Title: **New 3-D Electrolytic Cell Advances the Concept of Waste Minimization in Plating Applications***

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ABSTRACT

Individual conventional techniques available for the treatment of aqueous process and waste streams containing metals have the disadvantage of being inadequate and requiring additional technology to meet process specifications and effluent discharge limits, and/or they produce a secondary effluent metal-bearing solution or a mixed solid requiring further treatment. For example, the performance of conventional electrolytic cells (usually based upon metal plate or mesh cathodes in a tank) is limited at low metal ion concentrations of around 150 - 50 mg/L or ppm while effluent discharge levels are typically less than 5 mg/L and often below 1 mg/L. Similarly, ion exchange resins may reduce metal concentration to 2 mg/L levels but must be regenerated and the regenerant liquor further treated.

This limitation has been addressed by a patented electrochemical technology developed by EA Technology Ltd., being commercialized by Renovare International Inc., and known as RenoCell¨. The RenoCell design, for the first time, allows effective use of three-dimensional (3-D) porous cathodes through the flow path and current distribution embodied. The use of a 3-D porous cathode greatly enhances the performance of the electrolytic cell since the porous cathode has >500 time greater effective surface area than 2-D electrode of the same nominal size. RenoCell's high surface area allows metal removal at higher deposition rates, lower current densities and higher current efficiencies, and thus achieve lower final metal ion concentrations. RenoCell has demonstrated the capability to achieve metal discharge limits without further treatment; collect metals as elements ready for reuse or sale; use removable cartridges for ease of operations and maintenance; and improve cost effectiveness and reduce life cycle costs.

While the RenoCell can be applied in a variety of applications ranging from process water treatment to metal recovery to effluent treatment, the potential of waste minimization is being realized today in certain printed wiring board (PWB) plating applications. For example, the cell is being placed at point sources of copper and other metal releases such as dragout and rinse tanks. Instead of these process waters being released to waste treatment, the RenoCell recovers the metal at the source, allows the rinse water to be used longer thus reducing water use and discharges all at a substantial cost advantage over conventional technology. Such waste minimization applications and experience with a myriad of metal removal applications are provided with focus on heavy metals (e.g., Cd, Cu, Pb) and precious metals.

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Introduction

There are many industries where process operations result in large quantities of dilute metal solutions—typical examples being metal plating and surface finishing, and printed wiring board (PWB) manufacturing. These solutions represent a loss of metal and in many cases effluent problems particularly now that discharge of metals and disposal of most metal sludges is much more rigorously controlled throughout the world.

Various technologies including ion exchange, reverse osmosis, solvent extraction and electrolysis, have been developed to offer an economic solution. The goal has been to supplant the most commonly used method of effluent treatment—chemical precipitation, with improved methods that can recover the metal in a reusable form, and hopefully solve the effluent problem in a cost-effective manner.

These recovery methods are technically generally quite satisfactory when used together. Their economic justification, however, seems to be more difficult and so far, they appear to be competitive only where large throughputs, single metal streams and particularly stringent or difficult discharge conditions are encountered. Furthermore, after recovery, the solutions require further conditioning before discharge, e.g., neutralization, cyanide destruction, etc., where the single stage recovery effluent treatment approach is not entirely satisfactory.

Electrolysis in particular is generally used in the metals industry when high purity products are desirable and where different finished metal surface coatings are required. Electrolysis has the potential therefore of producing a directly reusable product from an metal-laden effluent solution. Ideally the metal should be in a solid form so that direct reuse can be achieved by smelting or dissolving as anodes in the main processes, e.g., plating, electrorefining.

There are two major problems to electrolysis of dilute (i.e., less than 1g/L) metal ion solutions:

- The process becomes mass transport limited, therefore either capital costs are high or current efficiencies and quality of the deposit are poor.

- The economic return from dilute solutions of metals is very small and imposes a serious limitation to the sophistication and costs a process system or application can afford.

Many electrolytic cells have been proposed for metal recovery over the past two decades. They are used mostly as concentrators where further stages of purification are required to obtain the metal in a directly reusable form. The most common configurations include parallel flat plate cathodes, reticulated cathodes, and high surface area cathodes. Various cell manifestations have been developed to minimize the mass transport limits and reduce the equipment footprint and costs. Some of the most common cells include the carbon particle packed bed (ER cell);

fluidized bed beads within electrodes (Chemelec cell); vertical metal or carbon foam electrodes (Retec cell); and various cylindrical rotating cathodes (Eco-Cell), as identified in Pletcher.[1]

Unfortunately, the performance of these conventional electrochemical cells is limited at low metal ion concentrations. While some of these cells can be effective down to metal ion concentration levels of around 50 - 150 mg/L, effluent discharge levels are typically less than 5 mg/L and often below 1 mg/L.

RenoCell¨ Technology

The problem of developing an electrolytic cell capable of removing metal to below 1 mg/L concentrations has been addressed effectively by a patented electrochemical cell technology known as RenoCell¨ (see Figure 1). The RenoCell design, for the first time, allows effective use of three-dimensional (3-D) cathode materials, in this case a porous carbon element, through the flow path and current distribution embodied in the RenoCell. The use of a 3-D cathode greatly enhances the performance of the cell since the porous carbon felt has at least a 500 times greater effective surface area than a two-dimensional electrode of the same nominal geometric size.

The patented design of the RenoCell makes this very high surface area available for metal deposition at higher current efficiencies, lower current densities and higher deposition rates for a given nominal cell size than commercial cells with 2-D and 3-D cathodes. The net result is that RenoCell can achieve lower final metal ion concentrations while using less energy to remove a given amount of metal from a metal ion bearing solution. In general, RenoCell is capable of two to three orders of magnitude lower final concentration of metal ions, and three to ten or more times higher current efficiency than other commercial electrochemical cells at concentrations between 50 and 5 mg/L. The current efficiency improvement is even higher (infinite in some cases) between 5 and 0.1 mg/L (or even 0.01 mg/L for some applications). Such low concentration levels are not even possible by present commercial electrochemical cells.

Physically, the standard RenoCell is constructed of plastic tubular sections that are mounted vertically to assure gases escape with effluent solution discharge. A standard RenoCell Model 500 for industrial applications consists of an 0.5 m long polypropylene housing with an outside diameter of 200 mm. The area of the cathode in this device, on a 2-dimensional basis, is approximately 0.11 m^2. The actual plating surface of the carbon element is at least 55 m^2. A larger standard RenoCell Model 1000 is also available consisting of a 1.0 m long housing of the same outside diameter, and having a 2-D cathode area of 0.23 m^2 and 3-D area of 115m^2.

In addition, for certain applications, a variation of the 0.5m standard RenoCell is the “divided” RenoCell Model 500/D, in which a hydroscopic membrane (normally a cation exchange membrane) is positioned concentrically between the cathode and the anode. In this case, two electrolyte solutions, anolyte and catholyte, and consequent dual solution storage, circulation and

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1 Derek Pletcher and Frank C. Walsh, *Industrial Electrochemistry,* 2nd Edition, Blackie Academic & Professional, London, 1993; p. 336-353.

control systems, are required. The divided cell system can be applied to solutions containing species that can be oxidized at the anode and that would interfere with the cathodic deposition process, e.g., chlorine generation from aqueous chloride solutions.

When the cathode is completely laden with metal to the point of blocking virtually all flow through the cell, as indicated by high pressure drop across the catholyte side of the cell, the cathode must be replaced or otherwise regenerated The spent cathode is recovered from the RenoCell by switching off the power supply and pumps; disconnecting the outlet piping; removing the top end plate; and then extracting the metal-laden cathode cartridge assembly. A new cathode cartridge assembly is then inserted into its locating position within the cell, the end plate, outlet hose and cathode current feed wire replaced, and the cell is ready for operation. The metal-laden cathode can then be regenerated or smelted.

Technology Performance

As noted, the performance of a “conventional” electrochemical cell is limited at lower metal ion concentrations (generally less than 50 mg/L) as illustrated in Figure 2. These devices are usually based on metal plate or mesh cathodes in a tank combined with some means of mass transfer enhancement (e.g., moving the electrodes or achieving turbulent process flow). Thus, to reach 1 mg/L or lower, an additional treatment process such as ion exchange, is required that increases complexity and costs when compared to RenoCell.

RenoCell is based upon the effective use of a 3-D cathode in metal ion removal applications. This technology has evolved from 2-D planar and cylindrical cathodes and fluidized bed 3-D cells (Chemelec). By taking advantage of the very high surface area of carbon and other materials, RenoCell has extended the metal ion (concentration) removal range two to three orders of magnitude lower than other commercial products (see Figure 3).

RenoCell has the potential of being applied to numerous metal ion removal or control applications. Such applications must be evaluated against the current RenoCell design and capabilities as noted in Table 1.

Technology Experience

Renovare considers RenoCell as a major extension of electrochemical deposition technology both in terms of effective treatment range and reduced life cycle costs. The technology has been successfully tested on the following metals in a variety of matrices:

Cadmium	Nickel
Copper	Cobalt
Mercury	Rhodium
Platinum	Gold

Iron	Lead
Osmium	Palladium
Ruthenium	Silver
Tin	Zinc

Other metals of possible interests include arsenic, antimony, polonium, molybdenum and tungsten that are recovered as alloys with other platable metals. While no metal electrodeposition occurs with chromium, manganese and titanium, they do electroprecipitate at the RenoCell cathode as oxides or hydroxides and are effectively removed. Other metal recoveries are being continually tested.

Based on over 600 tests performed over the past six years, the RenoCell technology has demonstrated excellent removal capability of a range of heavy metals, value metals and precious metals. Table 2 provides a partial list of installations by industry and application in the UK and U.S.

Table 3 presents typical experience for a variety of process liquors and rinses and effluent streams. Typical use of RenoCell includes plating bath maintenance, rinse bath treatment, enhancing ion exchange resin operating life, ion exchange regenerant treatment and reuse, as well as various precious metal recovery and heavy metal removal operations.

While the following discussion uses U.S. experience, statistics and regulations, it is noted that much of the industrial world has similar or more stringent regulatory environments and operational restraints.

U.S. Industrial Practices

Currently, metals in wastewater are removed by the addition of chemicals that precipitate the dissolved metals as metal hydroxide or sulfate in the plating and surface finishing industry. The solid particles are removed as a wet sludge by filtration or flotation and then disposed to landfill. Due to the addition of chemicals during precipitation treatment, the water generally cannot be recycled to rinse operation and consequently the treated water is discharged. In the mid-90s some 70,000 tons of Cu/Pb compounds and 230,000 tons of metals were disposed annually in the U.S. The cost associated with the transport and disposal of Cu/Pb sludges and metal sludges were in excess of $25M and $65M, respectively, with additional costs associated with the liability of future landfill cleanup. According to the survey of 318 U.S. plating shops in metal plating industry, an average of 160,000 L/day of water is discharged from one plating shop. For the entire printed wiring board industry (i.e. about 800 shops), this represents 30 billion liters/year of water discharged. With average water and sewer costs of $0.01/liter, this represents an additional cost of $25M/year. In addition, the costs of sewer and water are rising at 150% and 200% of the inflation rate, respectively. The actual cost of in shop treatment is not included in these figures.

Conventional recovery methods for metal in the U.S. include ion exchange, electrowinning, reverse osmosis, evaporation and freeze crystallization. Two columns of ion exchange (cation and anion exchange) can reduce metal concentration as well as TDS and neutralize pH for recycle to rinse operation. However, strong acid and alkaline solutions are needed to regenerate the cation exchange resin and anion exchange resin, respectively, and the resulting solution need to be disposed. While reverse osmosis, evaporation, and freeze crystallization technologies can provide water with low metal concentration for discharge, the concentrated stream generated needs further treatment and often the dilute stream needs to be polished. Conventional electrowinning is not efficient to treat low concentration of wastewater and the treated water cannot by recycled because pH is not neutralized. However, RenoCell, because of its excellent performance on dilute metal bearing solutions, offers a practical alternative to the high cost of waste sludge and long term liability risks.

Against this backdrop, it is noted that the U.S. metal finisher and PWB industries have been highly regulated and has been strongly encouraged to reduce waste generation and emissions. Since the passage of the pollution Prevention Act of 1990, the emphasis has been to prevent pollution at the source followed by recycling and treatment and disposal. Thus, waste minimization at the source is a desirable goal though rarely practical with conventional technology.

General Metal Finishing

RenoCell electrodeposition technology is applicable to the prevalent metals, and their complexes, that abound in the metal finishing industry. These metals include nickel, copper, cadmium, zinc, lead, tin, gold, silver, palladium, and chromium. In these industrial applications, RenoCell technology focuses on waste minimization and metal recovery in the context of a complex and diverse set of issues associated with chemical-based solutions used in metal finishing operations.

These issues involve:

- different types and concentrations of metals, concentrates and rinses;
- various volumes of metal contaminated liquids;
- more stringent metal compliance levels associated with environmental regulations; and
- increasing process and water treatment costs.

One of the higher profile industrial sectors of metal finishing is PWB and electronics manufacturing. This multi-billion dollar industry is a large user of water and major generator of metal contaminated waste water.

PWB Plating Operations

The conducting circuitry of a PWB contains copper as the most prevalent conductor along with the lesser use of nickel, silver, tin, tin/lead, and gold as etch resists or top-level metals. RenoCell electrodeposition technology has proven applications in removing these metals from process rinse waters.

PWB manufacturing involves over 50 different process steps. Subtractive processing involves the selective removal of copper to form the conductive circuit patterns. Initially, a photosensitive resist material is transferred to the virgin copper surface and the circuit patterns are exposed to UV light, and with the circuit pattern developed, the remaining unwanted exposed copper surface is then etched away by chemicals and rinsed by water.

The image resist material is then removed and a final protective solder resist is applied. Plated through-hole PWBs require the selective deposition of copper and tin or tin/lead on an image formed in a similar way. The plating resist forms the circuit pattern and, on its removal after plating, the etch resist (the tin or tin/lead) protects the circuit during etching of the newly exposed substrate copper. Subsequent similar processes selectively plate nickel and gold on the edge contact of the circuit.

RenoCell technology focuses on the removal of metals from these complex chemistries and provides for waste minimization and continued reuse of the rinse waters. RenoCell addresses the important management issues of:

- Increase in process and water treatment costs
- More stringent metal compliance levels associated with effluent regulations
- Various volumes of, and concentrations in, metal contaminated water rinses

- Reclaim of valuable metals

Two typical PWB plating lines will be reviewed for application of RenoCell for point source treatment opportunities.

<u>Pattern Plate Acid Copper and Tin/Lead Plating Line</u>

PWB process lines include concentrated chemistries for cleaning, etching, electroplating, and stripping, each followed by rinsing process steps.

Both acid sulfate and copper pyrophosphate copper plating solutions find use today industrially. Acid sulfate solutions are the predominant copper plating solutions used in the PWB industry, although pyrophosphate solutions are specified by some military applications where ductility of the deposit is of paramount importance. Both solutions are also used in the plating-on-plastics industry after an electroless strike has been applied to the non conductive surfaces. Acid sulfate copper solutions are also used to plate steel wire, stainless steel cooking utensils and zinc die castings (after a cyanide copper strike). Pyrophosphate solutions are often used in electroforming applications and in the plating of zinc, aluminum, and steel die castings.

Typical formulations for acid sulfate copper solutions are:

<u>General Purpose</u>	
Copper sulfate	190 - 300 g/L
Sulfuric acid	38 - 75 g/L
Chloride ion	30 - 60 mg/L

<u>High-Throw</u>	
Copper sulfate	60 - 90 g/L
Sulfuric acid	150 - 225 g/L
Chloride ion	30 - 60 ppm

These solutions are made up by adding the chemical constituents to deionized water. As can be seen from the difference in the formulations, high-throw solutions result from increasing the conductivity of the solution by increasing the acid/metal ratio. The purpose of the chloride ion is to promote the copper anode corrosion. Proprietary additives are normally employed to level and brighten the deposit, improve the throwing power and enhance the deposit's physical properties. It is these baths and rinse water contaminated by drag out from these baths that require treatment.

In a typical pattern plate acid copper and tin/lead line shown in Figure 4, the PWBs are passed through a tin/lead stripper etch, an acid cleaner, microetch, and then copper plated to build up the circuit patterns, which are then further covered by plated tin or tin/ lead etch resist. RenoCells are placed in the process stream to treat rinse waters at the source where they can be readily reused in the process. A specific pattern plating line capable of handling 100 boards per hour was referenced here to gather typical PWB volumes, values and other key parameters.

Conventional practice would be to have the drains and overflows from the rinse tanks go to a central treatment facility for eventual treatment by chemical precipitation. The opportunity to reduce waste generation and practice rinse water reuse is minimal since present treatment options cannot selectively remove metal and maintain process water specifications.

Micro-etch and Copper Plate Spray Rinse Water

In a typical process, the rinsing of the panels after micro-etch and copper plating is often performed in the same process stage, and often this is a spray rinse. The common copper concentrations of 25 g/L for micro-etch and 15 g/L for copper plate are used in this process sequence. When the rinse waters from these operations are treated with RenoCell, more than 1200 kg pounds of copper per year are recovered and rinse water usage is substantially reduced as are discharges to the facility's waste treatment system.

Tin Spray Rinse Water

Immediately after copper plating, tin/lead, as an etch resist, has been the predominant metal finish plated over the copper. Now, due to environmental concerns about lead, tin/lead is largely replaced with tin when a reflow finish is not required. Tin concentration of 14 g/L is used in this process sequence. RenoCell treatment of rinse water after the tin plating process recovers approximately 430 kg of tin per year. Tin reclaim by refiners is enabled because tin metal is not considered hazardous.

Waste Treatment

Copper is the only constituent of these plating solutions that is controlled by the U.S. EPA. As with most other controlled metals, the allowable discharge limits have fallen sharply in recent years. Current EPA wastewater effluent standards for existing metal finishing sources discharging to a Publicly Owned Treatment Works (POTW) for copper are 3.38 mg/L for a single day and 2.07 mg/L monthly average. In most shops the plating solution and its associated rinses are but one of many processes that contribute copper to the waste stream. Specific requirements are controlled by local regulations and can be much more stringent; each facility must deal with local as well as state and federal requirements. One facility discharging into surface waters in Ohio is limited to 23 µg/L as an average with a 35 µg/L daily maximum while a Detroit facility, discharging into the city sewer system, has a pretreatment daily maximum 24-hr composite sample of 4.5 mg/L of copper. This factor of over 100 in concentration limits severely challenge the available technologies.

Treatment requirements for wastes can be fairly extensive. Routine waste treatment by pH adjustment and clarification, ion exchange, or membrane technology has proven successful in meeting these requirements. Sludge from plating shops is classified as F006 waste and is affected by the land ban legislation. Copper-bearing sludges generated by platers must be disposed of in an EPA-approved manner. Recent changes in disposal regulations of metal-hydroxide sludges are coming into effect and require additional fixation or stabilization to prevent redissolution. Recycling of plating wastes is becoming a more viable alternative as new technology provides improved reclaiming processes.

Another typical PWB application is briefly addressed below.

Nickel/Gold Tab Plating Line

A typical lab connector plating line only immerses a small portion of the printed wiring board in the solution chemistries. The PWB proceeds sequentially through the tin lead stripper etch, copper electro-polish, cleaner, and micro-etch chemistries followed in line by nickel plate, gold strike and gold electroplate which completes the process. While less metal is generated in this process, the value of recovered gold and nickel significantly reduces overall process costs.

A specific nickel/gold tab line was referenced to gather typical PWB volumes, values, and other key parameters. This typical line will process 30-60 PWB panels hourly generating 72L/hr of contaminated rinse water (see Figure 5).

Tin/Lead Strip Rinse Water

The rinse of the solder-mask-over-bare-copper surface finish method (SMOBC) has made tin/lead plating unnecessary for most panels. Lead on the panel surface is a major source of waste lead in the process fluid. Lead concentrations are 50 g/L and tin concentrations 50 g/L. RenoCell removes approximately 150 kg each of tin and lead per year from rinse waters after the tin/lead strip sequence.

Copper Electro-polish and Micro-etch Rinse Waters

This sequence is a significant source of copper contamination in process fluids and rinses. Micro-etch strip etch copper concentrations of 25 g/L are used with this line process. The rinse water cycles after this sequence generate approximately 75 kg of copper per year.

Gold Plate Drag-out Rinse Water

Nickel/gold finishes may be selectively plated onto certain areas of a circuit. The most common application of hard gold is onto edge connectors. Here the panel is processed through a nickel/gold plating line with just the edge connector immersed in the plating fluid. Gold concentrations of 5 g/L and nickel concentrations of 50 g/L are used with these process sequences. RenoCell recovers approximately 15 kg of gold and 140 kg of nickel from rinse waters after the nickel/gold electrolytic strike and plate sequence.

The value of the gold and nickel recovered more than offsets the cost of RenoCell treatment for the entire nickel/gold tab plating line PWB process. There is a one-year initial payback of capital equipment costs. With respect to high value metals such as gold and nickel, the value of the metal recovered more than offsets the annual operating costs attributable to RenoCell. The value of the gold and nickel recovered can also be applied to the capital and operating costs of utilizing RenoCell source treatment in other parts of the PWB operation. When RenoCell is used as a source treatment, metal-bearing sludges are not generated, eliminating the costs and liabilities of handling and treating these hazardous sludges.

Gold carried into the drag-out is removed, giving concentrations at discharge from the RenoCell of 0.1 ppm (mg/L or lower). This reclaim effectively provides a major source of income which helps to fund the removal of copper from other rinse sources and render tab plater discharges suitable for disposal to drain without any precipitation processes. Usually the gold deposit on the RenoCell cathode cartridge is suitable for direct reclaim by precious metal specialists without the need for transfer of a hazardous liquid, containing the precious metal, between sites.

Conclusion

PWB process lines include concentrated chemistries for cleaning, etching, electroplating, and stripping each, followed by rinsing process steps. RenoCell provides PWB manufacturers with several major benefits:

- Virtual elimination of all metal-bearing hazardous sludges, saving over 40% in overall treatment costs

- Total operational cost savings of 70% over conventional treatment methods

- Lower initial capital costs with faster pay back periods (less than 2 years)

- Reduced wastewater loading on existing waste treatment facilities

- Conformance with national and local discharge compliance standards

When used as source treatment, the RenoCells remove copper, tin and tin/lead contaminant's without the manufacturer having to form metal-bearing sludges. Savings in disposal costs and water reuse minimizes annual operating costs and results in less than two years of amortization of capital costs. The use of RenoCell further results in a reduction of both rinse water volume and removal of metal contaminates sent to end-of-pipe treatment prior to discharge. These waste minimization practices clearly allow the user additional flexibility such as expansion of operations without an increase in the waste treatment system.

In the broader metal finishing operation, RenoCell has application in various operations involving concentrated baths, rinse and effluent treatment. These point source uses of RenoCell include bath dumps, rinse maintenance and ion exchange enhancement. The potential of waste minimization is currently being realized in both new plating line installations and retrofit upgrades of existing operations.

Renovare has found that the RenoCell is very cost effective on a life cycle basis and studies have indicated that pay back typically ranges from 9 months to 2 years depending upon the application and particular installation. RenoCell has a major operating cost advantage that, when coupled with the lack of secondary waste generation and subsequent cost of handling F006 sludges, provides an exciting new application of electrolytic technology that is capable of meeting effluent discharge standards.

The principle of electrodeposition is the same for all electrochemical cells. However, simply put, RenoCell technology works substantially better.

Figure 1
Standard RenoCell¨ (Undivided) Schematic Cross-Section

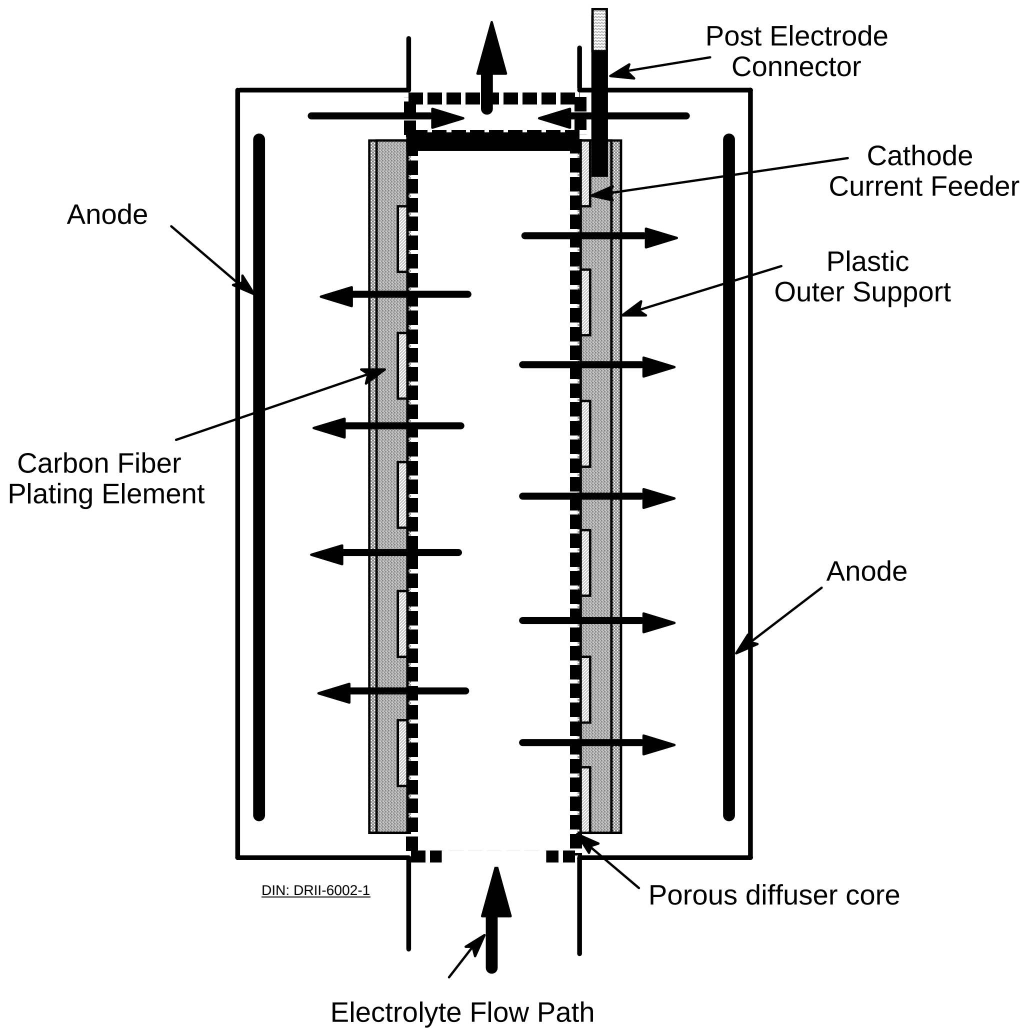

Figure 2 - Electrochemical Cells for Metal Recovery – The Dependence of Cell Design on the Concentration of Metal Ion in the Feed

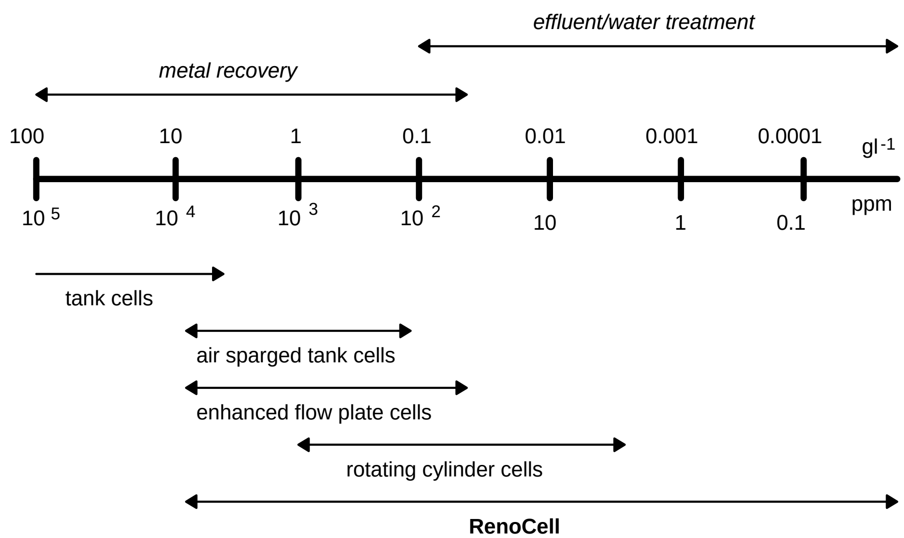

Figure 3 - Comparison of Conventional Electrolytic Cells on Copper-laden Process Solutions

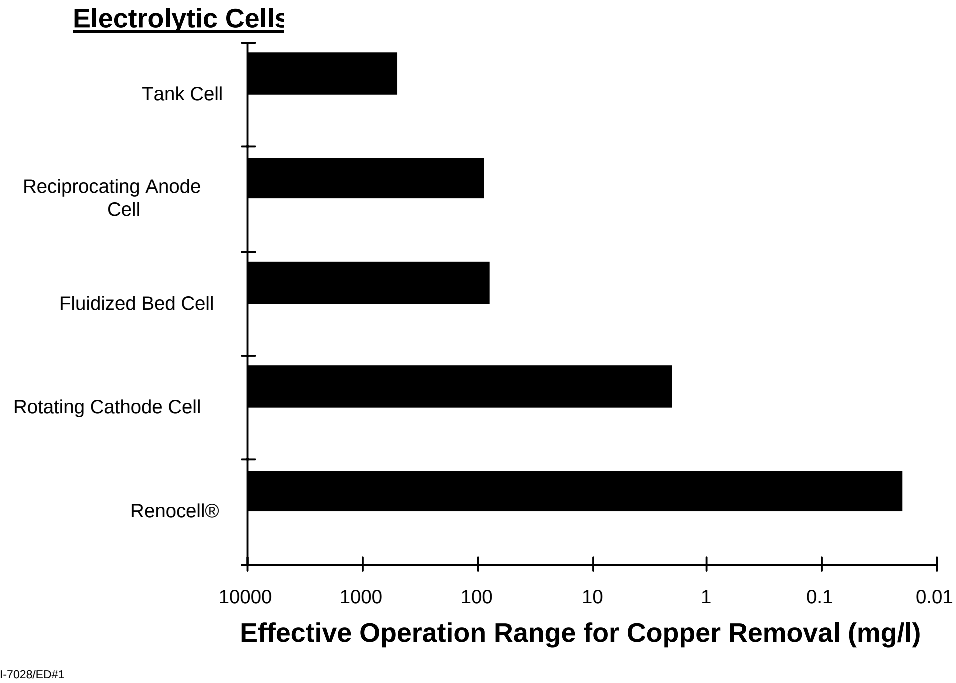
Electrolytic Cells
Tank Cell
Reciprocating Anode Cell
Fluidized Bed Cell
Rotating Cathode Cell
Renocell®
10000
1000
100
10
1
0.1
0.01
Effective Operation Range for Copper Removal (mg/l)
‹RII-7028/ED#1

Figure 4
Pattern Plate Acid Copper and Tin/Lead Plating Line

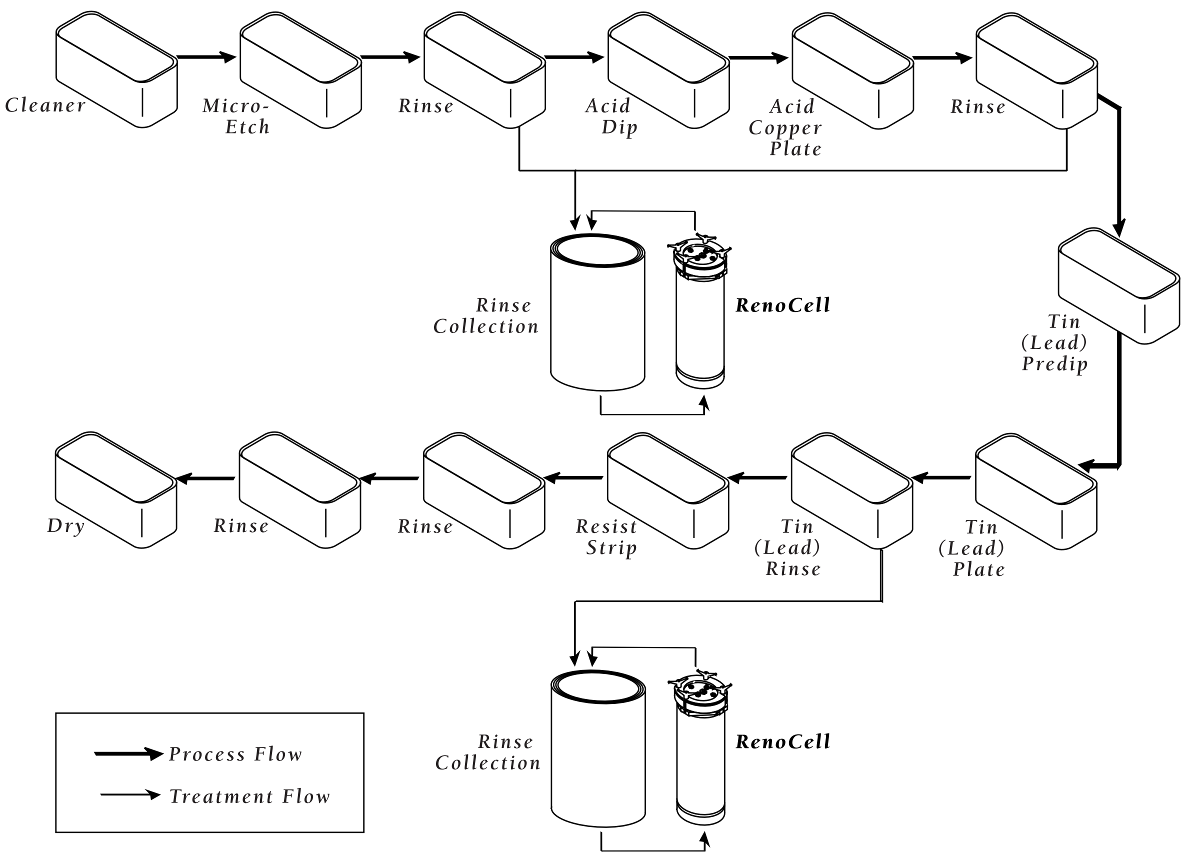

Figure 5
Nickel/Gold Tab Plating Line

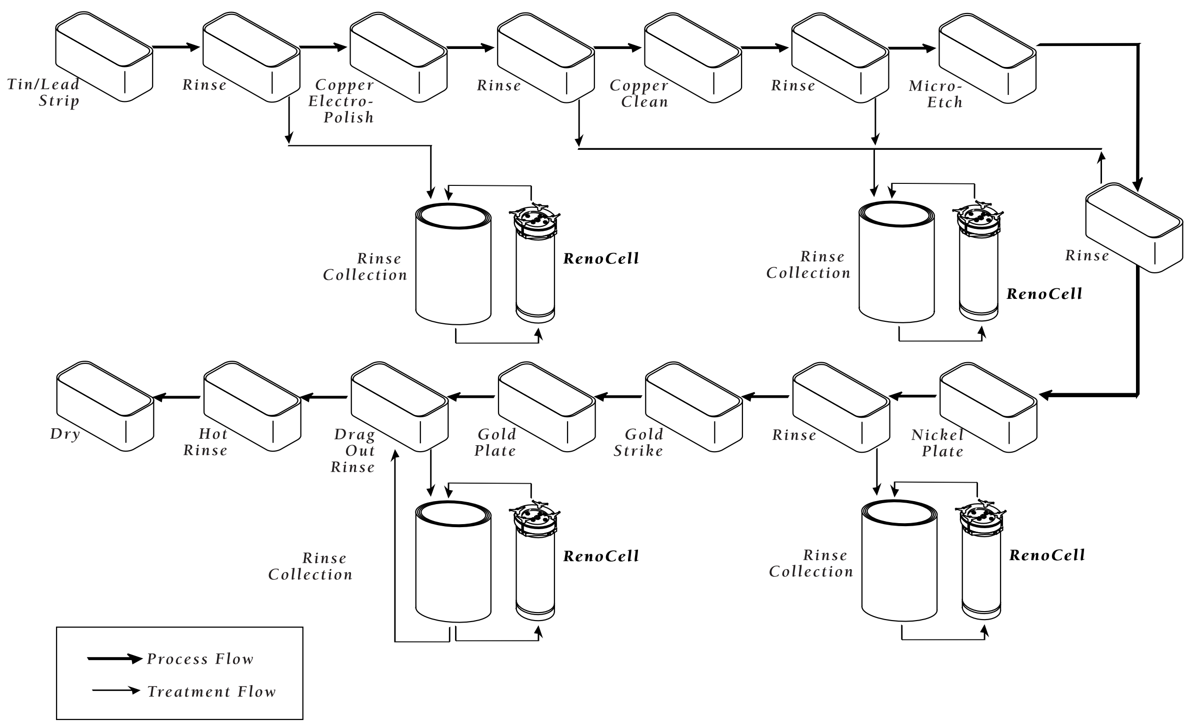

Table 1
RenoCell Features and Capabilities

Features	Capabilities
Porous carbon felt cathode	Greatly increased deposition surface area High metal extraction rates Effective at concentrations down to 1 mg/L and below Three to ten times more energy efficient
Metal deposits plated on fiber	Minimizes or eliminates generation of hazardous metal sludges
Replaceable cathode cartridges	Easy metal removal Quick and easy cathode replacement Low operation and manpower requirements
Compact, robust design	Increased reliability in industrial environments Very small footprint Capable of being wall mounted
Optional divided cell design	Allows treatment of anodically-sensitive solutions
Industry-standard components	Allows for modular design

Table 2
RenoCell Applications & Installations

Industry	*Application*	*Metal(s)*
Electroplating	Dragout tank recovery	Cadmium
Photographic	Photographic wastes	Silver
Chemical	Process effluent	Precious metals
Remediation	Ground water	Various
Electroplating	Rinse baths	Silver
Chemical	Ion exchange regenerants	Various
PWB/Electronics Manufacturer	Process wastes	Copper
Metal Finishing	Etchant solutions	Copper
Chemical Industry	Effluent	Various
Metal Finishing	Process effluent	Cadmium
Metal Finishing	Process treatment	Cadmium
Scotch Whisky	Water treatment	Copper

Remediation	Leachate	Various
Nuclear	Effluent	Various
Electric Utility	Various	Various

Table 3
RenoCell Testing and Operating Experience*

Effluent	*Metal*	*Concentration*		*Current Efficiency (%)*
		Initial (ppm)	*Final (ppm)*	
Acid sulfate rinse	Cu	910	0.02	41
	Cu	958	0.21	32.1
	Cu	98.4	1.0	27.4
	Cu	98.2	0.22	20.7
Cyanide plating rinse	Cu	105	0.34	2
	Cu	113	0.5	1
Fluoborate plating rinse	Cu	115	0.3	38.7
Electroless Cu rinse	Cu	82	0.8	14.2
Micro etch bath rinse	Cu	44	0.11	20
Cyanide plating rinse	Ag	99.4	0.6	5
	Ag	993	0.24	2.1
	Ag	740	0.34	7.5
Cyanide static dragout	Cd	107	0.34	2
Acid sulfate rinse	Cd	978	0.37	22
	Cd	247	0.51	18.8
Acid sulfate rinse	Zn	77.5	0.23	2
Acid sulfate rinse	Sn	93.2	0.5	7
Fluoborate plating rinse	Pb	85	0.32	6
Watt's bath rinse	Ni	105	0.5	4
Acid sulfate rinse	Cr(III)	124	1	1.6
Cyanide liquor	Au	330	<0.1	–
	Au	380	<0.1	–
Acidic liquors	Pt/Pd	24/110	1/0.01	4
	Pt	2000	0.5	–
	Pd	500	<0.5	–
	Au/Ir	3.2/3	0.8/1.2	–
	Au/Ir/Pd	4.5/6.3/0.2	0.5/1.0/0.02	-
Groundwater (acidic)	Hg	6.3	0.036	–

**All tests on 2.5 liter volumes using a 0.015m*^{2} *cell.*