Retrieval of Precious Metal from Waste Effluent at Precious Plate Inc.
in Niagara Falls, NY

Abstract

Precious Plate, Inc. is a local electroplating company that uses a variety of metals during its processes. Post-deposition, the aqueous phase used is designated for disposal, which poses problems regarding the metal content of the waste stream. First, EPA regulations mandate that metals be kept below specific levels. Even at levels capable of meeting EPA limits, the loss of metals within their waste streams can readily exceed thousands of dollars. Precious Plate, Inc. investigated the use of commercially available metal scavengers for lower metal concentrations. They found that despite loss of precious metals valued in excess of $400,000 per year, recovery was not profitable due to technical and economic limitations.

During this project we compared the performance of a commercially available scavenger with our XAD-Ybt developed resin. We have demonstrated the improved metal reduction capabilities of our XAD-Ybt resin in comparison to a commercial metal scavenger when applied to Precious Plate wastewater samples. The constructed prototype demonstrates that our developed XAD-Ybt resin offer elevated absorption kinetics compared to commercial scavengers with the ability to remove 95% of copper from wastewater. Furthermore, a thorough economic analysis was conducted, as well as a life cycle analysis, which provides further support for industries like Precious Plate to incorporate such a system into their wastewater treatment processes.
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1. Problem Statement

Precious Plate, Inc. is an electroplating company with expertise in depositing precious metals with extreme selectivity. The company is located minutes from SUNY at Buffalo in Niagara Falls, NY. The electroplating processes at Precious Plate uses a variety of metals that include nickel, copper, silver, gold, zinc, and palladium. The process is used across numerous settings and applications that encompass the automotive, electronics, medical, computer, and solar industries. For example, Precious Plate clients include Delphi, Tyco, Molex, Nortel, and IBM & Denso. Post-deposition, the aqueous phase used during electroplating is designated for disposal, which poses two significant problems regarding the remaining metal content of the waste stream. First, EPA regulations mandate that copper, nickel, zinc, chromium, silver, lead, and cadmium metals be kept below 3.38, 3.98, 2.61, 2.77, 0.43, 0.69, and 0.11 ppm, respectively. Hence, Precious Plate uses a precipitation method based upon solubility adjustment to initially reduce wastewater metal concentrations. However, this step is not always sufficient to ensure EPA regulations, and Precious Plate has been forced to withhold waste streams multiple times over the last year because of an inability to meet environmentally safe levels of metal content. Therefore, there is a need from an environmental viewpoint to implement new technologies to successfully ensure wastewater metal content meets regulatory demands.

However, even at reduced levels capable of meeting EPA limits, the loss of metals within Precious Plate waste streams can readily exceed $400,000 per year (based upon current metal prices). As such, a second significant concern on the part of Precious Plate is the recovery and re-use of metals lost in wastewater streams. To this end, Precious Plate has previously utilized scavenging agents. Metal scavengers are extremely selective for precious metals and are able to recover them from solutions containing less than 1 ppm, clearly making them the most effective method of metal recovery discussed thus far. However, the bond between the resin and precious metals can be very strong and often results in irreversible binding making recovery of bound metals challenging. Thus, Precious Plate seeks a cost-effective recovery step as a means of improving the overall economics of their plating processes.

Figure 1: Problem statement. Reduced concentration of pricy metals in waste water effluent can add up in big annual loss.
As a lab experienced in natural product metabolic engineering, we are interested in implementing our recent findings to address this challenge. Of particular interest is our newly developed functionalized polymeric resin with a natural inspired siderophore. Emphasis here is on a siderophore termed yersiniabactin (Ybt) and its novel analogues. We first heterologously biosynthesized the nonribosomal siderophore yersiniabactin (Ybt). Then, upon screening we found a cross linked polystyrene resin (XAD) that offers the utmost immobilizing ability for Ybt. The hypothesis was further supported by preliminary data which indicates elevated iron and copper removal potential of Ybt modified beads. To further support the use of the proposed technology, Ybt and anthra-Ybt (a novel analogue for Ybt) were bound to XAD and tested with field wastewater provided by Precious Plate. Selective removal was observed for silver and nickel. Even, the novel analogue of Ybt, anthra-XAD-Ybt beads, demonstrated 100% removal of silver during initial and un-optimized preliminary assessment. Unlike commerciality available metal scavengers, metal recovery in this system can be easily achieved by washing Ybt-metal complex from bead surfaces using methanol or by neutralizing Ybt, or the metal ion, in a pH gradient.

2. Project Summary

Precious metals such as gold, silver, palladium, and platinum have been sought after for investment, adornment, and industrial use for centuries. However, ever-growing applications in catalysis, electronics, and electroplating have given rise to gradual loss through waste effluents in the automotive, medical, computer, and solar panel industries. Effluents in these industries can contain low metal concentrations, in the range of 0.1 ppm (parts per million), which makes recovery a technical challenge. It is estimated that at least $2 billion of precious metals are lost globally in these industries annually.

Various techniques have been developed to capture and recycle precious metals from waste streams. Currently, the most effective recovery methods utilize functionalized absorbents known as metal scavengers (see appendix 1 for a list of providers). Metal scavengers provide recovery down to concentrations between 0.1 to 1 ppm. However, current scavengers are not efficient or economically feasible for metal concentrations less than 0.1 ppm. Furthermore, the bond between the resin and precious metals can be very strong and non-specific, resulting in irreversible binding to multiple less-desirable metals. These factors make recovery of precious metals challenging and in most cases uneconomical for small and moderate enterprises. For example, Precious Plate Inc., a Niagara Falls plating company and our first potential customer, investigated the use of commercially-available scavengers for lower metal concentrations. They found that despite loss of precious metals valued in excess of $400,000 per year, recovery was not profitable due to technical and economic limitations of current scavenging technologies (see appendix 1 for feedback). Consequently, they are still seeking a cost-effective recovery method to improve their plating process.

During this research we compare the performance of a commercially available scavenger (QuadraPure TU, a product of Johnson Matthey Scavenging Technologies) with our developed resin-based chemistry. Due to limited access to measuring instrument(s) (ICP-MS), we used a copper solution as a wastewater effluent model for Precious Plate Inc. Despite this drawback,
precious metal removal of 50 ppb concentrations were conducted for the developed resin. The preliminary data has been disclosed to the Technology Transfer Office at the University at Buffalo in order to secure intellectual protection, and the data will be described in at least two upcoming scientific publications. Furthermore, an economic analysis for a large scale implementation of the recovery unit has been performed to demonstrate the affordable and profitable aspects accompanying this system. In comparison, the commercial resin must be incinerated after loading the metals to recover the bounded metal, while our new developed resin can be easily regenerated by a simple backwash process. In addition to the savings associated with this reduce-reuse-recycle technology, a brief life cycle analysis revealed the environmental preference of our XAD-Ybt developed resin over available commercial scavengers.

3. Materials and Methods

3.a. Proof of concept

Our success in heterologous production of Ybt established a production platform independent of handling the native Y. pestis pathogen and benefiting from the well-studied recombinant features of E. coli [1, 2]. We also observed it might be possible to engineer the molecular structure of Ybt through the application of precursor-directed biosynthesis. As demonstrated in Figure 1, the Ybt pathway has shown flexibility in accepting alternative starter units. Produced Ybt has been utilized in capacity as a metal binding product. Copper was selected as the binding target, which was identified by Precious Plate as a key contaminant in their plating wastewater streams. Ybt has also been demonstrated to chelate copper during Y. pestis infection as a means of limiting the copper-induced host defense mechanisms[3]. Hence, the molecule has evolved to recognize and bind to copper, even in the presence of Fe3+. As a result, we proposed there might be opportunities to redirect this capability to address industrial challenges. In preparation for a practical removal assay, the produced small molecule, Ybt, should be immobilized first to ease downstream processes. Therefore, we screened commercially available micro beads for their ability to fix Ybt on the surface. We realized polystyrene resins show the most effective adsorption capability, up to 95% of Ybt was adsorbed in 2 hours. In addition, washing with methanol can elute almost all of the Ybt from the beads. The Ybt matrix then allowed a simple means of testing a solid-phase separation process for fluids containing copper. This is demonstrated in Figure 3. Across panels A-C, Ybt-modified XAD demonstrated clear removal capabilities compared to controls. Repeated extractions with Ybt
resulted in nearly 100% full solution removal (Figure 3C). The preliminary data for iron and copper removal support the binding and removal potential of Ybt (manuscript on this regard has been submitted to AEM). To further support the use of the proposed technology, field wastewater provided by Precious Plate was tested. As demonstrated in Figure 3D, selective removal was observed for silver and nickel during initial and un-optimized preliminary assessment. The results were a promising basis for the refined and extended plans. For a more detailed study, the binding ability of Ybt and its analogues were thoroughly analyzed using ICP-MS. A mixture of Fe, Cu, Al, Zn, Pt, Au, Pd and, Ag were prepared each with a concentration of approximately 50 ppb. The mixtures were contacted with modified beads for 2 hours, and the metal contents were subsequently measured using ICP-MS. The difference in metal content before and after treatment has been adopted as a basis to calculate the percent of metal recovery (or removal).

3. b. Prototype Study
The presented data in the previous section was based on a small scale batch process. For a realistic applicable process, we have used the NYSP2I grant to design and implement a continuous heavy metal removal and recovery system model. To be more specific, we have constructed a process prototype involving two sequential packed bed flow reactors with flow rate up to 2 lit/hour. Copper solutions with concentration between 1 to 10 ppm were treated as a Precious Plate effluent waste discharge model. The schematic of prototype is illustrated in figure 4a. Wastewater containing 3.3 ppm of copper was fed into a pack-bed containing 1) our developed beads, or 2) commercially
available resins. The commercial resin utilized was QuadraPure TU from Johnson Matthey due to its ability to effectively binding to copper. Figure 4b demonstrates that our developed XAD-Ybt beads offer elevated absorption kinetics compared to commercial scavenger. The commercial resin consistently removed approximately 25% of the copper. In comparison, our XAD-Ybt removed 90% of the copper for first 20 minutes; copper removal dropped to 50% for next 40 minutes, which indicated the resin had reached saturation. At the time 60 minutes, XAD-Ybt resins were backwashed with pH=12 buffer. After backwash, data shows the resin had been regenerated and can retrieve their initial copper removal efficiency. Another option is to introduce a pretreatment column prior to the column loaded with scavengers or XAD-Ybt. This column was filled with activated carbon, a general, non-specific, metal remover. Activated carbon is known for its inexpensive but high ability to remove environmentally dangerous heavy metals [4, 5]. This module will not only remove hazardous heavy metals, it will also minimize the interfering effects that other base ions have on the function of the second reactor. Figure 5b demonstrates this prototype can remove up to 100% of copper without any sign of saturation. Further measurements revealed that the activated carbon column by itself removed 75% of copper. For the next phase we are working on metal recovery by introducing a backwash unit (figure 6) with a pH gradient. Figure 6 works as a simplified scheme for the plant treatment. We are presently working on this concept, and the data will be presented at the time of the competition on April 22.
To conclude, during this project we aim to improve both environmental and economic aspects simultaneously: by reducing human and environmental exposure to hazardous heavy metals (i.e., discarded electronic devices), and by recovering pricey metals like silver, palladium, and gold the electroplated metal content destined for environmental contamination\cite{6, 7}. To do so we take advantage of our newly developed natural siderophore-resin system. The metal binding capabilities of the Ybt based resin is directed toward wastewater metal challenges faced by Precious Plate located in Niagara Falls, NY (appendix 2 is a photo of constructed prototype). With respect to the current application, if the proposed Ybt system can be successfully used to recover metal from electroplating processes, it is expected to have a significant future application given the growing volume of electronic waste.

![Diagram](image1)

Figure 5 A. Schematic of the constructed prototype. Waste water stream with 3.2ppm copper concentration was first entering an activated carbon pack-bed column. The stream then enters either a commercial resin pack-bed column or a pack-bed column filled with our developed resin. B. Copper content before and after treatment in each step was measured using a Zincon assay. Activated carbon can remove copper up to 75%. Using additional scavenger step can remove 95 to 100% of copper.

![Diagram](image2)

Figure 6. Schematic of possible large scale operational unit for pricey metal from wastewater stream. Purpose of backwash is to concentrate metal content by at least 1000 times.
4. Relationship to Sustainability

Implementation of a novel metal retrieval system at Precious Plate would have many benefits for the local environment and economy. Heavy metal related pollution threatens the health of humans and wildlife in a variety of ways including but not limited to: lead interferes with the nervous system development and can lead to learning disabilities and retardation in children; cadmium accumulates in humans and animal tissue and can lead to kidney damage; and (methyl) mercury affects cognitive thinking, memory, attention, language, and visual spatial skills in children[8-10]. For the past 200 years Lake Erie, the shallowest and warmest of the five Great Lakes, has served as a resource for industry, agriculture, shipping, and recreation to western New York. The lake has been contaminated with phosphorous and heavy meals due to fertilizers, till farming, and commercial detergents which have led to mass killing of fish, poisoning the food chain, and jeopardizing the source of drinking water for an estimated 11 million people[11-15].

Moreover, environmental issues are not the only concern for Precious Plate; they are also motivated by economic aspects of this project. Precious Plate discharges 60 – 90,000 gallons of waste water effluent laden with gold, silver, and palladium at concentration levels in the ppb range daily. Using 40,000 gallons per day and a concentration of 50 ppb as reasonable averages, a simple calculation shows this small business is wasting around 3 kilograms of precious metals in a normal year. It goes without saying that it will have a substantial impact on the profit margin of a company if they can scavenge and re-use these metals [16-18].

When a typical business, such as Precious Plate, trusts an academic group to move towards becoming more environmentally friendly and a more economically sustainable enterprise, it puts both public and industry pressure on other similar operations to recover their invaluable metals from waste. This will lessen the demand for fresh metal supplies, and it will eventually reduce environmental risks of metal mining, leaching, processing, and transportation. Lastly, successfully incorporating an on-site metal retrieval for Precious Plate will be indirectly promoting large-scale corporate sustainability, as well as local and regional sustainability.

5. Results, Evaluation, and Demonstration

5.1 Experimental data
Experimental data are presented in section 2 representing a laboratory bench scale batch process and a small-scale flow prototype. Briefly, we have proven the concept using a batch process. The XAD-Ybt and analogue-XAD resin (40 mg) were added to small-scale (10 mL) samples of wastewater resulting from a variety of plating applications conducted by Precious Plate. Incubation occurred in a certain temperature, and after specific time points, beads were separated (by gravity settling) and washed with Millipore water twice. The metal content of the wastewater samples before and after treatment were measured using inductively coupled plasma mass spectrometry (ICP-MS). ICP-MS capabilities were provided by Precious Plate. Due to the success of the laboratory model batch process, we assessed our findings to construct a small-scale continuous process prototype. The packed column reactor system was designed to purify 1 liter/hr of waste effluent. As previously described, the first column was packed with activated carbon, and the second column
contained either commercial resins or our developed beads. The results show the prototype was able to remove up to 95% of copper from the wastewater.

After successful binding and removal of metals by Ybt, the loaded resin can then be integrated into a metal recovery and re-use plan. The first strategy to be pursued when recovering metal from the Ybt-metal-XAD beads will be to remove the Ybt-metal complex using methanol. This approach is based upon our previous research in which 90% of Ybt is removed from the XAD resin when they are washed with methanol. The metal could then be recovered from the Ybt via pH variation to eliminate chelation [19, 20]. Variation in pH can also be applied to Ybt-metal complexes while Ybt is still bound to the XAD bead to remove the recovered metal while re-generating the XAD-Ybt particle for future wastewater treatment. Each of these approaches can also be applied to different Ybt analogue XAD beads. Once free metal has been recovered in solution, it will be recycled back to electroplating processes at Precious Plate. If needed, purification steps (using pH-based separations [21-23]) will be used to enrich certain metals for coating purposes. In this capacity, Ybt analogues that are selective for certain metals will be beneficial.

5.2 Economical Evaluation

A simplified environmental and economic analysis is presented here. A more sophisticated model and complete analysis follows. Table 1 lists the working parameters of daily waste effluent, including measured concentrations of four typical metals, and the total discharge volume. The reported concentrations come from actual discharged waste, meaning after the precipitation module. According to their claims, the concentration before entering the precipitation process can be up to 10 times more concentrated with metal ions.

The following calculations are based on the numbers from this table:

\[
\text{Au loss (\(Kg/\text{year}\)) = 70 \times 10^{-9} \left(\frac{kg}{L}\right) \times 40000 \left(\frac{\text{gallons}}{day}\right) \times 3.78 \left(\frac{L}{\text{gallons}}\right) \times 365 \left(\frac{\text{days}}{\text{year}}\right) = 3.86 \frac{Kg \text{ Au}}{\text{year}}}
\]

\[
\text{Pd loss (\(Kg/\text{year}\)) = 7 \times 10^{-9} \left(\frac{kg}{L}\right) \times 40000 \left(\frac{\text{gallons}}{day}\right) \times 3.78 \left(\frac{L}{\text{gallons}}\right) \times 365 \left(\frac{\text{days}}{\text{year}}\right) = 0.39 \frac{Kg \text{ Pd}}{\text{year}}}
\]

\[
\text{Ag loss (\(Kg/\text{year}\)) = 120 \times 10^{-9} \left(\frac{kg}{L}\right) \times 40000 \left(\frac{\text{gallons}}{day}\right) \times 3.78 \left(\frac{L}{\text{gallons}}\right) \times 365 \left(\frac{\text{days}}{\text{year}}\right) = 6.62 \frac{Kg \text{ Ag}}{\text{year}}}
\]

\[
\text{Ni loss (\(Kg/\text{year}\)) = 636 \times 10^{-9} \left(\frac{kg}{L}\right) \times 40000 \left(\frac{\text{gallons}}{day}\right) \times 3.78 \left(\frac{L}{\text{gallons}}\right) \times 365 \left(\frac{\text{days}}{\text{year}}\right) = 20.55 \frac{Kg \text{ Ni}}{\text{year}}}
\]

This brief list does not encompass all of the metal content in the waste effluent at Precious Plate. Furthermore, not all of the metals are valuable enough to motivate Precious Plate to incorporate metal recovery into their plating process. Having said that, the data can provide a better insight for potential savings by adopting a metal recovery system. The following calculation is based on the current price of each metal and the previous calculated numbers:
loss ($) = \(3.86 \left(\frac{Kg\ Au}{\text{year}}\right) \times 36000 \left(\frac{\$}{kg\ Au}\right) + 0.39 \left(\frac{Kg\ Pd}{\text{year}}\right) \times 24000 \left(\frac{\$}{kg\ Pd}\right) + 6.62 \left(\frac{Kg\ Ag}{\text{year}}\right) \times 480 \left(\frac{\$}{kg\ Ag}\right) + 20.55 \left(\frac{Kg\ Ni}{\text{year}}\right) \times 20 \left(\frac{\$}{kg\ Ni}\right)\)

\approx 152.00 \left(\frac{K\$}{\text{year}}\right)

Table 1. Measured parameters of waste effluent in Precious Plate

<table>
<thead>
<tr>
<th>Metal concentration (PPM)</th>
<th>Gold</th>
<th>Palladium</th>
<th>Silver</th>
<th>Nickel</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.07</td>
<td>0.007</td>
<td>0.12</td>
<td>0.636</td>
</tr>
<tr>
<td>Discharge volume (gallons/day)</td>
<td></td>
<td></td>
<td></td>
<td>40,000</td>
</tr>
</tbody>
</table>

Currently, there are no applications for recovering precious metals at such low concentrations (100ppb) from wastewater. Due to the profit losses of Precious Plate calculated above, the investment risk of current available commercial products and our novel XAD-Ybt product were evaluated and compared by calculating the net present value (NPV), the internal rate of return (IRR), and the simple payback period. For budgetary purposes assumptions were made to account for daily fluctuations in precious metal concentration and wastewater volume. An average volume of 10,000 liters of wastewater per day with a gold concentration of 50 ppb (0.05 mg/L) was used for calculating costs and returns. After determining the initial investment costs and operational costs associated with each application, it was clear that the feasibility of these products is highly dependent on both loading capacity and recovery efficiency of the resins. The loading capacity determines how much resin material is needed to remove a known concentration of metal, in this case 500 mg of gold per day.

\[\text{Loading Capacity} = \frac{x \text{ (mg loaded metal)}}{y \text{ (g of resin)}} \times 100\]

\[\text{Amount of resin needed per day (g)} = \frac{500 \text{ mg gold}}{\text{Loading Capacity}/100}\]

Based on this calculation it can be seen that a higher loading capacity is desirable to reduce cost of resin. The average loading capacity of the metal scavenger and XAD-Ybt resin is taken to be 7% and 5%, respectively. It should also be noted that the loading capacity is more important for the metal scavenger because it cannot be recycled like the XAD resin. The recovery efficiency also weighs heavy on the cost outcome. A higher efficiency leads to more profit, and is therefore more advantageous. Based on the metal scavenger supplier’s data, the recovery efficiency of metal scavengers is in the range of 1-15%, and the XAD-Ybt resin has a recovery efficiency of 60-80%. All calculations are based on these values.
NPV is a very common approach for determining if the project will have a positive or negative outcome. Because of the time value of money, a dollar earned in the future won’t be worth as much as one earned today. The discount rate in the NPV formula is a way to account for this[24]. A NPV greater than zero is considered a profitable investment to a company[25]. The NPV for both applications were calculated at discount rates\((i)\) of 0%, 5%, 10%, and 15% for a total period \((N)\) of 10 years using the following formula given time period \(t\) and the cash flow \(R_t\):

\[
NPV(i, N) = \sum_{t=0}^{N} \frac{R_t}{(1 + i)^t}
\]

Based on cash flow data, the NPV for XAD-Ybt is consistently above zero at its lowest efficiency, and it exceeds the NPV for the metal scavengers (Figure 7). Positive values indicate that a wastewater treatment method would be beneficial to Precious Plate.

![NPVs of XAD-YBT vs Scavenger](image)

Figure 5 NPV calculated for both metal scavengers (maximum loading and recovery efficiencies of 15%) and XAD-Ybt (average recovery efficiency of 70%) at discount rates from 0 to 15%.

The IRR is also a common method used to discern if a project is appealing to investors, and it is evaluated when the NPV is equal to zero[25]. An investment is acceptable if its IRR exceeds an established minimum acceptable rate of return (MARR). Typically the project is considered profitable if the IRR is 10%, a lower value would be rejected by an investor [26]. As IRR increases, a project becomes more desirable to investors. As such, IRR can be used to rank several prospective projects a firm is considering[25].

Commercial available scavengers with the highest loading capacity (15%) and a maximum recovery efficiency (15%) give an IRR of 15% while the XAD-Ybt treatment process at the lowest capacity and a minimum efficiency (60%) give an IRR of 21% (Figure 8). A higher IRR value compared with other project options suggests better and stronger growth.
A simple payback period was also calculated for both applications. This is a useful tool for assessing when the company will begin profiting from the investment. An earlier payback period is preferred. Assuming an average efficiency of 70% recovery for XAD-Ybt, the payback period of 3.5 years (Figure 9), while using the scavenger at a maximum efficiency at 15% has a payback period around 5 years.

![XAD-YBT Payback Period](image)

Figure 7 Simple payback period for XAD-Ybt based on incoming and outgoing cash flow with an average recovery efficiency of 70%.

The XAD-Ybt application is more attractive because recycling the resin, incorporating a backwash system, and using more ecofriendly methods for metal recovery significantly reduces the costs. Using the Ybt resin would still be more profitable with a larger initial investment cost of ~14K$. The metal scavengers are restricted to a single-use and cannot be regenerated after they are fully
loaded with metals. In addition, the loaded scavengers must be refined by energy intensive methods in order to recover the precious metals. These additional requirements make it less feasible for recovering metal at low concentrations.

Table 2 Summary of economics data comparing commercially available metal scavenger to XAD-Ybt product. See appendix 2 for a more detailed cost summary.

<table>
<thead>
<tr>
<th>Cost Analysis Summary</th>
<th>Metal Scavenger</th>
<th>XAD-Ybt</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capital Cost</td>
<td>$3,700.00</td>
<td>$14,080.00</td>
</tr>
<tr>
<td>Operational Cost (per year)</td>
<td>$421.57</td>
<td>$885.12</td>
</tr>
<tr>
<td>Profit (per year)</td>
<td>$1,058.04</td>
<td>$4,232.18</td>
</tr>
<tr>
<td>IRR (max)</td>
<td>15%</td>
<td>32%</td>
</tr>
<tr>
<td>NPV 10%</td>
<td>$210.86</td>
<td>$6,486.22</td>
</tr>
<tr>
<td>Simple payback period</td>
<td>5.5 years</td>
<td>3.5 years</td>
</tr>
</tbody>
</table>

5.3 Life Cycle Analysis
The goal of using the life cycle analysis (LCA) approach is for industries to make important decisions that takes into account potential human health and environmental consequences associated with various products, processes, and activities. There are several LCA software programs available to organize, compile, and evaluate data. For this project, Sustainable Minds® was utilized to compare the environmental impact of the commercial metal scavengers and our novel XAD-Ybt resin. The software enabled us to assess the impact of each product from manufacturing; however, the impact from disposal could not be assessed due to software limitations. From the manufacturing data, we concluded there was no significant difference between producing the metal scavengers and the XAD-Ybt resin. Although the available software could not be used to formulate a complete LCA, due to the different disposal methods, it can be readily accepted that the metal scavengers pose greater harm to the environment than our XAD-Ybt process. The metal scavengers are incinerated after a single use because of the irreversible binding strength between the metals and the metal scavengers, whereas the XAD-Ybt resin can be reused and regenerated through a simple pH change. Incineration, a thermal waste treatment process, would release ash, flue gas, and heat into the atmosphere.

6. Conclusion
Precious Plate, Inc. faces two major issues in regard to the disposal of the wastewater effluent post deposition. Metals including nickel, copper, silver, gold, zinc, and palladium remain in these streams at unsatisfactory concentration levels prior to precipitation treatment. Before adopting this
treatment, Precious Plate held wastewaters until environmentally safe levels of metal content were achieved, wasting time and storage space. However, Precious Plate easily loses $400,000 annually from discarded platinum, gold, and silver, even at EPA levels. Many actions have been taken by Precious Plate in the past to recover valuable metals from waste streams, including the use of metal scavengers. The metal scavengers are effective due to their ability to sequester precious metals in waste containing concentrations less than 1 mg/L. Despite that, based on trial experiences at Precious Plate and our own experimental data, the costs out-weight the benefits due to high material cost, low loading, and additional refinery services.

We have demonstrated the improved metal reduction capabilities of our developed siderophore based resins in comparison to a commercial metal scavenger when applied to Precious Plate wastewater samples. These results will support the use of this technology to address the environmental concerns expressed by Precious Plate in effluent stream disposal. Furthermore, our financial analysis indicates that the implementation of this XAD-Ybt wastewater treatment phase would be profitable and low-risk for Precious Plate, Inc.

We are currently working to demonstrate pricey metal recovery and re-use from Ybt or analogue metal complexes following waste stream treatment. This phase will offer a new opportunity for recovering fundamental starting materials used within Precious Plate’s manufacturing processes. The key deliverable will then be constructing a small-scale process prototype for wastewater metal removal, recovery, and re-use. This will be the basis for analyzing and designing for scale-up implementation within Precious Plate and other manufacturers facing the same challenges associated with metal contamination and collection.

To fulfill this goal, team member 1 contributed 40% as head of project, and the remaining three members each contributed 20%. Team member 1 and 3 were be in charge of preliminary data production and testing the batch process. The findings was implemented in the prototype design by team members 1 and 2 for optimization of the process, which will be demonstrated in the prototype. Team members 2, 3, and 4 were in charge of the economic analysis. This included calculating needed capital cost, operation cost, and payback period of the system. This method encompasses all of the economic costs and benefits of the system. Team members 3 and 4 performed the Life Cycle Analysis and environmental sustainability of the system. We had close interaction between our team and industrial experts at Precious Plate. Due to novelty of the developed technique, an IP agreement has been drafted between The University at Buffalo and Precious Plate, and it was officially completed prior to commencement of this project.

**Acknowledgements**

We would like to first acknowledge Professor Blaine Pfeifer Ph.D. for introducing us to this project, and for his help throughout its development. At Precious Plate Inc. in Niagara Fall, NY, Bill Lekki and Harry van der Zanden took the time to discuss the problem with us, which allowed us to better evaluate the scope, details, and impact of this project. Mr. Lekki was kind enough to perform ICP-MS tests for us. We also greatly appreciate the time given by Martin Casstevens and Tim Dee from The University at Buffalo office of science, technology transfer, and economic Outreach (STOR) which helped us to accelerate the patent documentation procedure.
References


Appendix 1. Metal scavenger providers and comparing them to resin developed by our team and Feedback from manufacturer who has used current metal scavengers in their process

<table>
<thead>
<tr>
<th>In-situ Recovery</th>
<th>Yes</th>
<th>Yes</th>
<th>No</th>
<th>No</th>
<th>No</th>
<th>No</th>
</tr>
</thead>
<tbody>
<tr>
<td>Selectivity</td>
<td>High</td>
<td>High</td>
<td>High</td>
<td>low</td>
<td>low</td>
<td>low</td>
</tr>
<tr>
<td>Below ppm</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Reusable</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Process Cost</td>
<td>Low</td>
<td>High</td>
<td>High</td>
<td>Moderate</td>
<td>Moderate</td>
<td>Moderate</td>
</tr>
</tbody>
</table>

Customers experience with metal scavengers

1. *None of them worked purely selectively* for only one type of precious metal. Gold was our target, but Silver was removed.
2. Sludge and scavenger need to be dried and burnt at a refinery to get the precious metals back and this typically adds costs.
3. If I made the balance for what the scavengers removed versus their costs and combined that with the additional material that would be filtered out, *it simply made no sense to us.*

What Customers want from a metal scavengers?

1. As *selective* for the metal to be scavenged as possible.
2. Preferably in an *easy to handle* form (pellets / large grains)
3. Scavenger costs as low as feasible compared to the scavenged material
4. Working in a wide pH range
Appendix 2. Constructed Prototype. Operating units and wastewater flow are marked.
Appendix 3. Numbers and assumptions used for economic analysis

### Cost Summary

<table>
<thead>
<tr>
<th></th>
<th>XAD-Ybt</th>
<th>Metal Scavenger</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Capital Cost</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pump + Motor</td>
<td>$1,200.00</td>
<td>$1,200.00</td>
</tr>
<tr>
<td>Tank</td>
<td>$2,500.00</td>
<td>$2,500.00</td>
</tr>
<tr>
<td>XAD (initial supply)</td>
<td>$1,380.00</td>
<td></td>
</tr>
<tr>
<td>Bioreactor</td>
<td>$6,500.00</td>
<td>$2,500.00</td>
</tr>
<tr>
<td>Autoclave</td>
<td>$2,500.00</td>
<td></td>
</tr>
<tr>
<td><strong>Annual Cost</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ybt Production</td>
<td>$596.58</td>
<td></td>
</tr>
<tr>
<td>XAD production</td>
<td>$13.80</td>
<td>$206.83-$3102.50</td>
</tr>
<tr>
<td>Scavenger cost*</td>
<td>-</td>
<td>$206.83-$3102.50</td>
</tr>
<tr>
<td>Refining services**</td>
<td>-</td>
<td>$40.00</td>
</tr>
<tr>
<td><strong>Operating Costs</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pump Power</td>
<td>$82.54</td>
<td>$82.54</td>
</tr>
<tr>
<td>Agitator Power</td>
<td>$92.19</td>
<td>$92.19</td>
</tr>
<tr>
<td>Bioreactor Power</td>
<td>$50.00</td>
<td></td>
</tr>
<tr>
<td>Autoclave Power</td>
<td>$50.00</td>
<td></td>
</tr>
</tbody>
</table>

*Scavenger costs depends on loading capacity (1-15%).

** Refining services are estimated based on 2lbs of loaded metal scavenger per month

### Production Supplies

<table>
<thead>
<tr>
<th>Supplies</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>XAD resin</td>
<td>$138.00/g</td>
</tr>
<tr>
<td>Metal Scavenger</td>
<td>$170.00/kg</td>
</tr>
<tr>
<td>ybt Media cost</td>
<td>$20.02/g</td>
</tr>
</tbody>
</table>

### Assumptions

<table>
<thead>
<tr>
<th>Assumption</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electricity rate*</td>
<td>$0.12 per kW-hr</td>
</tr>
<tr>
<td>Gold rate (3/12/15)</td>
<td>$38.65/g</td>
</tr>
</tbody>
</table>

*Quoted by National Grid
Appendix 4. Support Letter from University at Buffalo office of science, technology transfer, and economic Outreach (STOR). PreMeR X is name of a Start-up which formed by Mahmoud Kamal Ahmadi and Blaine Pfeifer based on the results presented in this report.

Memorandum of Understanding
between
The Research Foundation for State University of New York
for and on behalf of the University at Buffalo
and
Mahmoud Kamal Ahmadi

The University at Buffalo Office of Science, Technology Transfer and Economic Outreach ("STOR") is responsible for identifying, protecting and commercializing the University’s intellectual property for the benefit of the public good. STOR is authorized to act on behalf of The Research Foundation for State University of New York ("Foundation") to protect and license intellectual property owned by the Foundation for and on behalf of the University at Buffalo.

Foundation has a legal interest in certain technology developed at the University at Buffalo and embodied in STOR docket R-6960, titled “Heterologous production of Peptide Siderophore Compounds and Associated Applications” (hereinafter referred to as “Technology”).

Mahmoud Kamal Ahmadi is a doctoral candidate in Dr. Blaine Pfeifer’s laboratory at the University at Buffalo and is a co-inventor of Technology. Mahmoud Kamal Ahmadi anticipates forming a new business entity, tentatively referred to as PreMeR X, LLC ("PreMeR X") that may license Technology from Foundation for the purpose of commercialization. Upon successful formation of PreMeR X and PreMeR X meeting the requirements below, STOR may enter license negotiations with PreMeR X for the Technology.

The purpose of this Memorandum of Understanding is to acknowledge the relationship between the parties that may result in negotiation of an exclusive license agreement in certain fields of use and in which STOR would license the available Technology to PreMeR X in a manner consistent with the Patents and Inventions Policy of State University of New York and other Foundation technology transfer policies, and subject to any other obligations or third party rights in Technology, and provided PreMeR X presents a viable commercialization plan that is accepted by Foundation. The terms of the license agreement will include, among other provisions:

- Granting of rights to PreMeR X sufficient to allow the manufacture, use and sale of Technology. The parties acknowledge that such rights may include sublicensing rights;
- Financial considerations commensurate with the rights granted to PreMeR X;
- Development milestones to ensure that PreMeR X is advancing the Technology and its business so that the Technology can benefit the public good; and
- Retained rights for Foundation to use the Technology for internal research and development.

The term of this is a non-binding Memorandum of Understanding will be from the Effective Date through June 30, 2015. Either party may terminate for convenience at any time during the term.

IN WITNESS WHEREOF, the undersigned duly authorized representatives of the parties have executed this Memorandum of Understanding, effective as of March 16, 2015 (the “Effective Date”).

MAHMOUD AHMADI

By: [Signature]
Name: Mahmoud Ahmadi
Date: 03/16/2015

THE RESEARCH FOUNDATION FOR STATE UNIVERSITY OF NEW YORK for and on behalf of University at Buffalo

By: [Signature]
Name: Jeffrey A. Burbar
Title: Director
Date: 03/16/2015