# Task 3: Heavy Metal Removal via Phycoremediation

## Proposed and sponsored by Freeport-McMoRan

### Background

Bioremediation describes a diverse array of technologies that rely primarily on biological organisms (e.g., plants, microbes) to remediate impacted water and soils. Varieties of bioremediation strategies are applicable to the remediation of mining-impacted waters because of the ability of biological organisms to remove metals and other constituents of concern through various mechanisms, including biotransformation and biosorption. For example, sulfate-reducing bacteria and wetland plants have been successfully used for several decades to treat mining-impacted waters.

Phycoremediation, on the other hand, is an emerging technology within the field and it describes the use of algae for remediation. Phycoremediation is still in its infancy and has not been as well studied. As such, the field presents many opportunities for identifying candidate organisms, characterizing their remediation potential, and implementing them in novel environmental technologies.

Freeport-McMoRan has observed algae growing sparsely in its metal-rich, low pH mine waters (pH 2.0-3.0) and is interested in exploring the potential of this (or other) species of algae to remove heavy metals from the waters.

### Problem Statement

The goal of this project is to assess the efficacy of select microalgae as a candidate for passive or semi-passive bioremediation. Achieving this goal will require an evaluation of the potential for increased propagation of selected microalgae in mining-influenced water, quantifying metal-removal efficiency by select algae, and exploring the requirements for scaling up the process to industrial levels.

Positive results include identifying several species with a high tolerance for acidic (pH 2.0 –3.0) and metal-laden waters, determining conditions necessary for healthy growth and propagation, demonstrating a total metal removal efficiency of at least 90%, and consideration of strategies for recovering metals from the biomass.

Although other acidophilic or acid-tolerant algae species may be considered, special attention should be paid to the sample provided to you (species unknown) that is currently growing (albeit sparsely) in Freeport-McMoRan's mining-influenced waters.

Lastly, information gained from this project should be used as the basis for a preliminary technical design for a full-scale treatment system, including rough order-of-magnitude cost estimate, operating and maintenance tasks, and footprint required for treating an impacted stream of up to 10 gpm, as demonstrated with a residence time curve for the bioreactor.

**Design Considerations**

Your team's design must adhere to the following guidelines and/or produce the following outcomes:

- You must submit to WERC a List of Pre-treatment Methods for approval no later than 27 January 2020.
- Design a continuous remediation/recovery process on the bench scale that is comparable to a base-case plant that operates at rates of up to 10 gallons per minute.
- Identify one or more species of algae that can thrive in water of chemistry indicated in the table below, with special consideration of the algae species that will be provided to you by Freeport-McMoRan.
- For the sample provided, Identify the algae species and compare to candidates identified in the literature
- Explore commercially available acidophilic algae strains as candidates for phycoremediation, and learn to cultivate them prior to receiving your sample of algae from our staff. (One algae source: UTEX.org)
- Establish an appropriate algae propagation process that would be easily implemented at lab scale
- Successfully propagate algae from a 1-liter sample provided by Freeport-McMoRan for use in experimental trials. Sample algae will be shipped one time, most likely the third week in January (TBA).
- Determine amounts/types of nutrients necessary to stimulate algae growth in the specified water chemistry; Nutrients may include addition of O or $CO_2$, but other properties of the mine waters, such as pH, may not be altered, and no additional pre-treatments to sequester metals may be added.
- Metal removal must occur through biological processes related to the algae, and not pre-treatment processes;
- Conduct remediation trials using a synthetic mine-impacted water;
- Determine residence time requirements for metal removal in a full-scale design;
- Metal-removal efficiency will ideally be at least 90% with a single pass through the treatment system;
- Monitor water quality using standard physicochemical parameters (e.g., pH, oxidation-reduction potential, electrical conductivity, dissolved oxygen) and metal concentrations in influent and effluent water samples;
- Provide cost and size estimates for a full-scale treatment system designed to treat up to 10 gpm of impacted water.
- All pre-treatment chemicals must be identified in the experimental safety plan (due by February 24, 2020) and in the List of Pre-treatment Methods (due no later than January 27, 2020).

In addition to the above-mentioned outcomes, in your write-up, propose the evaluation of:

- Metal recovery potential from the biomass produced;
- Alternative uses for the biomass collected (e.g., biofuel production, secondary feed sources, etc.).

**Bench-scale Demonstration**

Demonstrate the removal of heavy metals via phycoremediation on a bench-scale basis using a synthetic mine water. The bench-scale unit should demonstrate a continuous process that can be scaled up to a base-case plant that treats 10 gallons per minute of mine water.

In addition to the bench-scale demonstration, teams may include video productions, computer simulations, tabletop displays, and scale or architectural models to assist in the presentation; these inclusions can be extremely beneficial to your presentation but shall not be substitutes for the bench-scale demonstration.

Each team will be provided with 18 liters of synthetic mining-influenced water to work with during the bench-scale demonstration. At the end of the treatment process, each team will submit 100 mL of treated solution for analysis.

The bench-scale demonstration, shall treat water of the following basic chemistry. All constituents of a synthetic solution shall be sulfate-based salts, as is typical of mine-impacted waters.

| Analyte | Amount salt per liter synthetic solution |
|---|---|
| Aluminum, as $Al_2(SO_4)_3 \cdot 16H_2O$ | 197.07 milligrams |
| Arsenic, as $As_2O_3$ | 0.26 milligrams |
| Cadmium, as $CdSO_4 \cdot 5H_2O$ | 0.37 milligrams |
| Copper, as $CuSO_4 \cdot 5H_2O$ | 5.89 milligrams |
| Iron, as $FeSO_4 \cdot 7H_2O$ | 547.18 milligrams |
| Lead, as $PbSO_4$ | 0.15 milligrams |
| Manganese, as $MnSO_4 \cdot 4H_2O$ | 252.27 milligrams |
| Nickel, as $NiSO_4 \cdot 6H_2O$ | 0.09 milligrams |
| Zinc, as $ZnSO_4 \cdot 7H_2O$ | 228.57 milligrams |
| Sulfate, final concentration needed* | 850 mg/L |
| pH, adjusted with $H_2SO_4$ or NaOH as needed | 2.60 |

*Final sulfate concentration will be adjusted with sulfuric acid or sodium sulfate, if needed.

Analytical Testing Techniques

- ICP-OES to quantify metal-removal rates.
- Dissolved oxygen measured on-site to determine algae health.

**Algae Supply, Culture, and Propagation**

Freeport-McMoRan will provide a 1-liter sample of algae that are currently growing in the company's mine waters. Note that only one sample of this algae will be provided to each team.

Clearly, conditions are suitable for this particular species of algae, and each team is asked to identify the species and explore the potential of that species to healthily propagate and to successfully sequester metals.

Prior to receiving the algae sample from Freeport-McMoRan, teams are strongly encouraged to obtain and work with at least one other species of acidophilic algae to become proficient with algae culture, measurement processes, and potential for heavy metal sequestration (see potential algae species in references below). Though there are commercial sources of algae, WERC has identified UTEX.org as a potential source.

For the purpose of this task, no restrictions will be made on survivable temperatures for the algae, but if you would like to optimize algae selection for Freeport-McMoRan, the algae currently grows in sunlight in waters of 60-70°F. The large volumes of water keep the temperatures fairly stable at the mine.

During the contest, your bioreactor will be in direct sunlight and may be stored outdoors overnight . We recommend that you research expected day/night weather conditions for early April in Las Cruces, NM. It is reasonable to provide your bioreactor protection from the elements, but unnatural propagation methods beyond those that might ordinarily occur in mining waters, such as additional heating for the purpose of rapidly propagating the algae, during the bench-scale demonstration may not be used.

**Written Report Requirements**
The written report should demonstrate your team's insight into the full scope of the issue and include all aspects of the task and your proposed solution. The report will be evaluated for quality of writing, organization, clarity, logic, and coherence. Standards for publications in technical journals (e.g., APA, CBE) apply. In addition to the listed requirements, your report must address in detail the items highlighted in the Problem Statement, Design Considerations, and Evaluation Criteria sections.

**Evaluation**
Each team is advised to read the Participation Guide for a comprehensive understanding of the contest evaluation criteria. For a copy of the Public Involvement Plan and Participation Guide and other important resources, please visit the WERC website:
(https://iee.nmsu.edu/outreach/events/international-environmental-design-contest/guidelines/).

Additionally, your team will be evaluated based on the following:

- Metal removal efficiency of the listed metals per kg algae;
- Impacted stream of up to 10 gpm, as demonstrated with a residence time curve for the bioreactor.
- Algae viability/active growth assessment and recommended nutrients included written reports;
- Post-treatment water quality;
- Discussion of the potential for metal recovery;
- The treatment system design should be as energy efficient as possible (e.g., solar powered, gravity fed)
- Other specific evaluation criteria may be provided at a later date (watch the FAQs).

**FAQs/Deadlines**

- Teams are expected to watch for FAQs related to this task for updates in the task requirements.
- One-liter sample of algae from Freeport-McMoRan's mine waters shipped to you ~3rd week in January.
- Submit the List of Pre-treatment Methods for approval no later than 27 January 2020
- The Experimental Safety Plan (ESP) is due 24 February, 2020.
- Written Report due 23 March, 2020.

**References**
[1] Bwapwa, J. K., A. T. Jaiyeola, and R. Chetty. 2017. Bioremediation of acid mine drainage using algae strains: A review. South African Journal of Chemical Engineering 24:62-70.

[2] Kumar, K. S., H.-U. Dahms, E.-J. Won, J.-S. Lee, and K.-H. Shin. 2015. Microalgae – A promising tool for heavy metal remediation. Ecotoxicology and Environmental Safety 113:329-352.

[3] Sivakumar, G., J. Xu, R. W. Thompson, Y. Yang, P. Randol-Smith, and P. J. Weathers. 2012. Integrated green algal technology for bioremediation and biofuel. Bioresource Technology 107:1-9.

[4] Zeraatkar, A. K., H. Ahmadzadeh, A. F. Talebi, N. R. Moheimani, and M. P. McHenry. 2016. Potential use of algae for heavy metal bioremediation, a critical review. Journal of Environmental Management 181:817-831.

[5] Nancucheo, I. and D.B. Barrie Johnson. 2012. Acidophilic algae isolated from mine-impacted environments and their roles in sustaining heterotrophic acidophiles. Frontiers in Microbiology 2:325.

[6] Valente, T. and C.L. Gomes. 2007. The role of two acidophilic algae as ecological indicators of acid mine drainage sites. Journal of Iberian Geology 33(2) 283-294.

**Awards**

Each year, the WERC Environmental Design Contest and its sponsors award more than $30,000 in cash prizes. Successful completion of every stage of the design project qualifies each team for the following awards.

1. Task awards (First, Second, Third Place; minimum amounts: $2500-$1000-$500, respectively).
2. Freeport-McMoRan Innovation in Sustainability Award ($2500)
3. WERC Resources Center Pollution Prevention/Energy Efficiency Award ($500)
4. Judges' Choice Award ($500)
5. Peer Award ($250)
6. Terry McManus Outstanding Student Award. (Minimum: $500, according to funding).

*Award amounts listed are minimum amounts and may increase with available funding.*
*Detailed criteria for each award:*
https://iee.nmsu.edu/outreach/events/international-environmental-design-contest/guidelines/