.
Setup: Treat 500-2000 L of real or realistic groundwater spiked with 6:2 FTS, PFBA, PFBS, PFHxA, PFHxS, PFOA, PFOS at 0.5-5 ug/L each through lead/lag IX columns. Regenerate lead column with selected low-water regenerant at fixed bed volumes. Destroy regenerant in a 25-100 cm^2 BDD recirculating cell under optimized current program. Recover solvent/salt and repeat for 10 cycles. Include chloride-brine and non-chloride-control regenerants.
Instrumentation: LC-MS/MS for parent and short-chain PFAS; combustion ion chromatography or total oxidizable precursor assay if available; fluoride ISE and ion chromatography for F-; IC for chlorate/perchlorate/chloride/sulfate; TOC/COD; GC-FID for methanol; conductivity, pH, ORP, temperature; inline flow, voltage, current, kWh meter; resin pressure drop.

Kill Criteria: Kill if any two hard thresholds are exceeded: <95% full-flow PFAS capture before target bed volumes, <70% PFAS strip from resin per regeneration, <50% fluorine recovery as F- after BDD at economic charge dose, chlorate/perchlorate exceeds potable or discharge limits after reuse cycles, or modeled all-in energy exceeds 10 kWh/m3-treated.
Rescue Pivot: Switch from chloride/methanol brine to sulfate/carbonate or ammonium-based regenerant, add a pre-BDD solvent recovery step, use foam fractionation/RO before IX to reduce resin load, deploy EO only as a polishing/destruction step for still-bottoms, or outsource destruction to plasma/incineration while retaining the IX concentration skid.
Cost: $25k-$90k if LC-MS/MS/IC are outsourced or shared; $8k-$25k incremental if analytical instruments and BDD cell are already available.
Time to Signal: 2-4 weeks for initial kill/validate on mineralization and byproducts; 8-12 weeks for 10-cycle closed-loop durability and cost signal.

Refinement Deltas

Risks Addressed:
* Chloride-rich regenerants are fundamentally mismatched with BDD because high anodic potentials favor chlorate/perchlorate formation; avoiding this may sacrifice strip efficiency or conductivity.
* C4 PFAS and precursors may break through IX early in high-DOC, sulfate, nitrate, or competing-anion waters, undermining full-flow capture claims.
* PFAS disappearance is not enough; incomplete defluorination may simply transform C8/C6 PFAS into regulated or mobile short-chain species.

Red-Team:
* Challenge: Chloride-rich regenerants are fundamentally mismatched with BDD because high anodic potentials favor chlorate/perchlorate formation; avoiding this may sacrifice strip efficiency or conductivity.
* Challenge: C4 PFAS and precursors may break through IX early in high-DOC, sulfate, nitrate, or competing-anion waters, undermining full-flow capture claims.
* Challenge: PFAS disappearance is not enough; incomplete defluorination may simply transform C8/C6 PFAS into regulated or mobile short-chain species.
* Challenge: BDD electrode CAPEX, finite coating life, fouling/scaling, and high cell voltage could make the measured 3 kWh/m3-treated anchor unrealistic at municipal scale.
* Challenge: Methanol handling creates flammability, air-permitting, worker-safety, and residual-solvent issues; distillation energy and solvent losses may erase the cost advantage.

Budget Ranges

Prototype: $80,000
Pilot: $450,000
Scale: $2,500,000

30/60/90 Plan

Day 30: Bench-scale IX column tests with spiked groundwater matrix; characterize PFAS loading capacity, breakthrough curves for C4-C8 compounds, and regenerant strip efficiency across methanol/NaCl ratios
Day 60: Operate bench BDD cell on synthetic regenerant concentrate; measure energy consumption per gram PFAS mineralized, quantify perchlorate/chlorate byproducts, and evaluate electrode stability over 200+ hours
Day 90: Integrate IX columns with BDD cell in closed-loop skid; run 30-day continuous pilot on real impacted water, validate 3 kWh/m^3-treated target, and produce techno-economic model for full-scale design
Dominance Axis: cheaper -- Concentration still cuts destruction volume dramatically; cost edge now depends on regenerant reuse and BDD current efficiency, not a blanket 1000x claim.

Top Uncertainties & Assumptions

* Corrosion of pressure vessel internals and seals in hot caustic service at 320degC may cause rapid material degradation and unplanned downtime
* Incomplete defluorination of PFAS sulfonates and fluorotelomer precursors at target residence times could leave persistent short-chain intermediates in the effluent
* Solvent recovery efficiency degradation over regeneration cycles may increase operating costs and reduce the economic advantage over incineration
* Short-chain PFAS (C2-C4) electrosorb weakly under competing anion load, potentially breaking through CDI stage before regeneration cycle triggers
* Chloride in the NaCl regenerant electrolyte generates perchlorate and chlorate at BDD anode, creating regulated byproduct accumulation in the closed loop

C4.57 L1 T230,144