Closed Loop Chemical Recovery Systems for PCM

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May 19, 2025 – Verona PCMI

Agenda

- Introduction
- Central Recovery Systems
- FeCl3 Recovery Systems
- Photoresist Developer & Stripper Recovery Systems
- Cleaner Purification Systems

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Introduction/Background

After 20 years of watching the PCB Fab industry downsize by 90% in the USA, Alex Stepinski designed and built the first fully automated PCB Fab facility in the world which operated at lower cost than China, with zero discharge and zero emission systems while working for an OEM in New England. He subsequently also designed 3 additional facilities for other US OEM's before leaving in 2021 and founding Smart Factory Design, with a focus on realizing sustainable, autonomous PCB Fab factories designs for Developed Countries; where labor costs and environmental regulations had historically made business challenging.

Since 2021, the company has planned projects with a total investment value of over $600M in the USA and has recently begun expanding internationally with our first projects in India and Southeast Asia.

With a cross-functional team of 11 PhD's and field applications experts, the company designs automated, green PCB Fab factories, as well as custom chemical and wastewater recycling systems for PCB Fab and related industries. Our business model is to prove out new recycling technologies at Top OEM's and then deliver robust, proven versions to the general market.

Recycling Systems are delivered by our regional partners and can be integrated with any wet process equipment. Our four global integration partners are longstanding equipment providers with excellent financials and efficient operations; with a combined annual turnover of $190M USD, and over 200 engineers on staff. We are always open to adding more integrators to our AVL as well.

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KEY EUROPEAN PARTNER – MEGA GROUP

PROUD
to be a Czech company

30+
years of production experience

240
total employees

70
R&D employees

€60M
turnover in 2024

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CENTRAL RECYCLING SYSTEM CONCEPT for Chemicals and Wastewater

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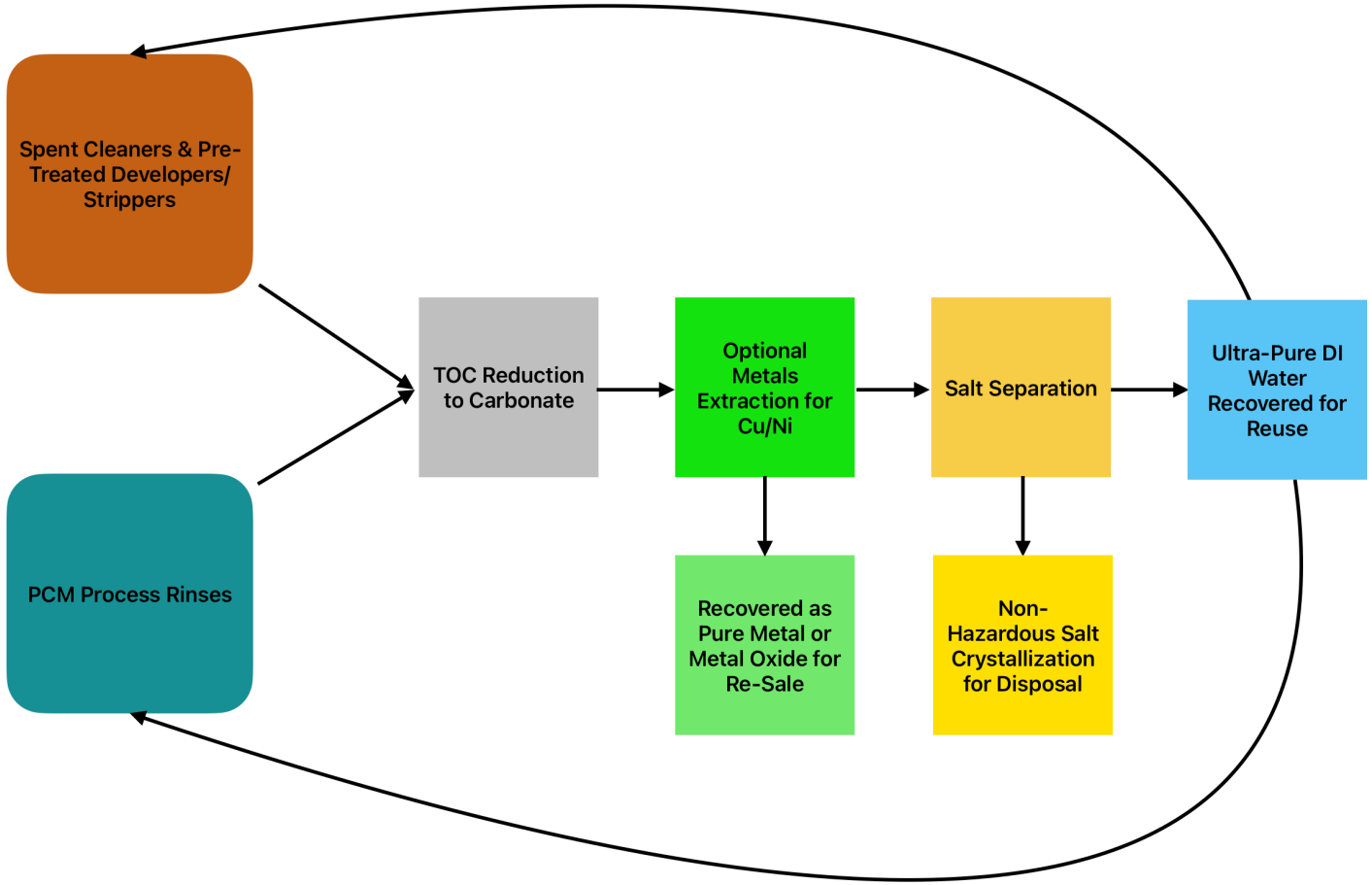
PCM Central Rinsewater & Non-Etchant Recycling ZLD



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Generational Advances in Closed Loop ZLD ARCHITECTURE

GENERATION 1: Evaporative-Based Systems used mostly in the US OEM Captive Electronics Market and India. Very high operating and capital cost due to the use of evaporators with a very expensive metallurgy. Literally boiling the ocean. Additionally, a unique segregation plan is required. Not economical and only deployed where discharge is not an option. These systems have been available for decades, but at very high cost,

GENERATION 2: Electrolytic-Separation-Based Systems were invented in 2021, beta tested in 2022 and deployed commercially beginning in 2023. This new design architecture reduced the operating cost of ZLD by over 80% compared to GEN 1 and reduced the CAPEX BY 50%. It also works with a standard segregation plan and does not require manufacturing process modification. This system design has been the PARETO frontier of cost efficiency and sustainability for Greenfield investments the past few years.

GENERATION 3: Autonomous, Desegregated, Electrolytic-Separation Based Systems were invented in 2023, beta tested in 2024, and are being deployed commercially in 2025. Systems do not need primary treatment segregation, self-adjust operational mode based upon the detected contamination level, and need less than one hour per day of labor to manage. In electronics manufacturing settings, the systems are profitable to operate due to the creation of circular economy products instead of sludges. This is the first time that a positive ROI is attributable to a PCB Fab wastewater investment globally and projects are now being realized in India, Southeast Asia, and the USA based upon this technology on scales from 6-80 m3/hr of turnover. For PCMI projects where valuable metal recovery options are more limited, the operating costs of the system are still significantly lower than traditional designs.

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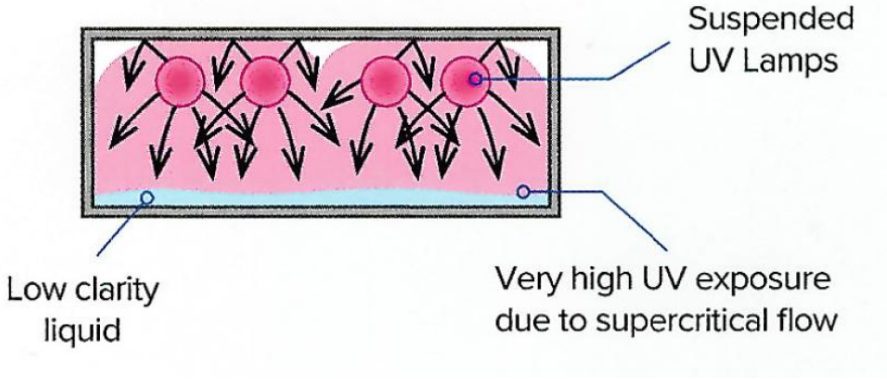
FeCl3 Photolysis Delivery Detail

Our Reduction Method is also useful for purifying process baths of organics (eg. FeCl & CuCl etchants)



A critical parameter when considering UV disinfection is the UV transmittance (UVT) of the liquid. UVT is a measure of how much UV light can pass through a liquid. A UVT of 100% means all the UV light can pass through the liquid, whereas a UVT of 0% is opaque not allowing any light through.

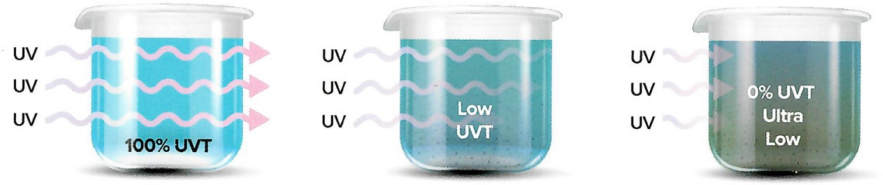
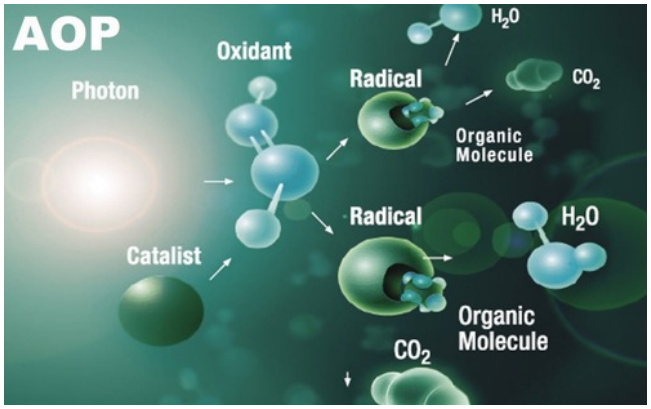


Figure 1: UV transmittance through different liquids.



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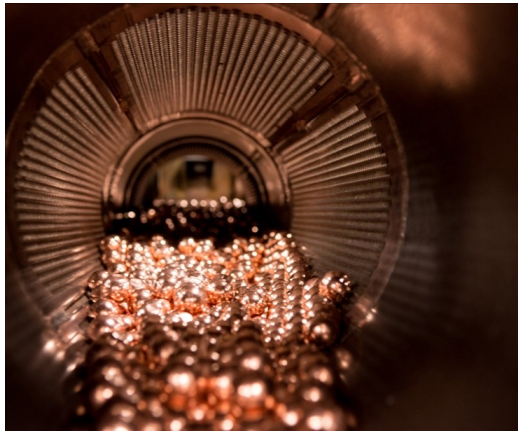
Copper Conversion to Electroplating Anodes or Cu Oxide for High Value Resale



99.99%+ Purity Cu, Cu-P, or CuO

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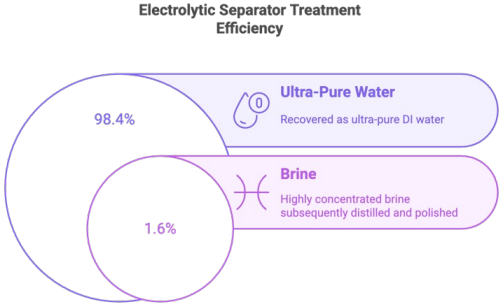
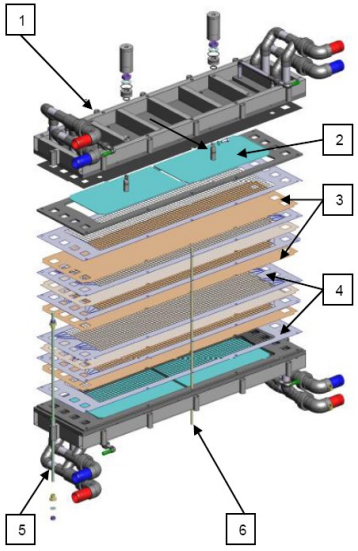
Electrolytic Separation

Description of the Electrolytic Separation Process

The electrolytic separation process contains stacks of ion exchange resin sheets and electrodes. The ion exchange resin sheets are of similar composition to ion exchange resin beads but are manufactured in the form of flat sheets instead of individual beads. IX sheets are either of anion form, cation form, or a hybrid bipolar form (whereby one side of the sheet has an anion function, while one side has a cation function). On their own, the sheets function just like an ion exchange resin bead by binding with dissolved ions in the waste stream and can be chemically regenerated with acids and bases just like an ion exchange resin bead. They also have the added benefit of being chemically resistant from a pH of 0-14 just like IX beads. By combining the stacks with electrodes, however, the regeneration of the resin sheets can be transformed into a continuous process without the need for chemicals. In applying the appropriate bias to the electrodes with such a stack, the aqueous component of the waste stream is split into H+ and OH- resulting in a continuous regeneration of the sheets and a concentration gradient which can be custom engineered based upon a synthesis of the number/size of sheets in the system compounded by the bias applied. The concentration gradient is then dynamically adjusted through current density change based upon the total dissolved solids of the feed stream measured by interpolation of in-line conductivity sensors on the input and output pipes.





Example of Galvanic Membrane Stacks

1- Tightening boards with built-in collectors

2 - Electrodes

3 - Ion exchange membranes

4 - Spacers

5 - Tie-rods, washers and nuts

6 - Assembly pins

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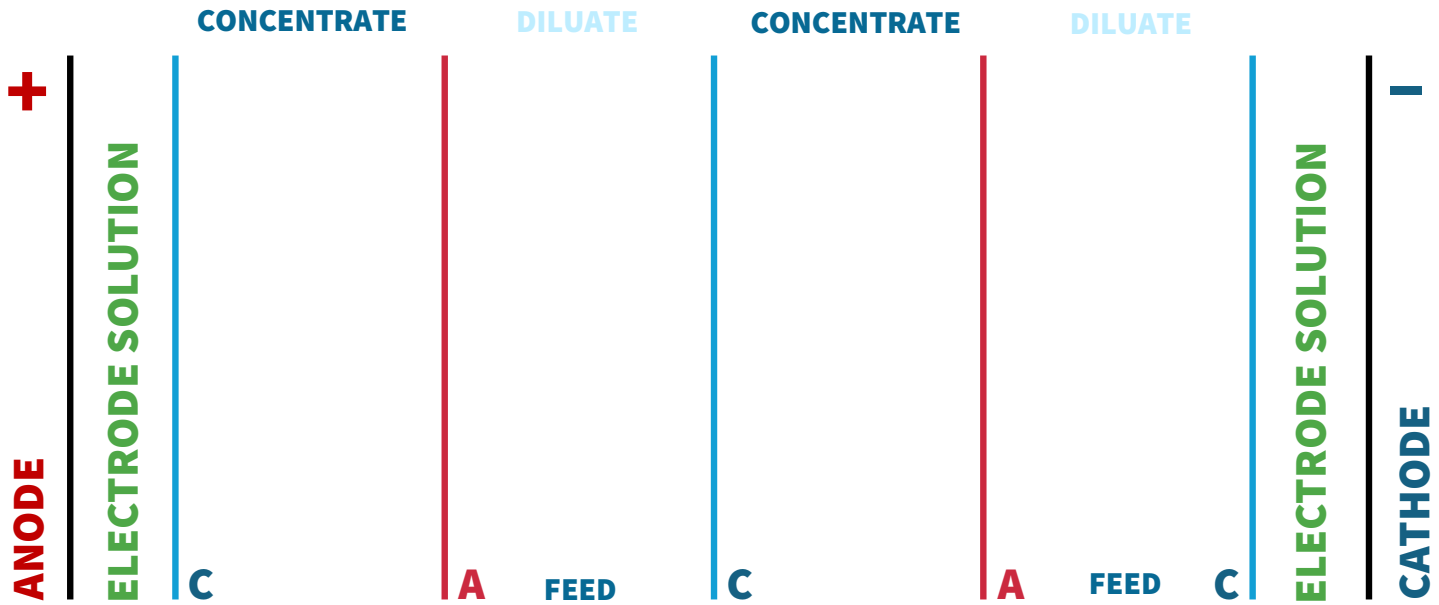
HOW GALVANIC MEMBRANES WORK

- A combination of membranes allows both cations and anions to be removed



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Vacuum Crystallization

- Distillation of residual water from an incoming brine of 1.23 density from the electrolytic separator.
- Concentration of Sludge in a Vertical Cement Mixer Style Vacuum Distillation Unit with Integrated Auger.
- An optional Conveyorized Drying Process Direct to a Roll-Off is also available.

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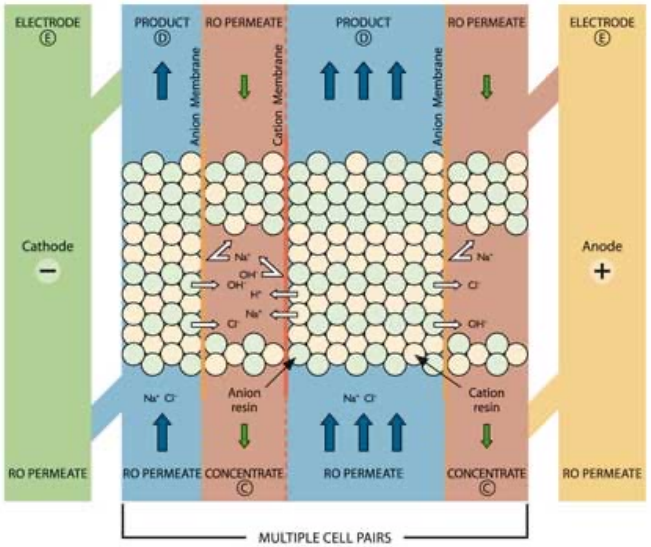
Ultra-Pure Water for Perfect Rinsing

- UPW Water is generated by an industrial EDI (electro-deionization), and then directed to a distribution tank which is under constant disinfection
- We customize the plumbing distribution plan for each facility to eliminate the potential for biological contamination.
- An array of sensors is monitoring the tank return from the process, comparing it to the outgoing water quality to assess the delta. The delta is the total contamination from the factory plumbing distribution process.
- Guaranteed UPW specifications up to 18 megaohm are available, but typical for PCM is >1 megaohm resistivity.



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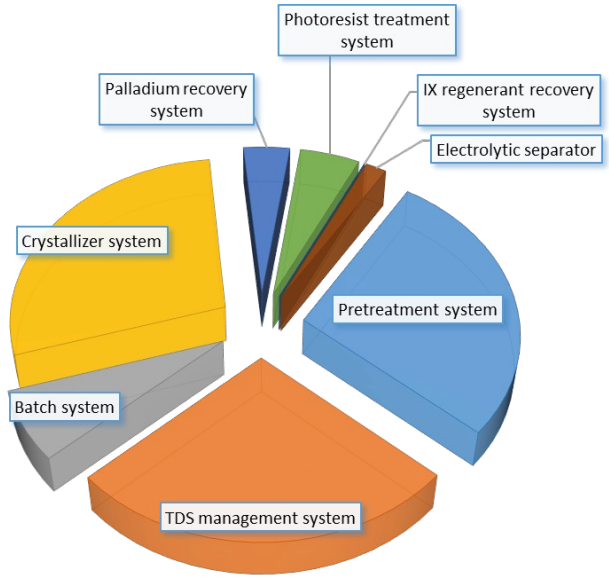
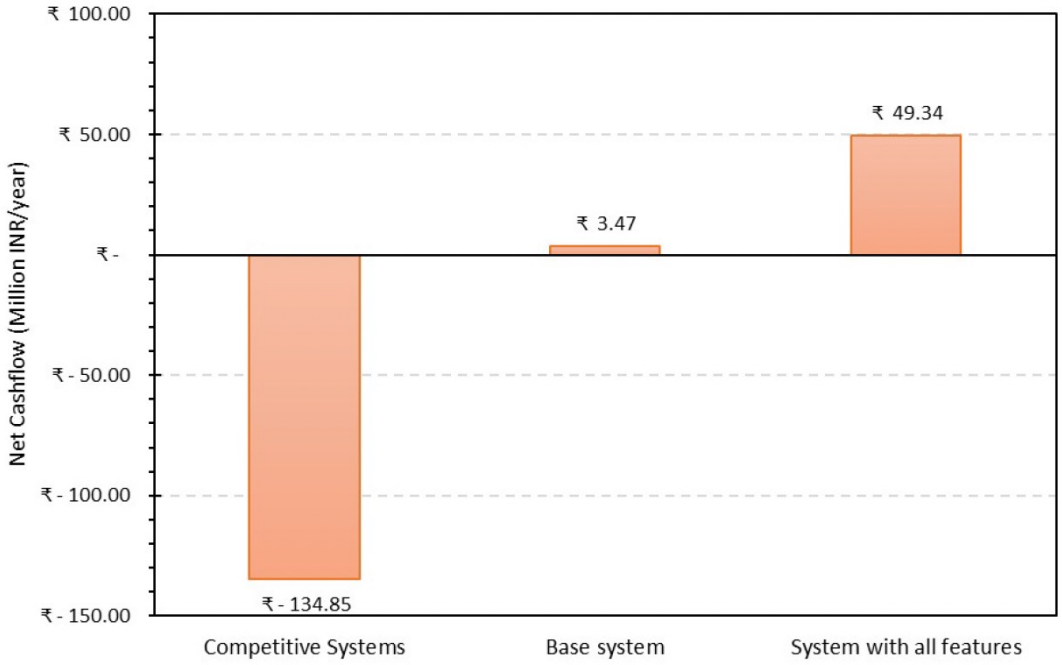
OPEX Breakdown of a sample GEN 3 50m^3/hr Project in India





2.5M Euro Annual OPEX Savings on 4M Euro Investment vs Traditional Design in Most Competitive Global Region

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Key Overall System Attributes – Gen 3 ZLD Systems

- <10% of the chemical usage of traditional plants with NO proprietary chemicals necessary.
- Only 20-50% the footprint of typical plants.
- <1 m3/day of water is necessary to operate the plant aside from the first fill-up. This small amount can be generated from the air using an electrochemical method, from HVAC, or by using a softened city water supply.
- The system makes DI water as the product with over 99% water recovery, zero liquid discharge, and zero evaporative emissions.
- Energy consumption is A FRACTION of any other ZLD system.
- Very durable, long-lifecycle equipment design with over 10 years of ZLD system field experience.
- Specialized in treating hard to manage molecules. Particularly experienced in avoiding the build-up of low-level organics in plating/etching baths which shorten bath life. (major hidden cost)
- Leveraging our factory design experience, we also assist our clients in optimizing their manufacturing process equipment specifications to safely lower their chemical costs and waste volumes.

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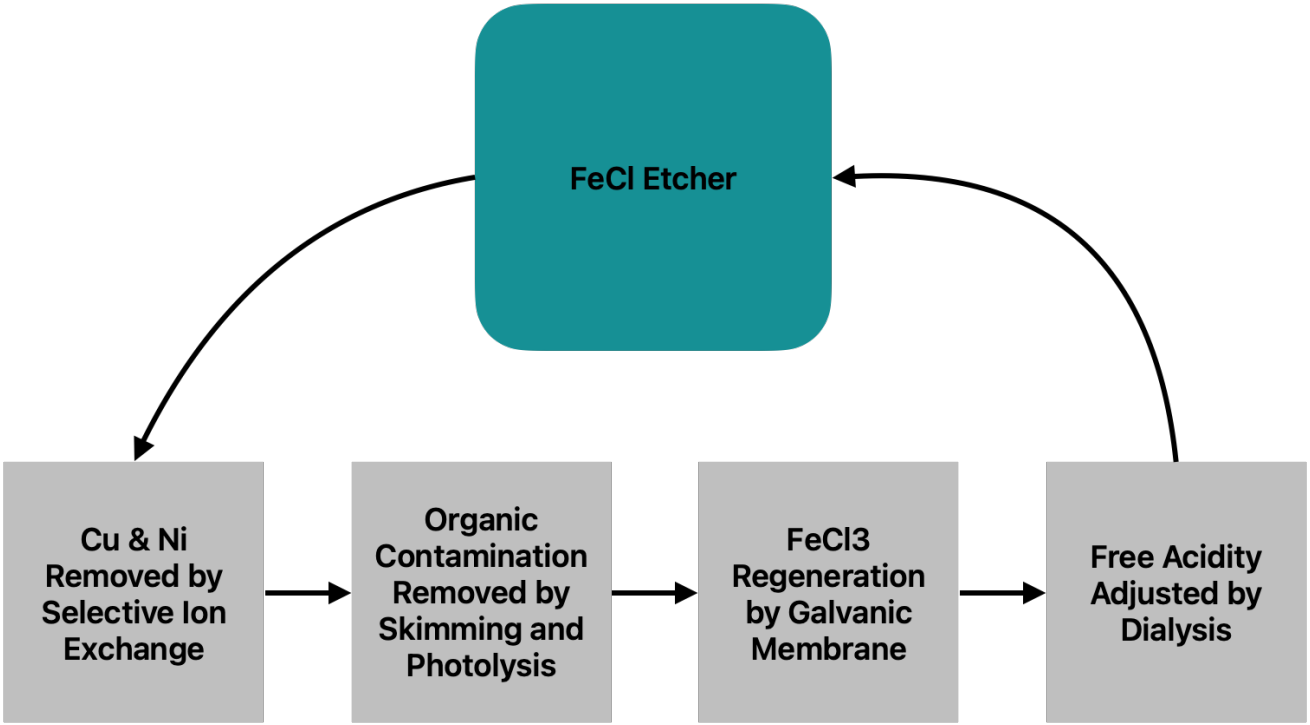
Closed Loop FeCl3 Etching



Integrated System of all Four Steps Made in Europe
CuCl2 Systems are also available (only difference is the regen method)

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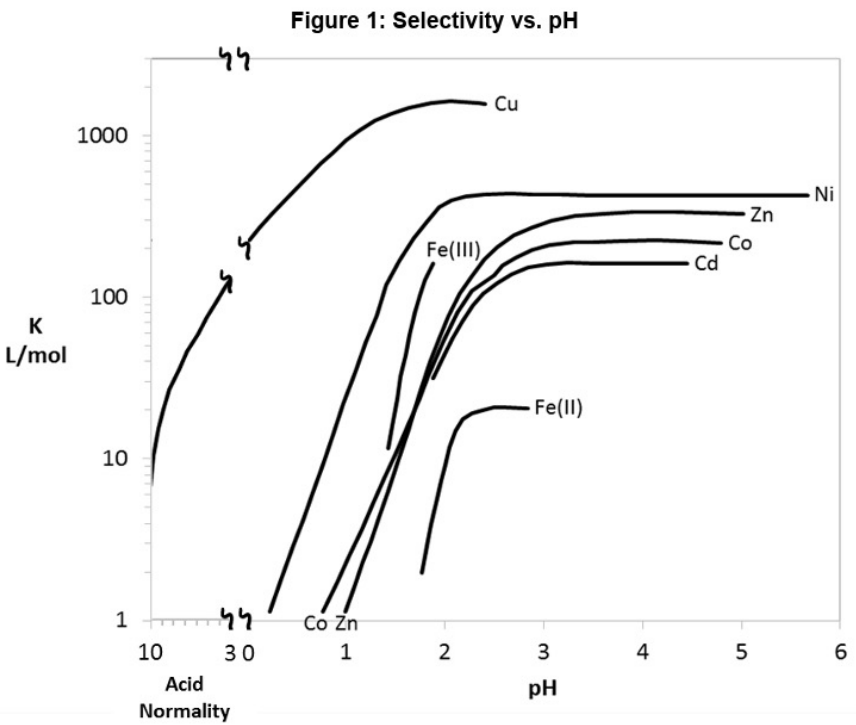
Selective Removal of Cu and Ni from FeCl3



Specialized Resins facilitate removal of non-ferric metals for purification of FeCl3.

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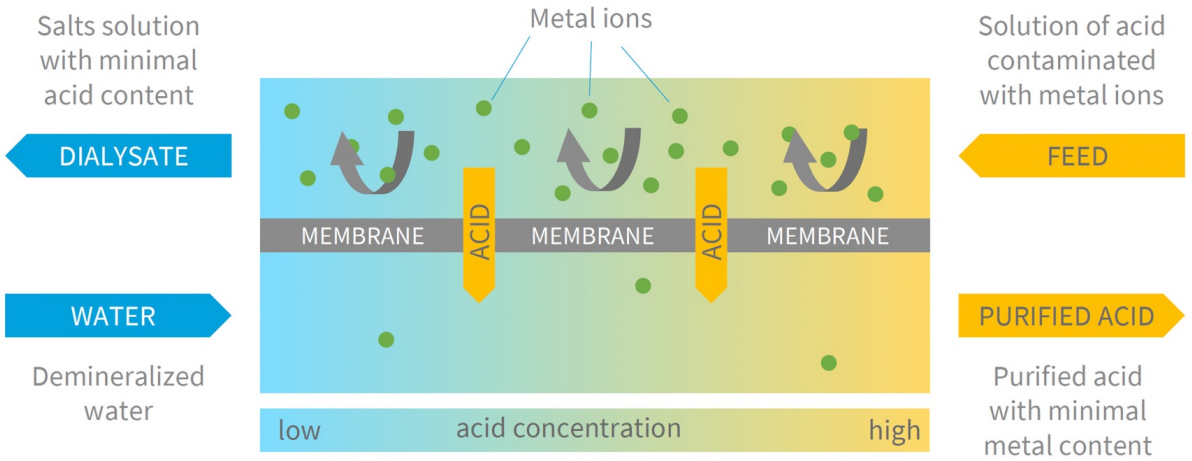
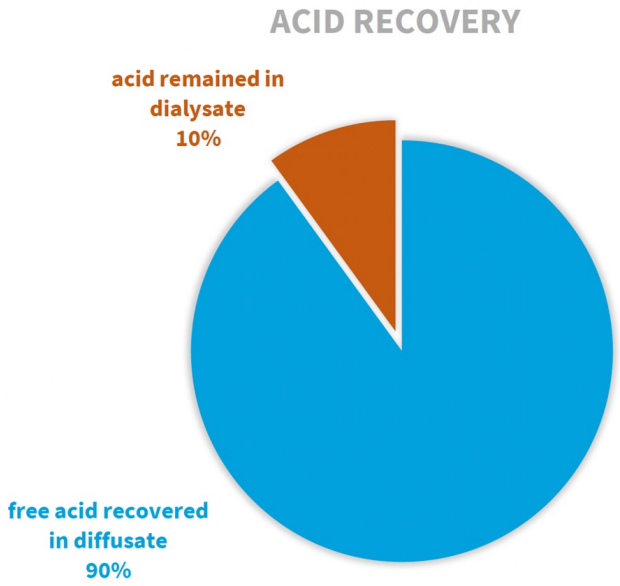
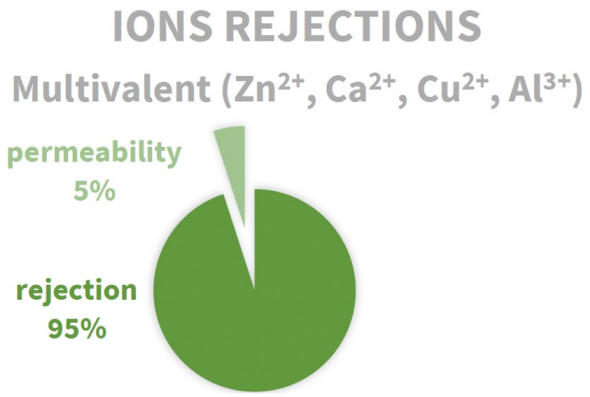
Dialytic Adjustment of Free Acid & Metal Contaminant Scavenging



Anion-exchange membrane repulses metal cations which are kept in dialysate in the form of salts. Acid is transported through the membrane into the water and purified.





Proven in FeCl3 Applications!

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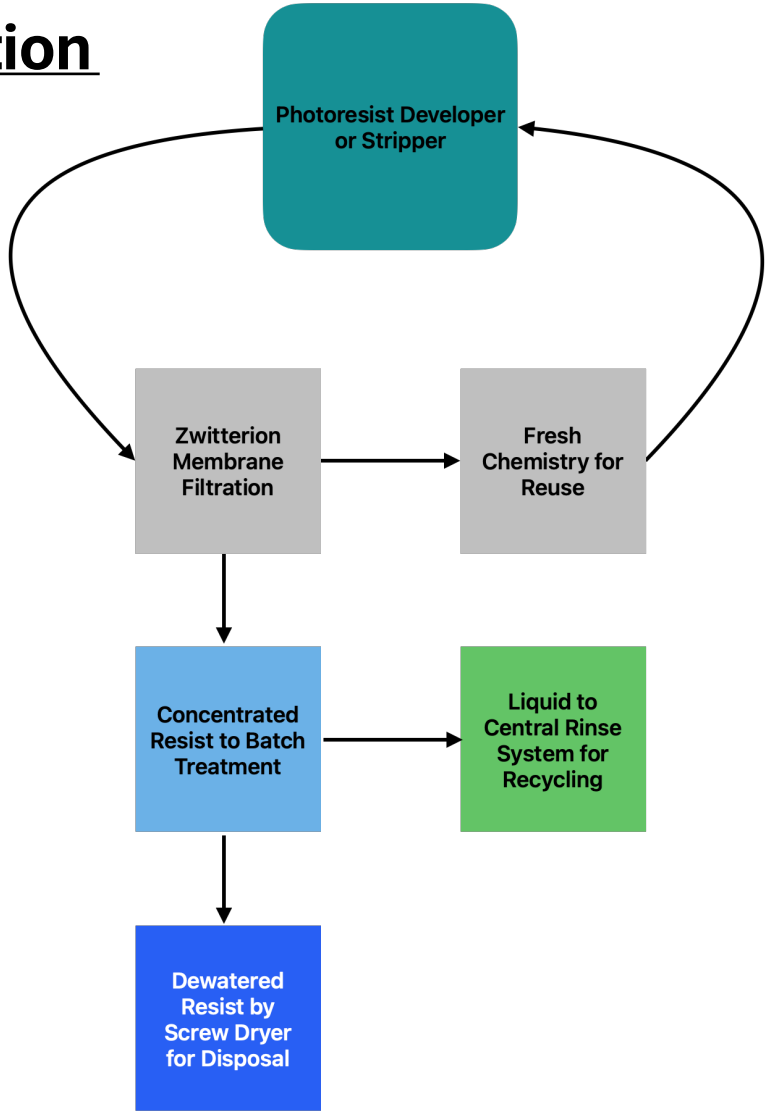
Photoresist Developer & Stripper Regeneration

- 90% reduction in chemical usage
- Resist is removed as a dried solid and the residual liquid is converted to DI water for reuse.
- Solvent-Free Process
- Unique Zwitterion Membranes



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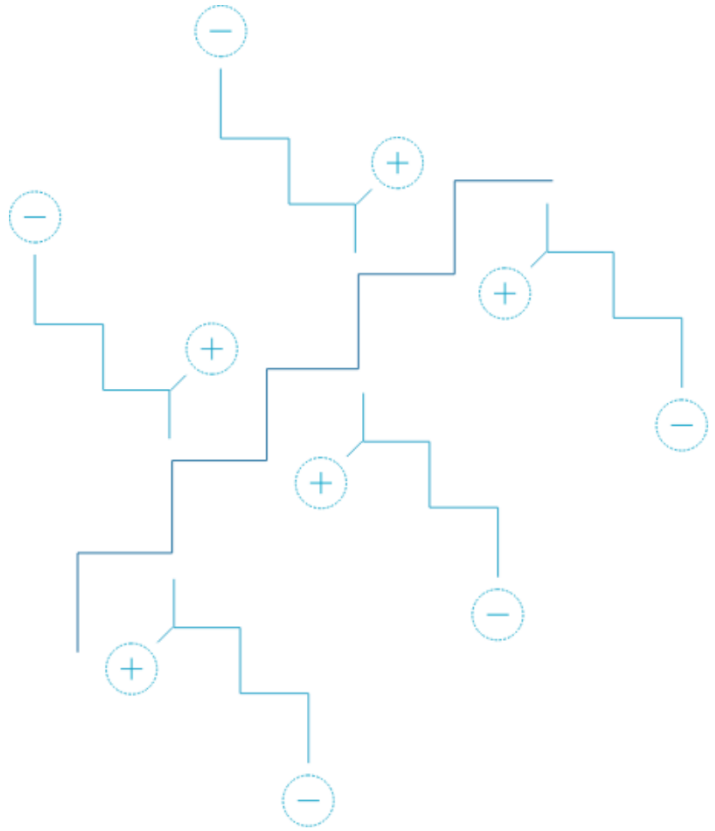
Organic Separation Technology for oils, photoresists, and other organics



01. POSITIVE + NEGATIVE CHARGES

Zwitterions attract to water molecules.

Zwitterions have an equal number of positive and negative charges, so they exhibit an immense, salt-like attraction to water molecules.

This hydrophilic property pulls water to the membrane, actively displacing or repelling organic compounds so they cannot adhere to and foul the membrane.

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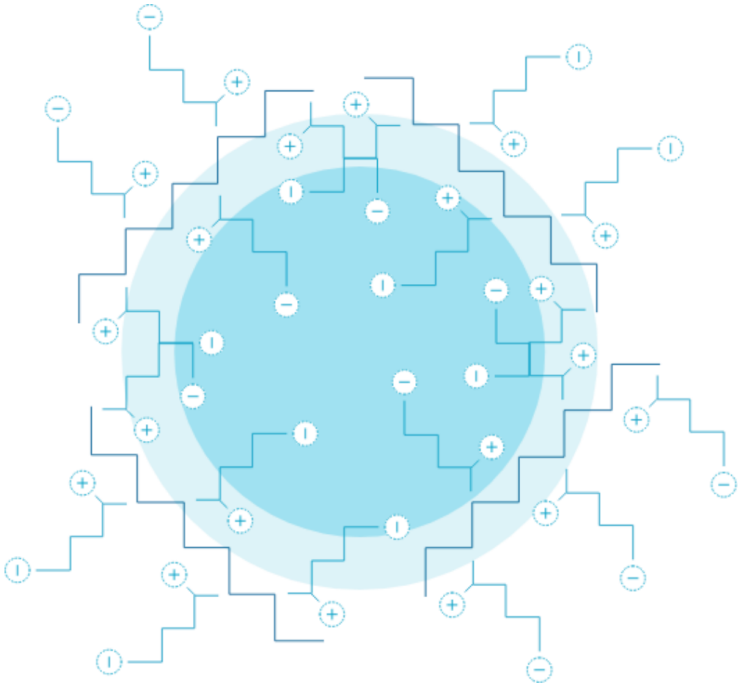
Organic Separation Technology for oils, photoresists, and other organics



02. PROPRIETARY CO-POLYMERS

Copolymers bind zwitterions with hydrophobic molecules.

proprietary co-polymers permanently bind hydrophilic zwitterionic molecules to strongly hydrophobic molecules.

The hydrophobic molecules give the co-polymer stability in water, preventing zwitterions from wearing away over time.

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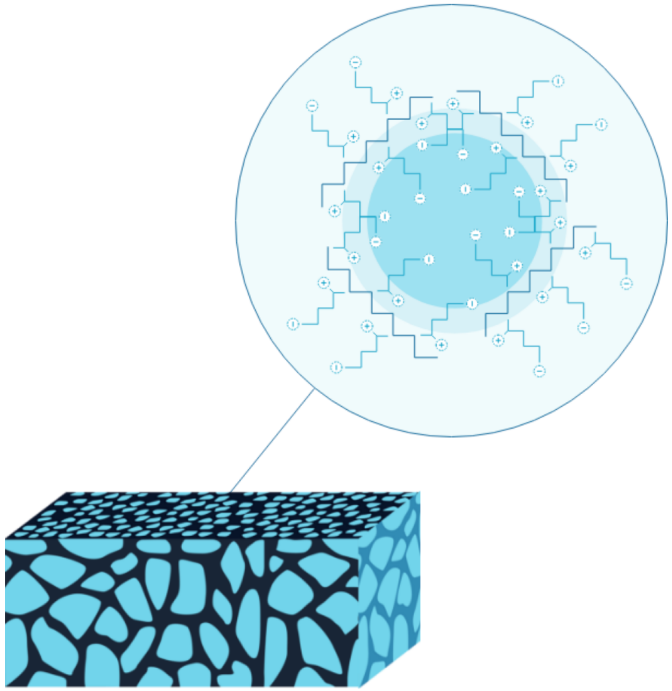
Organic Separation Technology for oils, photoresists, and other organics



03. FOULING IMMUNITY

Zwitterions create fouling-immune, water-loving channels.

With traditional membranes, the most severe membrane fouling occurs within the pores. Using the latest techniques in molecular self-assembly, the zwitterions in our polymeric membranes form water-loving channels throughout the membrane layer.

These zwitterionic channels act as the membranes' pores, ensuring that the internal architecture, as well as the external surface, is immune to fouling.

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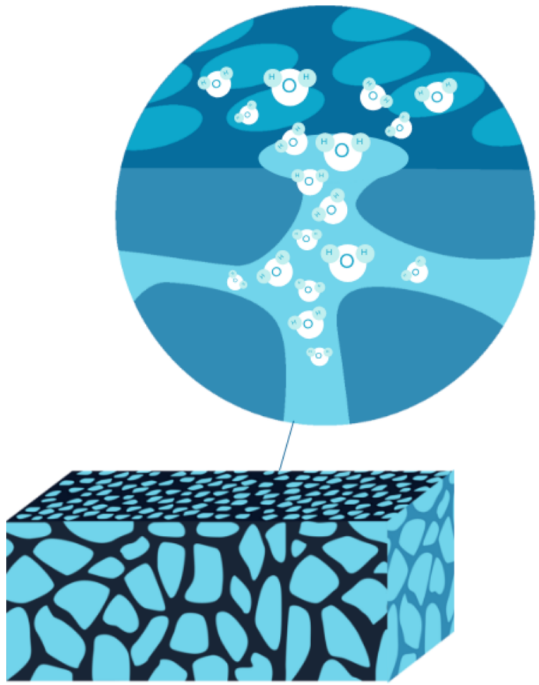
Organic Separation Technology for oils, photoresists, and other organics



04. CLEAN PERMEATE

Zwitterionic channels retain contaminants and produce clean water.

During filtration, water molecules are attracted to the water-loving regions and can flow through the zwitterionic channels, passing from one zwitterionic chain to the next.

A clean permeate stream is generated as water molecules exit the membrane free of contaminants that were too large to fit through the zwitterionic channels.

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Adoption & Benefit

Our experience is that GEN 3 central systems and Point Source Solutions can be implemented in 95% of operations for a 6 month to 5-year ROI depending on system scale. The exact ROI for a given project is calculated in the preliminary financial analysis.

The solutions are being adopted by companies of all scales, but the bigger the Factory the bigger the ROI. Many other recycling options (ie. individual chemicals) are also possible, and in use globally.

Reference accounts and our technical partners are available for site visits. We would love to talk and assess a potential fit.

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THANK YOU!