Task 3. Request for Proposals:
Mitigation of Evaporation in Mine Tailings Storage Facilities

Proposed and sponsored by Freeport-McMoRan

Background

Freeport-McMoRan (FMI) is challenging your team to help preserve the nation's fresh water supply as you develop new, innovative technologies to reduce water evaporation in mine-tailings storage facilities.

Mine Tailings Storage Facilities

Copper mine tailings are the result of the copper beneficiation process as metals are recovered from their ores. When processing copper ore, the rock is mined and then finely ground (milled) to liberate the copper minerals from the host rock. These fines are then mixed with water and moved as a slurry through the ore-recovery process that may include adding quick lime, surfactants, anti-scalants and flotation reagents**.** After the valuable minerals are removed, the slurry of remaining host rock + water (the tailings) is sent to large-scale tailings storage facilities (TSFs) for long-term disposition and management. The tailings slurry that is delivered to the TSF is approximately 50% sediment and 50% water on a volume basis.

TSFs are engineered to safely store tailings, reclaim the water from the slurry, and limit adverse impacts to groundwater resources. Their designs vary widely around the world due to local climate, geomorphology, and other factors. Guidelines governing safe operating parameters are set forth in the Global Industry Standard on Tailings Management [1].

The descriptions of TSFs that follow are specific to the arid U.S. Southwest, since it is the location of interest for this task. Although there are wide variations even within FMI's TSFs in the Southwest, we can outline general features. The slurry is delivered to a pond in the center of the TSF through a series of pipes having outlets positioned along its perimeter. As the slurry flows toward the pond, sediments begin to settle out, with the coarsest (and well-draining) sediments being deposited near the perimeter and finer sediments (water-retaining) naturally settling near the center of the pond. After the sediment settles out of the water, the remaining supernatant (clear) water forms a pond on the surface of the TSF [Figure 1]. Note that as additional tailings are added to the TSF, the pond and tailings facility progressively increases in elevation. Periodically, the supernatant water is collected and recycled back into the milling process, resulting in water-depth fluctuations in the pond area.

This task assumes an upstream construction method in which a starter dam is constructed around the perimeter of the TSF. As more tailings are added, new step-in construction is added, incorporating a "lift" of an additional 8' – 10' in height of the dam with as each successive lift dam is added [2]. Figure 1 illustrates the starter dam at the base and raise construction progressively stepped in toward the center of the TSF. Note that the ponds are designed to maintain required water flow patterns and rates.

Factors that create challenges to operations include large surface areas of the TSFs (many over 1000 acres) and relatively small pond surface areas (they may be less than 10% of the total area of the TSF). Distances from the perimeter banks of the TSF to the pond may exceed one mile. To further complicate the issue, the pond basin is difficult to navigate. The sediments directly below and immediately surrounding the supernatant pond are mostly silts and clays that have low permeability, making the pond basin an unstable, saturated, muddy slurry that may have significant water content. Thus, any operations near the pond, including collecting the supernatant water for recycling, are challenging. To access the water for recycling, floating-barge pumping systems are usually used to recover the water and deliver it to the ore-recovery process for reuse via pipeline.

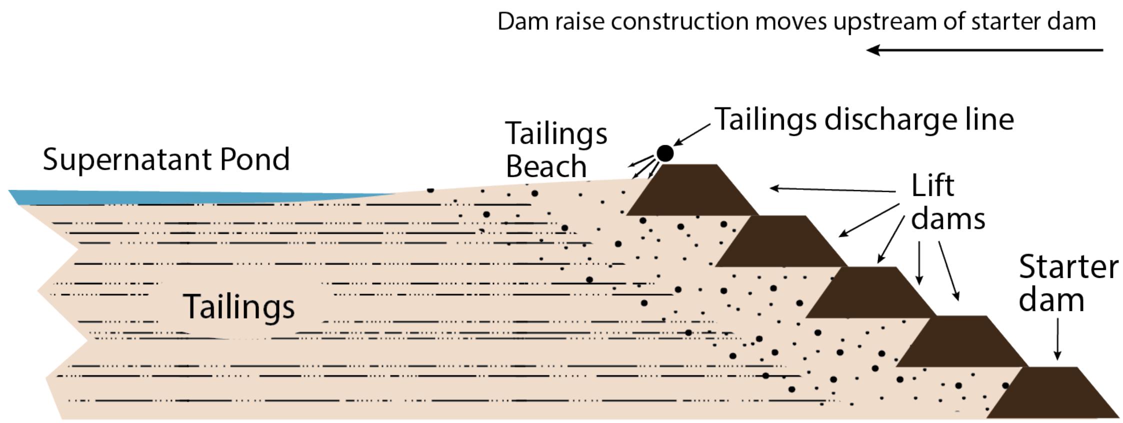

Figure 1. Cross-section of TSF illustrating the upstream construction method.

Mitigating Water Loss

Many Freeport-McMoRan (FMI) operations are in the arid U.S. Southwest, making water conservation and reuse critical to the sustainability of mining operations. Therefore, FMI is seeking new, innovative technologies that will decrease evaporation thereby increasing water recovery for reuse. This would ultimately translate to a more environmentally sustainable processing system that conserves fresh water supplies, reduces impacts on existing operations, and reduces operating costs. Rain harvesting efforts are already in place at FMI sites. Therefore, teams are asked to focus on mitigating losses due to evaporation.

Large quantities of water are stored and managed as part of the design and operation of TSFs. When developing a sense of scale, teams are urged to research mines in the arid U.S. Southwest, such as the Morenci and Bagdad Mines in Arizona and the Chino Mine near Hurley, New Mexico.

Data that may be helpful includes an approximate evaporation loss of 6 feet/year based on WRCC data for Arizona and New Mexico [3], reclaimed pond water quality [Table 1], and meteorological data for the area collected January – December 2021. The meteorological data can be downloaded from the WERC website (See Task 3 box, WERC website) [4].

Considerations and Constraints

Teams are asked to seek innovative technologies and not re-use solutions that have been previously implemented. Solutions to reduce evaporation should not adversely affect chemistry in the mill. As examples, (although not an exhaustive list of prohibited items) teams must not introduce any type of oils (e.g., petroleum lubricants, greases, etc., or hydrocarbon-based substances) or dissolved inorganic chemicals that may affect copper recovery in the mill, such as dissolved iron.

Table 1. Copper Mine Tailings Storage Facility - Reclaim Pond Water Quality.
Assume that all metal ions in solution (such as Al, Cu, Hg, Zn, etc.) not listed below are at a concentration of less than 0.01 mg/L

Bicarbonate as $Ca(HCO_3)_2$	(mg/L)	30
Calcium	(mg/L)	680
Carbonate as CaCO3	(mg/L)	<2
Chloride	(mg/L)	292
Fluoride	(mg/L)	3
Magnesium	(mg/L)	87.7
Nitrate/Nitrite as N	(mg/L)	3.09
Potassium	(mg/L)	55.5
Sodium	(mg/L)	286
Sulfate	(mg/L)	2090
Total Alkalinity	(mg/L)	30
Cation-Anion Balance	(%)	2.4
Conductivity @ 25C	(micromhos/cm)	4220
Hardness as CaCO3	(mg/L)	2060
pH	(S.U.)	7.4
Total Dissolved Solids	(mg/L)	3700

Request for Proposals—Problem statement

Your team will research, evaluate, design, and demonstrate a technology for reducing evaporation at Freeport-McMoRan TSFs in the arid U.S. southwest for a mill that operates at a rate of 100,000 metric tons of mine ore processed, with the same rate being delivered as tailings to the TSF. Your design should:

1. Be innovative.
2. Maintain compatibility with current storage facility design and operations.
    a. Not adversely affect water chemistry
    b. Not alter existing FMI-designed pond size, geometry, or depth. The ponds have been designed to maintain required water flow patterns and rates.
3. Require minimal maintenance and allow for implementation over a muddy substrate.
4. Be cost effective. Your team should examine the cost vs. amount of water estimated to be saved or recycled. Basically, how much "bang for the buck" can a mining company expect to realize if the proposed technology were implemented? Assume the average cost of water to be $500 per acre-foot.
5. Work within safety guidelines for tailings management (See [3]).

Design Parameters:

Your proposed design should provide specific details and outcomes as follows.

- Present an innovative technology for reducing evaporation in a full-scale TSF that operates at a rate of 100,000 metric tons of mine ore processed, with that same rate being delivered as tailings to the TSF.
- Assume an evaporation rate of 6 feet/year.
- Include a process-flow diagram of your solution, complete with mass and energy balances.
- Maintain existing parameters: the solution should not adversely affect water quality or alter water flow patterns or rates.
- Allow for TSF conditions: Tailings surface elevations will rise over time; windy conditions can exist.
- Take into account water analyses data, weather data, and mill operational information provided by FMI in this document and on the WERC website.
- Address any waste products or by-products that may be produced.
- Present a Techno-Economic Assessment and Analysis (TEA) to construct a full-scale evaporation mitigation process. State the number of feet per year of water conserved and the related cost savings as a result of your technology.
    - The TEA will include your estimate of capital costs (CAPEX) and operational costs (OPEX) for a full-scale solution and appropriate graphical representation of your cost data.
    - Include a financial analysis of any potential by-product or secondary beneficial use associated with your design.
    - Assume the cost of water to average $500 per acre-foot.
    - Capital expenses typically include, but are not limited to, equipment, pipes, pumps, etc. Do not include costs of buildings and appurtenances to the treatment process.
    - Operating expenses should be calculated on an annual basis for the full-scale process including, but not limited to:
        - Materials needed, including consumables (chemicals, sacrificial components, etc.)
        - Operating costs: In addition to other operating costs that your team identifies, include these operating costs: staff labor rate of $70/hour; solids disposal costs ($50/ton); energy requirements (cost/yr and Kwh/yr): research an industrial natural gas rate and state in $/MM BTU; use an electricity rate of $0.10/kWh.
    - Visualization tools: Sensitivity analyses, etc.
    - Teams are advised to create a multi-disciplinary team by inviting a business major to help draw up economic plans for full-scale implementation of your designs.
- Include a Public Involvement Plan, if applicable (see Team Manual).
- Address safety aspects of operating your technology. Safety issues for both the full-scale design and the bench-scale demonstration should be addressed in both the written report and the Experimental Safety Plan (ESP).
- To be considered for the WERC P2 Award, in a separate section of the report (titled "Pollution Prevention"), document success in improving energy efficiency, pollution prevention, and/or waste minimization, as it applies to your project.
- Discuss the intangible benefits of your team's solution, if any.

Bench Scale Demonstration
Bench-scale demonstrations will serve to illustrate the design considerations listed above. The bench-scale setup should demonstrate your team's evaporation mitigation technology.

Synthetic Solution: At the contest, your team will be provided with a synthetic solution representing the average water chemistry found in TSF ponds. To make the synthetic solution, WERC will use the source chemicals and amounts listed in Table 2.

Volume of Synthetic Solution: The volume of water provided will be determined later by WERC, with consideration made to team's ESPs. Watch the FAQs for this task.

Special ESP Requirements: In the ESP, specify your team's plans for the bench-scale demonstration, including volume of water needed and plans for an evaporation pan or other water containment during the demonstration.

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.

Analytical Testing at the contest

- Each team will be provided with water representing the water in FMI's supernatant ponds (Table 2).
- Your team's bench-scale set-up will be operated at the contest for a minimum of two days after which time evaporation rates will be measured by WERC staff.
- Results will be measured against a control pan having no mitigation measures.
- Success in reducing evaporation will be measured by a method to be determined (Watch task FAQs for details).

Table 2. Synthetic Solution for TSF waters.

Constituent	Desired Range (mg/L)	Source Chemical	Amount added per L of water	Resulting Concentration (mg/L)
Calcium	450 - 700	CaO (lime)	0.77	550
Chloride	130 - 300	NaCl (salt)	0.41*	200
Sodium	140 - 530	NaCl (salt)	*	160
Sulfate	1600 - 2500	$MgSO_4$ (epsom salt)	2.5	2000
TDS	2300 - 3900	N/A	N/A	3680 (approximate)
pH	7.0 - 8.3	HNO_3 (nitric acid)	as needed	—

* The amount of NaCl added for "Chloride" also contributes the sodium needed in the final solution.

30% Project Review
Suggested submission date: Feb. 6, 2023
Final submission date: February 24, 2023

An engineering "30% Project Review" reviews the preliminary design and aspects of a project with a client. It provides the client an opportunity to suggest modifications for inclusion in the final design. The goal is to define the scope of the project, present a project schedule, report progress to date to meet the final deadline, and determine fatal flaws, if any.

For the design contest, the review should not exceed four pages. Submit the project review as soon as possible. You are allowed to change your plans after submitting it. Although the review is not scored, your team will receive feedback from the judges for improving your project.

At a minimum, the review must include:

- **A brief description of your project:** One bulleted list outlining: goals, planned solution to the problem, and any anticipated drawbacks.
- **A project schedule** (schedule for completion of the contest solution, including progress to date)
- **Process flow diagram** with all mass and energy balances, as needed.
- **Table of Contents** planned for the technical report (place topics in order, one line per topic)

Experimental Safety Plan (ESP)
The ESP outlines your team's plans for safely operating your bench-scale demonstration at the contest. This document is submitted in February (see dates below). Instructions are provided in the team manual. The Team Leader, or a designated team member, shall attend a mandatory short course that outlines the ESP process. Teams will not be able to run a bench-scale demonstration if the ESP is not received by the deadline. Your team should follow your school's safety procedures while conducting tests prior to attending the contest.

Evaluation Criteria
Each team is advised to read the 2023 Team Manual for a comprehensive understanding of the contest evaluation criteria. As described in the manual, there are five events: a written report, a formal oral presentation, a demonstration of your technology using a bench-scale representation, a poster presentation, and a Flash Talk. Criteria used by the judges in evaluation of these five components are described in the Team Manual.

For a copy of the Team Manual, Public Involvement Plan, and other important resources, visit the WERC website: Guidelines | werc.nmsu.edu

Your response to the problem statement will be evaluated on the following points.

- Potential for real-life implementation, effectiveness in reducing evaporation rates, ease of use, cost savings, expected reliability, and maintainability of your technology.
- Thoroughness and quality of the process-flow diagram.
- Thoroughness and quality of the economic analysis.
- Originality and innovation represented by the proposed technology.
- The results of your bench-scale demonstration. In particular, demonstrable and significant reduction of evaporation rates.
- Other specific evaluation criteria that may be provided at a later date (check FAQs online regularly).

Short Courses

WERC will offer two short courses for the 2023 contest:

- ***Mandatory:*** Preparing the Experimental Safety Plan. The Team Leader, or a person assigned by them, must attend the course prior to submitting the ESP (and before February 20, 2023).
- ***Optional:*** Environmental Health and Safety (EH&S). The course is designed to prepare teams to complete the EH&S portion of their technical report. Course fees will be waived for contest-registered students, faculty, and judges. Watch the WERC website for schedules and registration information. Individuals who complete the course can earn a digital badge to add to their professional development portfolio.

Dates, Deadlines, FAQs (*dates subject to change—watch website FAQs*)

- Today: Email us to let us know you are interested in this task. We will contact you with breaking news.
- Opening mid-December 2022: Optional Course: WERC Safety and Environmental Topics. Live— See website & Team Manual for more information, including dates and times.
- Opening mid-December, 2022: Mandatory Course: Preparing the Experimental Safety Plan. February 20, 2023: deadline for attending. On-demand—See website & Team Manual for information.
- February 6 - 24, 2023: 30% Project Review due.
- February 6 - 24, 2023: Experimental Safety Plan (ESP) due.
- April 5, 2023: Technical Report due
- Weekly: Check FAQs weekly for updates:
  - Task-specific FAQs: 2023 Tasks/Task FAQs
  - General FAQs: 2023 General FAQs
- All dates and task requirements are subject to change. Check FAQs for updates online.

References

[1] Global Industry Standard on Tailings Management – Global Tailings Review
https://globaltailingsreview.org/

[2] Jon Engels. Conventional Impoundment Storage – The Current Techniques
https://tailings.info/disposal/conventional.htm

[3] Western Regional Climate Center. WRCC: Comparative Table (dri.edu)

[4] Meteorological data for US Desert Southwest, 2021 (See WERC website, Task 3 box).