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Comparison between Xogen's Electro-oxidation Technology to Remove Cyanide and Ammonia from Precious Metal Mining Effluents and Existing Technologies

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1 Executive Summary

This report is compiled to compare Xogen's electro-oxidation technology to remove cyanide and ammonia from precious metal mining effluents with incumbent technologies that are listed in Hatch's Interim Study Report: *Study to Identity BATEA for the Management and Control of Effluent Quality from Mines*, 2014.

Canadian Precious metal operations are subject to the current Metal Mining Effluent Regulations (MMER) and per Environmental Canada's 10-Year Review of Metal Mining Effluent Regulations. Specifically, precious metal operations subject to MMER have been identified by Environment Canada as being potentially impacted by the changes in discharge limits proposed for the parameters that are currently regulated (arsenic, copper, cyanide, lead, nickel, ammonia and zinc), changes to the allowable discharge amendments to the Metal Mining Effluent Regulations will be implemented when published in Canada Gazette II.: http://www.gazette.gc.ca/rp-pr/p2/2018/2018-05-30/html/sor-dors99-eng.html. .
Existing technologies specifically available for cyanide and ammonia removal from precious metal mining effluent are discussed. These technologies, including air stripping, zeolite ion exchange, active aerobic biological oxidation, and ion exchange were identified by Hatch's Interim Study Report (2014) as the Best Available Technologies (BAT) for precious metal mining effluent treatment.

Xogen's electro-oxidation technology is discussed in detail as a promising alternative for ammonia and cyanide removal from precious metal mining effluent. Xogen's electro-oxidation technology has been added to the Hatch analysis for comparative purposes, demonstrating Xogen's Advanced Electro-Oxidation technology as a favorable alternative to the incumbents described due to its treatment efficacy and attractive economics. It should be noted that Xogen's results are based on bench scale testing only and would be expected to improve at full scale due to process optimization that is achieved during plant/process commissioning.

Comparison specifics used:
- Peak flow rate: 600 m3/h
- Remove ammonia from 20 ppm to 0 ppm
- Hydraulic retention time (HRT): 0.8 min

Comparison of Treatment Efficacy

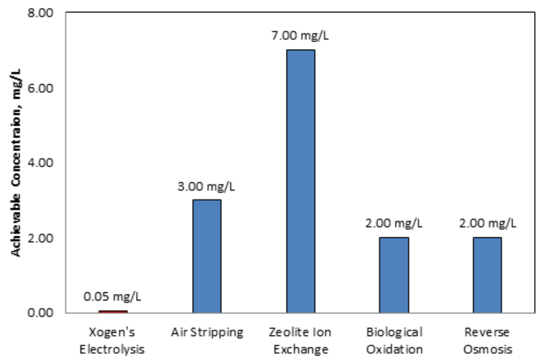

Figure 5.1.1 Comparison of Achievable Ammonia Concentration

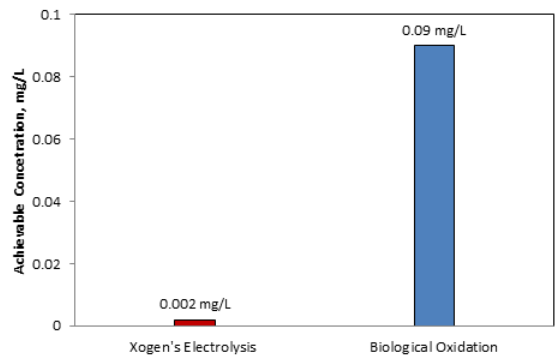

Figure 5.1.2 Comparison of Achievable Cyanide Concentration

Comparison of Capital & Operating Cost

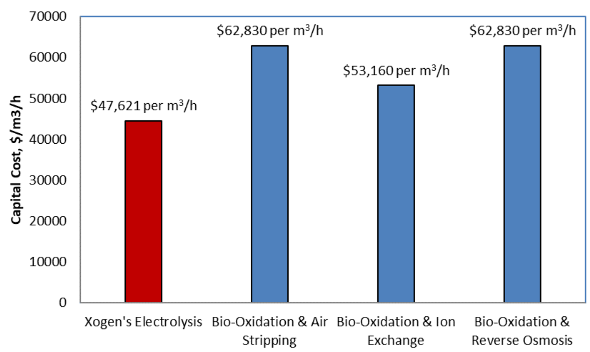

Figure 5.2.1 Comparison of capital cost

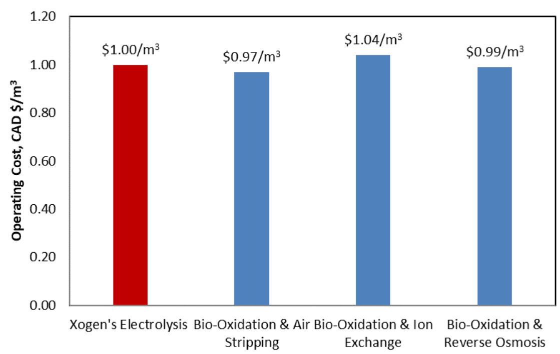

Figure 5.3.1 Comparison of operating cost

2 Precious Metal Mining Effluent

2.1 Regulations Overview

Operating Canadian Precious metal operations are subject to the current *Metal Mining Effluent Regulations* (MMER) and per Environmental Canada's 10-Year Review of *Metal Mining Effluent Regulations*. Specifically, precious metal operations subject to MMER have been identified by Environment Canada as being potentially impacted by the changes in discharge limits proposed for the parameters that are currently regulated (arsenic, copper, cyanide, lead, nickel and zinc), as listed in Table 2.1.1. However analysis concerning the potential impact of additional parameters (ammonia, iron, selenium) proposed by Environmental Canada is not available.

Table 2.1.1: Metal Mining Exiting Limit [1]

Deleterious Substance	*Maximum Authorized Monthly mean Concentration*	*Maximum Authorized Concentration in a Composite Sample*	*Maximum Authorized Concentration in a Grab Sample*
pH	6.0-9.5	6.0-9.5	6.0-9.5
Cyanide	**1.00 mg/L**	**1.50 mg/L**	**2.00 mg/L**
Arsenic	0.05 mg/L	0.75 mg/L	1.00 mg/L
Copper	0.30 mg/L	0.45 mg/L	0.60 mg/L
Lead	0.20 mg/L	0.30 mg/L	0.40 mg/L
Nickel	0.50 mg/L	0.75 mg/L	1.00 mg/L
Zinc	0.50 mg/L	0.75 mg/L	1.00 mg/L
TSS	15.00 mg/L	22.50 mg/L	30.00 mg/L
Total Ammonia	**--**	**--**	**--**

In particular, for metal mining effluent, Environment Canada has proposed the addition of aluminum, iron, selenium, and total ammonia, and has proposed the reduction of authorized limits for chloride, phosphorus, ammonia, and TSS concentrations in effluent discharged to environment, as well as the pH.

2.2 Effluent Characteristics

It is expected that the quality of effluent generated by mine operations will be variable from operation to operation based on site specific conditions. Many different contaminants are present in untreated effluent at precious metal operations. The most commonly reported contaminants in untreated effluent in concentrations above MMER limits and targeted by effluent treatment plants are pH (above or below discharge limits), total suspended solids, arsenic, copper, nickel and cyanide. Among them, only cyanide and ammonia are considered as contaminants of interest for comparison in this report. Table 2.2.1 listed the average concentration of parameters detected in untreated precious metal mining effluents.

Table 2.2.1: Quarterly Average Concentrations of Parameters in Untreated Effluent at Precious Metal Operations [3]

Parameter	*Minimum*	*Average*	*95th Percentile*	*Maximum*
Cyanide	**0.002 mg/L**	**7.8 mg/L**	**34 mg/L**	**41 mg/L**
Total Ammonia	**2.3 mg/L**	**19 mg/L**	**30 mg/L**	**32 mg/L**
pH	2.5	7.1	9.3	10.2
TSS	2 mg/L	65 mg/L	189 mg/L	536 mg/L
Arsenic	0.0008 mg/L	1.2 mg/L	3.8 mg/L	28 mg/L
Copper	0.0003 mg/L	9 mg/L	53 mg/L	81 mg/L
Nickel	0.002 mg/L	0.8 mg/L	4.7 mg/L	7.1 mg/L

According to MMER reported discharge volume [1], the estimated annual hourly discharge volume ranges from 0 to 1,563 m^3/h, with an average of 179 m^3/h. Therefore, 600 m^3/h was selected for the design capacity of the precious metal mining effluent treatment system in Hatch's Report [12]. This value was utilized for capital estimating for system augmentation. Meanwhile, 180 m^3/h was elected as nominal flow rate and was utilized for operating cost estimate.

2.3 Effluent Treatment Technologies

Precious Metal operation employs a wide range of technologies for effluent treatment and target a large number of parameters. Existing technologies employed at precious metal operations include hydroxide precipitation, co-precipitation and coagulation, natural degradation, passive treatment, ion exchange, oxidation, cyanide destruction, air stripping and solid/liquid separation for the removal of metals, cyanide, ammonia, and TSS.

Among these technologies, air stripping, zeolite ion exchange, biological oxidation, and reverse osmosis are screened out as Best Available Technologies (BAT) for ammonia and cyanide removal of Canadian precious metal mining. These 4 technologies meet the following criteria [11]:

- The technology can achieve existing *MMER* authorized limits for targeted existing and proposed limit for ammonia and cyanide
- The technology has been demonstrated at full scale on mining effluent
- The technology has been demonstrated under representative Canadian climate conditions

Recently, emerging technologies such as Electro-oxidation represented by Xogen Technologies Inc. might be considered as a promising alternative to these existing technologies, due to impressive efficiency for cyanide and ammonia removal. The comparison between Xogen's Electro-oxidation technology and existing BATs is discussed in section 5.

3 Existing Treatment Technologies

3.1 Air Stripping

Air stripping process has been used to volatize un-ionized ammonia gas (NH_3) from effluent at alkaline pH. Typically effluent droplets are atomized by spray nozzles and distributed evenly across the tower. As the effluent droplets fall through a bed of packing, ambient or heated air is blown to the effluent flow counter-currently. The tower contains packing which provide surface area for mass transfer. Unionized ammonia gas is stripped from the effluent to the air. Then the pH of the effluent is re-adjusted typically with carbon dioxide to meet discharge limits prior to discharge.

Air stripping systems are designed to achieve specific ammonia removal efficiency. However, the typical lower achievable limit for ammonia is 3 mg-N/L. The process efficiency is highly sensitive to variation in effluent and ambient temperatures. Therefore, pre-heating of effluent and/or air, and/or seasonal operation may be required.

Pre-treatment for total suspended solids may be required to counter plugging of the stripping tower packing and treatment for hardness, iron, manganese, phosphate, and microorganisms may be required to counter scaling/fouling of the stripping tower and packing.

According to Hatch's report [6], this process has following features as shown in Table 3.1.1.

Table 3.1.1: Features of Air Stripping process for precious metal mining effluent treatment

Efficacy	• Ammonia > 3mg-N/L
Capital Cost	• \$35,500 per m^3/h of precious metal mining effluent
Operating Cost	• \$0.53/m^3 of treated precious metal mining effluent
Risks/Concerns	• Sensitive to ambient temperatures • Heat exchange system is required to maintain ammonia removal efficiency year round, leading to high energy costs • Scaling and plugging may impact performance and pre-filtration is required for reliable operation • Equalization of flow and contaminant loadings is required

3.2 Zeolite Ion Exchange

Zeolites are naturally-occurring crystalline hydrated aluminosilicates that have high ion-exchange capacities and high specific-surface area, and demonstrate an affinity for cations, especially ammonium ions (NH_4^+). Clinoptilolite, a type of zeolite, has been identified as particularly suitable for ammonium removal, due to its high ammonium selectivity, adsorption capacity and performance at low temperature. As wastewater passes through the zeolite, naturally occurring cations affixed to the zeolite crystals are exchanged for ammonium ions, due to the higher affinity of zeolite for ammonium than for many other cations.

According to Hatch's report [7], this process has following features as shown in Table 3.2.1.

Table 3.2.1: Features of Zeolite Ion Exchange process for precious metal mining effluent treatment

Efficacy	• Ammonia : 7 to 9 mg-N/L
Capital Cost	• \$25,830 per m^3/h of precious metal mining effluent (Include capital costs for media filtration pre-treatment)
Operating Cost	• \$0.60/m^3 of treated precious metal mining effluent (Includes operating costs for media filtration pre-treatment)
Risks/Concerns	• Pre-filtration is required. Depending on effluent chemistry, additional pre-treatment may be required. • Equalization of flow and contaminant loadings is required • Regenerant management must be carefully considered based on site-specific factors and could add significant operating and capital costs

3.3 Active Aerobic Biological Oxidation

Aerobic biological oxidation may be used to oxidize ammonia (NH_3/NH_4^+), cyanide, cyanate (OCN^-), and thiocyanate (SCN^-) to nitrates (NO_3^-). Biological ammonia oxidation, or nitrification, is a two-step biological process in which ammonia is first oxidized to nitrite and then nitrite is oxidized to nitrate via two distinct groups of autotrophic bacteria, Nitrosomonas and Nitrobacter, respectively.

Aerobic biological oxidation can be accomplished in suspended growth and attached growth/fixed film processes. In suspended growth processes, microorganisms are maintained in suspension in the effluent to be treated via mixing. In attached growth processes, microorganisms are attached as biofilm to inert packing material through which the effluent to be treated flows. Integrated fixed film activated systems combine both suspended growth and attached growth/fixed film processes.

According to Hatch's report [8], this process has following features as shown in Table 3.3.1.

Table 3.3.1: Features of Active Aerobic Biological Oxidation process for precious metal mining effluent treatment

Efficacy	• Ammonia < 2 mg-N/L • Cyanide < 0.09 mg/L
Capital Cost	• \$27,330 per m^3/h of precious metal mining effluent
Operating Cost	• \$0.44/m^3 of treated precious metal mining effluent
Risks/Concerns	• Equalization of flow and contaminant loadings is required • Systems are difficult to start-up at low effluent temperature (<10 ºC) and require heat exchange systems. Heat exchange to year-round operating could substantially increase operating costs (e.g., increasing effluent temperature by 5 ºC for half of the year would bring the operating cost to approximately CAD \$0.69/m^3). • Residual biomass typically requires thickening and dewatering prior to disposal.

3.4 Reverse Osmosis

Reverse Osmosis (RO) removes total solids (including dissolved metals, selenium, phosphorous, chlorides, ammonia and cyanide by the high-pressure application of effluent to selectively permeable membranes that exclude dissolved solids but allows the passage of water molecular. The high feed pressure is required to overcome the osmotic pressure that develops across RO membranes, pushing the water molecules through the membrane to generate low TDS permeate stream. Dissolved solids are retained on the feed side of the membrane and exit the pressure vessels in the high TDS concentration reject stream.

Reject management is a critical consideration in the design of reverse osmosis systems for mine effluent treatment and can add significant capital and operating cost. Reverse osmosis membranes typically require replacement every 3 to 5 years, generating an additional waste stream that must be managed.

According to Hatch's report [9], this process has the following features as shown in Table 3.4.1.

Table 3.4.1: Features of Reverse Osmosis (RO) process for precious metal mining effluent treatment

Efficacy	• Ammonia < 2 mg-N/L
Capital Cost	• \$35,500 per m^3/h of precious metal mining effluent (Includes capital costs for media filtration pre-treatment)
Operating Cost	• \$0.55/m^3 of treated precious metal mining effluent (Includes operating costs for media filtration pre-treatment)
Risks/Concerns	• Equalization of flow and contaminant loadings is required • At minimum, pre-filtration is required. Additional pre-treatment may be required depending on effluent chemistry • RO permeate is typically lower pH than feed pH and is low in alkalinity. PH adjustment and re-mineralization may be required prior to discharge to meet pH and acute toxicity requirements. • Concentrate management must be carefully considered based on site-specific factor. If concentrate is returned to water management features on site, there is a risk of solutes (e.g. Cl^-, Na^+) cycling up in site water. Concentrate management may require advanced technology (e.g. evaporator/crystallizer) which would add significant capital and operating cost

4 Xogen's Electro-Oxidation Technolgoy

4.1 Company Overview

Xogen Technologies Inc. is an original equipment manufacturer (OEM) that is focused on providing industry and government with innovative wastewater treatment systems worldwide. Xogen's patented electro-oxidation technology is designed to address the acute needs in the rapidly growing multi-billion dollar wastewater industry in mining, pharmaceutical, municipal, industrial, power generation and oil & gas Industries.

XOGEN® Wastewater Treatment Systems combine the benefits of electro-oxidation, electro-flotation, electro-coagulation, electro-flocculation and disinfection into one unit process. Xogen's electrochemical process effectively eliminates many types of targeted and challenging contaminants in industrial wastewaters. Xogen's technology is proven effective for the reduction of organics, ammonia, cyanides, nitrates, metals, oil and grease and suspended solids. Xogen's process eliminates the production of bio solids, is odorless, and its treatment of wastewater achieves, and exceeds, regulatory requirements with a speed that is unmatched by current technologies. Wastewater is treated using an electrolytic process that also produces a mixture of hydrogen, oxygen, and nitrogen gas. These gases are a valuable commodity, which can be used to generate energy that can be sold back to the grid or re-used to reduce operating costs. Wastewater treatment is primarily accomplished through a scalable single unit process that occupies up to 75% less space than conventional treatment systems.

Xogen delivers complete electro-oxidation wastewater treatment solutions, including process design, build, installation, commissioning and service. Xogen's treatment process helps customers to reduce environmental liabilities and produce clean water that can be re-used or safely discharged to the environment.

Xogen has thousands of hours of pilot plant operating experience both at industrial and municipal sites in Canada. Xogen operates a full service laboratory in Orangeville, Ontario, where wastewaters from clients can be evaluated on the company's technology for treatment efficacy, as well as operating expenditure (OPEX) and capital expenditure (CAPEX) estimates for commercial scale installations.

Xogen was awarded the Cleantech Next 10 – Most Promising Cleantech Startups from Corporate Knights in 2011.

4.2 Process Description

The XOGEN® Wastewater Treatment System is a form of advanced oxidation that utilizes primarily hydroxyl radicals and chlorine based radicals to oxidize many different compounds. Specifically in the landfill water, the electro-oxidation cell will generate hydroxyl radicals, chlorate radicals and a small amount of hypochlorite.

The technology uses an applied electrical potential to generate the oxidants in the wastewater that oxidize organic compounds to carbon dioxide, water and nitrogen gas. The cell consists of an inert cathode that is customized to the application as well as an active dimensionally stable anode. The anode contains a proprietary coating that, when an electrical current is passed through the plate, generates powerful oxidizing compounds at the boundary of the plate and water phase. A process schematic of Xogen's technology is shown in Figure 4.2.1.

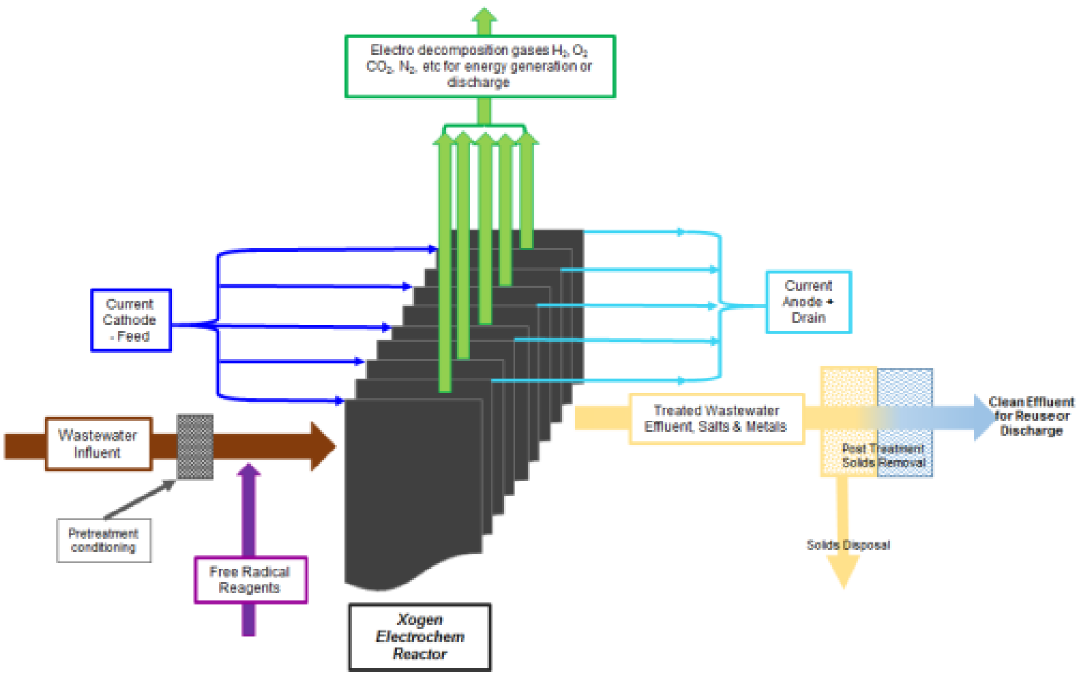

Figure 4.2.1 Xogen's Electro-oxidation process

Wastewater will be collected in a holding tank prior to the reactor assembly. The wastewater is analyzed online/inline for targeted contaminants of concern which are recorded. The Xogen technology does not require filtering; however, particles larger than 3 mm can cause damage to the reactor. The wastewater is pumped through a simple mesh screen before the reactor assembly.

The wastewater is pumped into the bank of reactor pack assemblies where it is treated with the Xogen technology as described in the above sections. Generally, several "5 packs" form a bank and treatment can occur either in parallel or in series with respect to each bank. For example, a plant with 50 packs can have 5 banks of ten, 2 banks in parallel cascading to 2 more banks in parallel cascading to the last bank on standby in larger than normal water flow conditions.

Each pack consists of a gas liquid separator and a blower. The blower expels the generated gas away from the plant and the liquid continues into an instrumentation cluster. Xogen employs inline and online process control to monitor key performance indicators, and adjust power settings, as required, in a form of process control. Following the instrumentation cluster, the water can continue to another bank of reactors or is discharged depending on the setup.

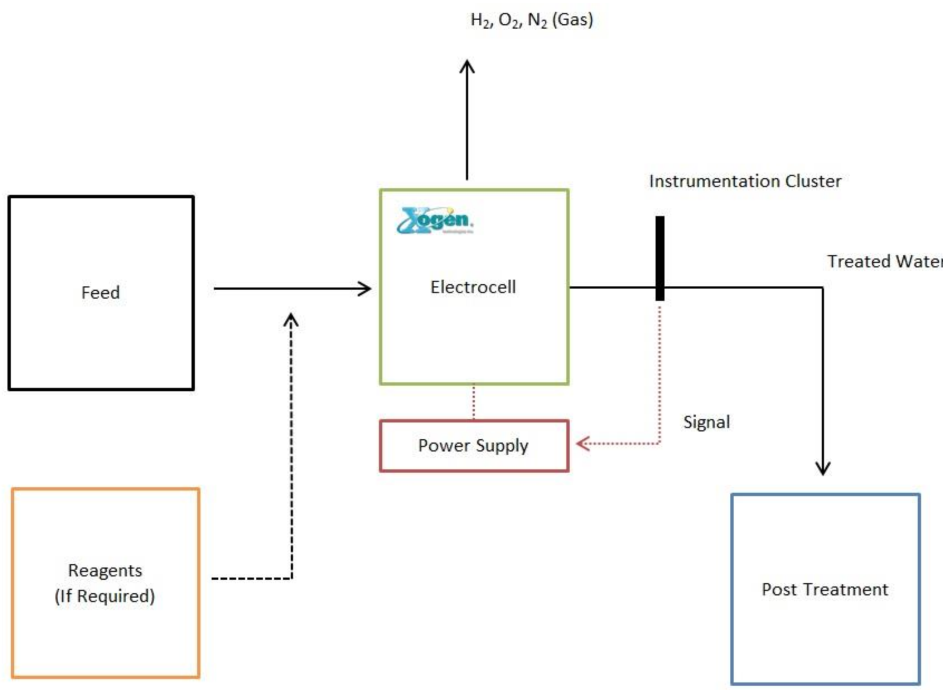

Figure 4.2.2 Generic Process Flow Diagram for Ammonia and Cyanide Removal

4.3 Treatment Efficacy

Xogen has conducted bench-top tests for precious metal mining effluent from a Fortune 500 gold mining company. The test results indicate that Xogen's technology was able to achieve 94.9% removal of total cyanide from 0.039 mg/L to less than 0.002 mg/L, and 99.1% removal of total ammonia from 5.71 mg-N/L to 0.05 mg-N/L. The test results are summarized in Table 4.3.1 [10].

Table 4.3.1: Ammonia and Cyanide Removal Efficacy of Xogen's Electro-oxidation Process

Parameter	*Raw Effluent*	*Treated Effluent*	*Treatment Target*	*% Removal*
Cyanide (total)	0.039 mg/L	<0.002 mg/L	<0.1	94.9
Ammonia (total)	5.71 mg/L	0.050 mg/L	<1.0	99.1

4.4 Capital Cost

The Xogen Cell Reactor is a 12”L x 8”W x40”H anode/cathode plate stack (it contains multiple anodes and cathodes arrayed in parallel sheets) with a fixed internal volume, see Figure 4.4.1 Xogen Reactor .

Figure 4.4.1 Xogen Reactor

In commercial or large pilot plant installations; there are 4 cells per reactor “pack” which are depicted below in Figure 4.4.2 Four pack reactor assembly. Each pack will contain a liquid/gas separator, a feed system and a power supply. Adding or subtracting packs is a fast process. The technician uses a forklift to remove a pack for maintenance (as required) and replaces it with another pack. The overall pack size is 63”L x 47”W x 63”H and weighs approximately 800 pounds. Overall flow varies between plants, but a flow rate of 5 gpm to 10 gpm is typical per pack.

Figure 4.4.2 Four pack reactor assembly

Since the process is based on modular units with Xogen electro-oxidation reactors, the system is easily scalable for any capacity. Capital cost estimate for a XOGEN Wastewater Treatment System with a total treatment capacity of 600 m^3/h is shown in Table 4.4.1. Following criteria are adopted for this estimate:

- Peak flow rate: 600 m^3/h
- Remove ammonia from 20 ppm to 0 ppm
- Hydraulic retention time (HRT): 0.8 min

As shown in the table, the capital cost is estimated to be $28,572,866 CAD. The incremental capital cost for XOGEN® wastewater treatment system is $47,621 per m^3/h.

Table 4.4.1: Capital cost estimate for XOGEN® Wastewater Treatment System

CAPEX Components	*Total (CAD)*
Xogen Electro-oxidation Reactor Modules	$6,857,488
Reactor Power Supply Modules	$4,571,659
System integration	$17,143,719
Capital Cost in Total:	**$28,572,866**

4.5 Operating Cost

The majority of the operating cost of the XOGEN® Wastewater Treatment System consists of: chemical consumption, energy consumption and labor cost.

The energy consumption includes the power supplied for the electro-oxidation cells of Electro-Oxidation (EO) unit, and the power supplied for ancillary pumps of the system. Each pack of 4 electro-oxidation reactors requires 10kW power.

Labor cost for operating the system may varies from site by site. In general, the system needs 3 hours per day for maintenance.

The estimated operating cost for XOGEN® Wastewater Treatment System with nominal flow capacity of 180 m^3/h is shown in Table 4.5.1. This estimate is for operating Xogen Equipment and Instrument only, excludes operating any pre/post treatment unit (e.g. filtration, clarification, GAC adsorption).

Following criteria are adopted for this estimate:

- Average flow rate: 180 m^3/h
- Power of reactor: 2.5 kW pe reactor
- Electricity rate: $0.12/kWh
- Backwash frequency: 2 times per day
- Operation hours: 24/7, 90% utilization rate

As shown in the table, total operating cost is $1.00/m^3$ wastewater treated.

Table 4.5.1: Operating cost estimate for XOGEN Wastewater Treatment System

OPEX Components	*Per m^3 Cost ($/m3)*
Electricity cost	$0.72/m^3$
Chemical cost	$0.10/m^3$
O&M cost	$0.18/m^3$
Operating Cost in Total:	**$1.00/m^3$**

4.6 Risks/Concerns

Depending on the chemistry of precious metal mining effluent, extra pre-treatment or post-treatment process may be added, these processes may include pre-filtration, chemical enhanced clarification, GAC adsorption. These modifications may increase capital and operating cost of the system.

Since hydrogen and oxygen gas is generated as byproduct by the XOGEN® Wastewater Treatment System, there is a safety concern of the system. Venting system and hydrogen alarm system must be carefully maintained to avoid accumulation and explosion of hydrogen gas.

In addition, the XOGEN® Wastewater Treatment System is designed to be operated within a facility or building protected from the elements. Extreme conditions without temperature control may affect the performance of the system.

The features including risks/concerns of XOGEN® Wastewater Treatment System is summarized in Table 4.6.1.

Table 4.6.1: Xogen's Electro-oxidation technology for precious metal mining effluent treatment

Efficacy	• Ammonia : <0.05 mg-N/L • Cyanide: <0.002 mg/L
Capital Cost	• $47,621 per m^3/h of precious metal mining effluent
Operating Cost	• $1.00/m^3$ of treated precious metal mining effluent
Risks/Concerns	• Equalization of flow and contaminant loadings is required • Gaseous by-products such as hydrogen should be carefully handled to avoid dangerous issues • Extreme conditions without indoor temperature control may affect treatment performance

5 Comparison

5.1 Comparison of Efficacy

As shown in Figure 5.5.1 and Figure 5.5.2. Xogen electro-oxidation technology shows extremely high efficiency for ammonia and cyanide removal from precious metal mining effluent, compared with the existing BATs. Xogen's electro-oxidation technology removes 99.1% of ammonia and 94.9% of cyanide from effluent samples from a Northern Ontario gold mine. Xogen's Electro-oxidation technology reduces ammonia concentration down to less than 0.05 mg-N/L and cyanide down to less than 0.002 mg/L in the treated effluent. The treated effluent meets the treatment target at ammonia concentration less than 1.0 mg/L and cyanide concentration less than 0.1 mg/L.

Compared with Xogen Electro-oxidation Technology, none of the existing BAT technologies discussed in section 3 could achieve such low ammonia and cyanide concentrations in treated effluent.

Biological oxidation and reverse osmosis can reduce ammonia concentration to 2.00 mg/L, while air stripping can reduce ammonia concentration to 3.00 mg/L at most. For zeolite ion exchange, achievable ammonia concentration is even higher, as 7.00 mg/L. Xogen electro-oxidation technology achieves 40 times lower ammonia concentration then the best BAT for ammonia removal.

As for cyanide removal, only biological oxidation process shows the ability to reduce cyanide concentration down to 0.09 mg/L for precious metal mining effluent. Other BATs shows no cyanide removal efficiency. Xogen electro-oxidation technology achieves cyanide concentration to less than 0.002 mg/L, which is 4.5 times lower than biological oxidation technology.

These results indicated that Xogen electro-oxidation technology's ammonia and cyanide removal efficiency is incomparable, compared with existing BATs for precious metal mining effluent treatment.

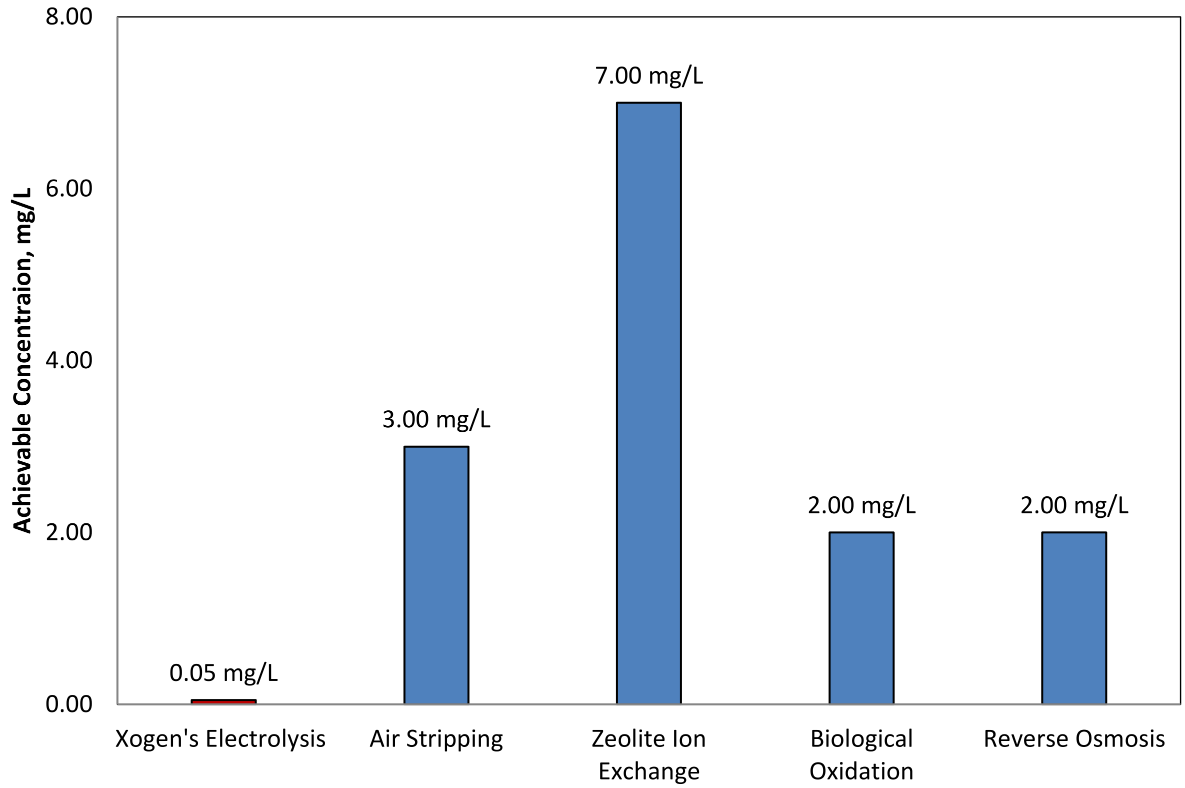

Figure 5.1.1 Comparison of Achievable Ammonia Concentration

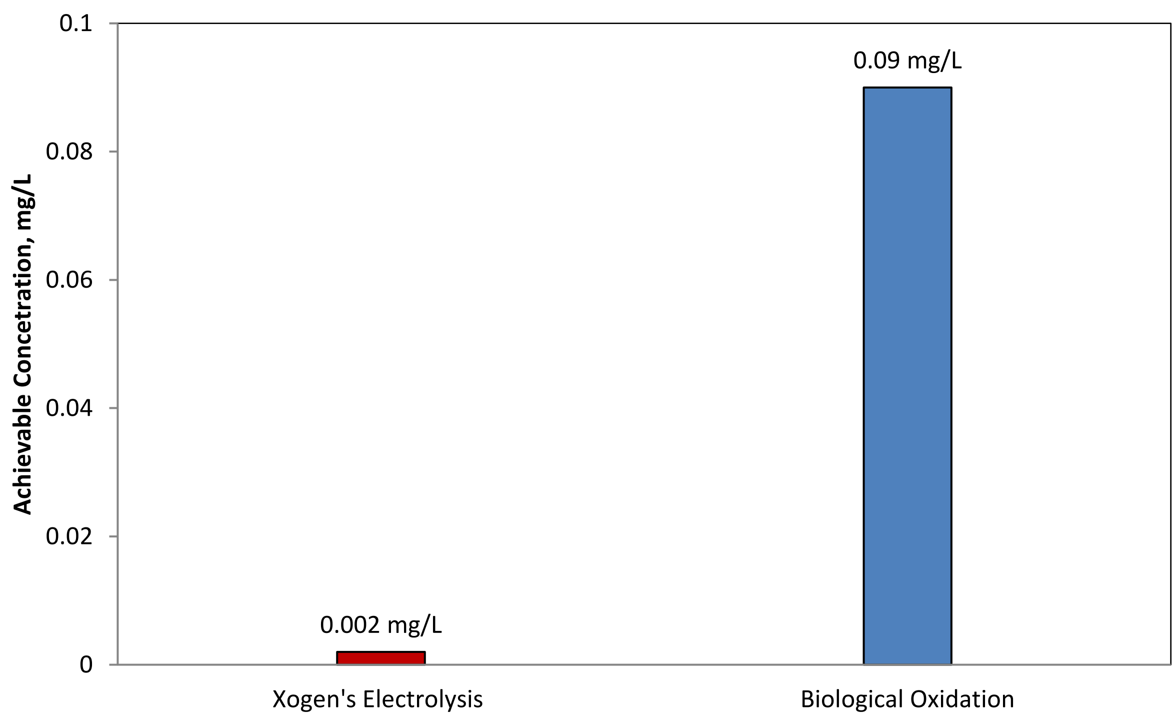

Figure 5.1.2 Comparison of Achievable Cyanide Concentration

5.2 Comparison of Capital Cost

Since only biological oxidation technology shows cyanide removal ability among BATs as shown in Figure 5.1.2, combination of various BATs has to be adopted in order to achieve both ammonia and cyanide removal from precious metal mining effluent. It should be noted that, biological oxidation should not be utilized alone as high levels of ammonia and cyanide may kill the bacteria rendering the process inoperable.

The comparison of incremental capital cost for ammonia and cyanide removal from precious metal mining effluent between Xogen's Electro-oxidation technology and other BAT combinations is shown in Figure 5.2.1. Compared with different BAT combinations, capital cost for Xogen's electro-oxidation technology is relatively lower:

- **25 % lower** than biological oxidation combine with air stripping technology
- **25 % lower** than biological oxidation combine with reverse osmosis technology
- **11 % lower** than biological oxidation combine with ion exchange technology

In addition, all BATs require extra pre/post treatments that could increase capital costs significantly, such as pre-filtration for air-stripping, ion exchange, and RO; sludge handling system for biological oxidation; heat exchange system for air stripping and biological oxidation; regenerant management system for ion exchange; and concentration management system for RO. In comparison, Xogen electro-oxidation system requires less and simpler pre/post treatment processes.

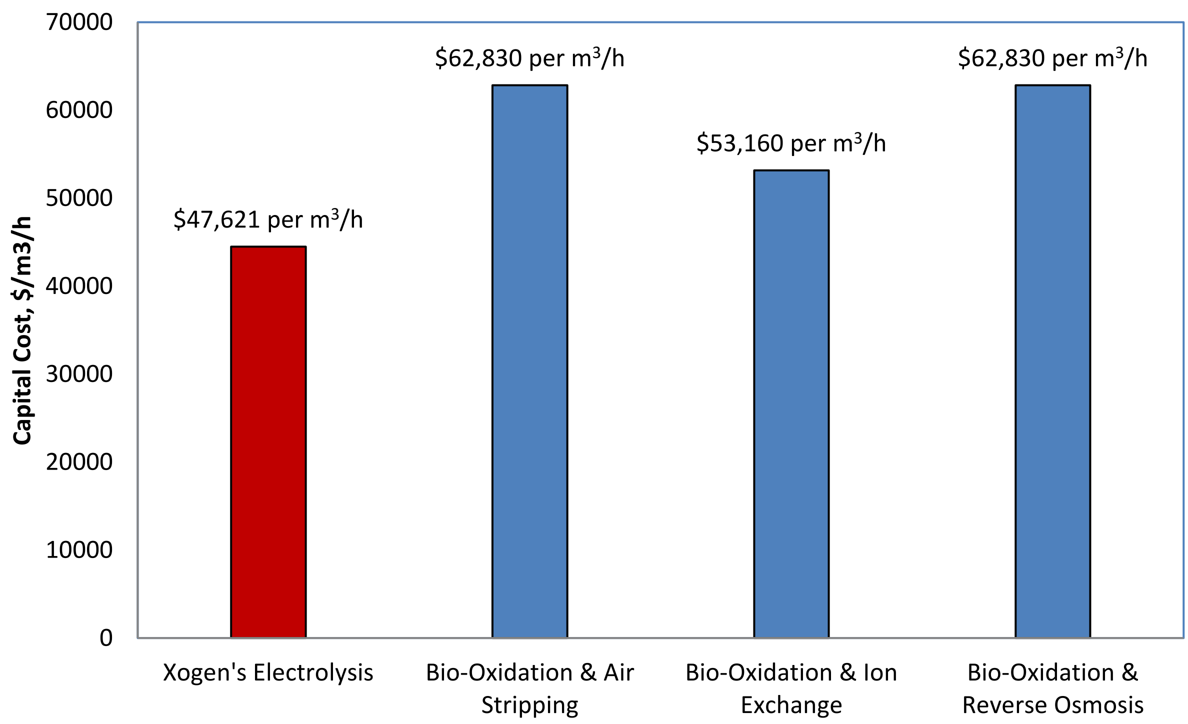

Figure 5.2.1 Comparison of capital cost

5.3 Comparison of Operating Cost

As shown in Figure 5.3.1, the incremental capital cost of Xogen's electro-oxidation technology is very close to BAT combinations for ammonia and cyanide removal from precious metal mining effluent:

- $1.00/m^3 for Xogen electro-oxidation technology
- $0.97/m^3 for biological oxidation combine with air stripping technology
- $0.99/m^3 for biological oxidation combine with reverse osmosis technology
- $1.04/m^3 for biological oxidation combine with ion exchange technology

Therefore, only insignificant differences of operating cost between Xogen's and BATs combination could be observed. Additional consideration should be given to pre/post treatment process that may increase operating cost significantly.

Air stripping and biological oxidation are very sensitive to temperature and require heat exchange systems. Heat exchange for year-round operating purpose could substantially increase operating costs. Increase effluent temperature by 5 ºC for half a year would bring the operating cost to approximately $0.69/m3. Residual biomass of biological oxidation typically requires thickening and dewatering prior to disposal, which may increase the operating cost by 50%. Regenerant management for zeolite ion exchange could add significant operating cost to the system and concentrate management for RO could increase operating costs to $2.5/m^3.

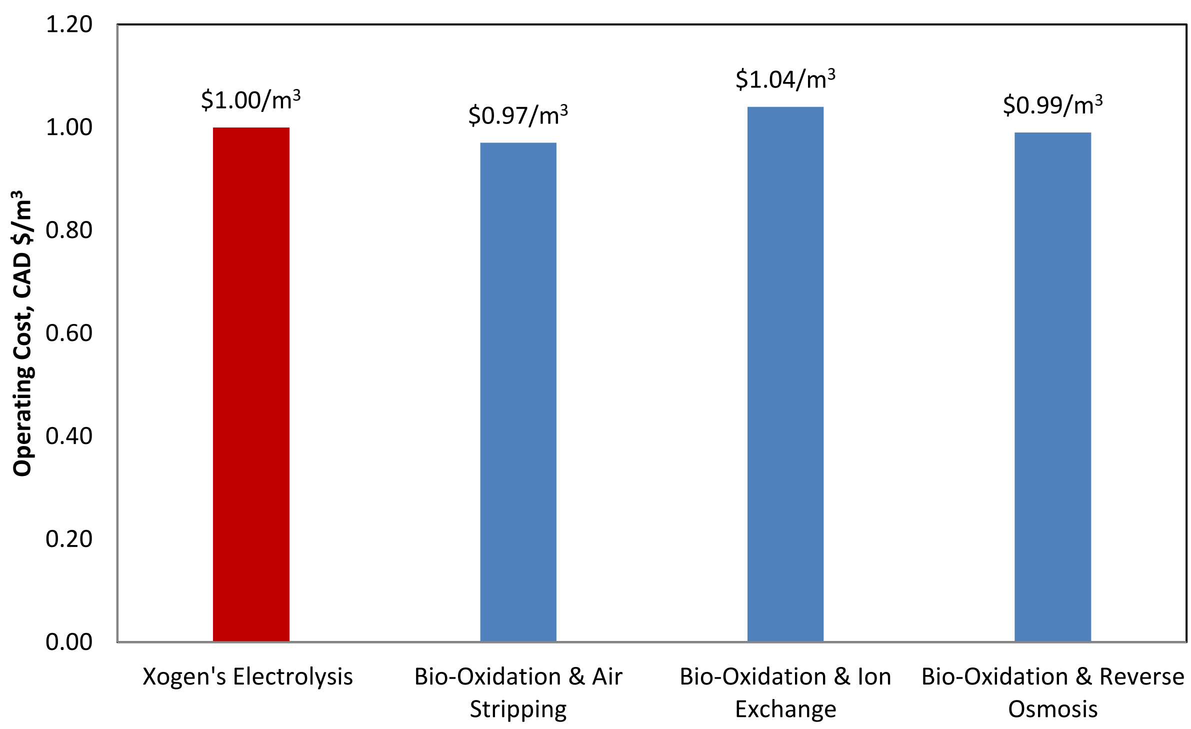

Figure 5.3.1 Comparison of operating cost

5.4 Risk Mitigation

The risks and concerns of utilizing Xogen electro-oxidation technology are compared with existing BATs in as shown in Table 5.4.1.

As shown in the table, pre-filtration is not strictly required by biological oxidation and Xogen electro-oxidation technology. However, any particles larger than 3mm must been screened out prior to entering Xogen electro-oxidation cells. Xogen electro-oxidation technology does not need to worry about sludge management, like biological oxidation.

Same as other existing BATs, Xogen electro-oxidation also requires flow and load equalization of the wastewater; however, this is a minor concern and can be handled through Xogen's electro-oxidation wastewater system with automatic flow and level control function.

Compared with zeolite ion exchange and RO which require complex and expensive systems to manage onsite by-products such as regenerant and concentrate, Xogen electro-oxidation only requires managing the gaseous by-product generated from the electro-oxidation cells. The gaseous by-products consist of hydrogen, oxygen, and nitrogen gas, which will be collected by a venting system. In a commercial installation, these gases might have value as an energy source to offset electricity consumption of the system.

Similar to air stripping, there is a minor concern of scale build up on the Xogen electro-oxidation cells. Xogen electro-oxidation wastewater treatment system contains a backwash unit to clean electrodes regularly.

Table 5.4.1 Comparison of risks and concerns

Legend:
- Major Risk
- Minor Risk
- No Risk

	Xogen Electro-oxidation	Air Stripping	Zeolite Ion Exchange	Biological Oxidation	Reverse Osmosis
Require pre-filtration		Minor Risk	Major Risk		Major Risk
Require flow and loading equalization	Minor Risk	Minor Risk	Minor Risk	Minor Risk	Minor Risk
Sensitive to ambient temperature	Minor Risk	Major Risk		Minor Risk	
Onsite by-product management	Minor Risk		Major Risk		Major Risk
Scaling and Plugging	Minor Risk	Major Risk			
Require sludge handling				Major Risk	

6 Conclusions

According to the comparison between Xogen's electro-oxidation technology to remove cyanide and ammonia from precious metal mining effluents and exiting BAT technologies, following conclusions can be made:

- **Efficacy.** The ammonia and cyanide removal efficacy of Xogen's electro-oxidation technology is significantly higher than any of the existing technologies investigated in this report. Xogen's electro-oxidation technology is able to reduce ammonia concentration down to 0.05 mg-N/L and cyanide concentration to 0.002 mg/L in precious metal mining effluent. The achievable ammonia concentration of Xogen's electro-oxidation technology is more than 40 times lower than any of the existing technologies reviewed and cyanide removal is 4.5 times lower than those technologies reviewed.
- **Capital cost.** The incremental capital cost of Xogen's electro-oxidation technology is $44,490 per m^3/h of treated effluent. This cost is 16% to 30% lower than any of the combinations of existing technologies in order to achieve both ammonia and cyanide removal.
- **Operating cost.** The incremental operating cost of Xogen's electro-oxidation technology is $1.00/$m^3$, which is at the same level of combinations of existing technologies for ammonia and cyanide removal. However, it should be noted that Xogen's results are based on bench scale testing and it is expected based on pilot results that a 20 to 40 percent improvement in these numbers could be realized at full scale.
- **Risks.** The major risks that would need to be mitigated for Xogen's electro-oxidation technology include scaling, plugging and gaseous byproducts management, all issues that have been managed in previous pilot projects. Compared to the technologies reviewed in this report, the risks of Xogen's electro-oxidation technology can easily be avoided through proper design and operation of the system.

7 Citations

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4. **HATCH**. *Study to Identify BATEA for the Management and Control of Effluent Quality from Mines, Interim Study Report, Page 96.* 2014
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11. **HATCH**. *Study to Identify BATEA for the Management and Control of Effluent Quality from Mines, Interim Study Report, Page 178.* 2014
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