GIANT MINE
Oversight Board

Box 1602 . 5014-50th Avenue . Yellowknife, NT X1A 2P2
Phone 867.675.0788 . **Fax** 867.675.0789 . **Web** www.gmob.ca

Giant Mine Oversight Board Research Program

TERRE-NET
2020 (Year 2)
Summary Report

2020 01 20

Year 2 Q2 Progress Report
Remediation Strategies for the Long-term Management of Arsenic-trioxide-bearing Roaster Wastes at the Giant Mine, Northwest Territories

This report was prepared by Toward Environmentally Responsible Resource Extraction Network (TERRE-NET) personnel to provide an update through the Year 2 Q2 (to September 30, 2020) of the main aspects of the TERRE-NET-GMOB research project and to identify any research and budget challenges experienced to date. The research projects reviewed herein include:

Project 1: Examination of arsenic trioxide dust composition and solubility
Project 2: Sulfidation of As_2O_3 to low-solubility arsenic sulfide (As_2S_3)
Project 3: Incorporation of As_2O_3 into cemented-paste backfill
Project 4: Leaching behaviour and geochemical stability of vitrified arsenical glass

The overall goals of the four projects proposed within Phase 1 are to: provide an enhanced understanding of the physical and geochemical properties of the roaster waste; and screen for potentially viable remediation alternatives that may warrant additional research (*e.g.*, long-term laboratory experiments, pilot-scale trials).

The total combined budget of the proposed research activities within Phase 1 is $931,731 and Year 2 expenditures to end of Q2 are briefly summarized in the report (including for the Administrative portion of the project). Phase 1 projects will provide direct stipend support for the training of six highly-qualified personnel (HQP), including two MSc students, one PhD student, two Post-doctoral Fellows (PDFs), and one undergraduate summer student. HQP will be supported by the TERRE-NET co-investigators and administrative and technical staff, and academic collaborators.

Project 1: Examination of arsenic trioxide dust composition and solubility

Investigators:
Joyce McBeth (University of Saskatchewan)
Matthew Lindsay (University of Saskatchewan)
Heather Jamieson (Queen's University)
Jullieta Lum (University of Saskatchewan)

1.1 Research update

Our research aims to (i) improve understanding of arsenic (As) and antimony (Sb) geochemistry in arsenic trioxide roaster waste (ATRW) from the Giant Mine and (ii) assess effects of Sb substitution for As in arsenolite [As_2O_3] – a major component of ARTW – on its solubility. The work is primarily being conducted by Jullieta Lum (PDF).

Characterization of nine ATRW samples has been completed to assess geochemical and mineralogical heterogeneity and to identify As and Sb host phases. Our research integrates complementary analytical techniques including X-ray diffraction (XRD), X-ray fluorescence (XRF), transmission electron microscope-selective area energy diffraction (TEM-SAED), and TEM-energy dispersive X-ray spectroscopy (TEM-EDS). These results have been supplemented with X-ray absorption spectroscopy (XAS) to determine the speciation and coordination of As and Sb in the ATRW samples.

Following reinstatement of laboratory access, TEM-SAED and TEM-EDS analyses has been conducted to constrain morphology, crystallinity, and chemistry at micrometer to nanometer scale. These new analyses, coupled with previous results, are the basis for a manuscript documenting the geochemical and mineralogical heterogeneity of the ATRW samples, and on the host phases and forms of As and Sb in these samples. This information will improve understanding ARTW stability and the long-term potential for As mobilization in both management and environmental contexts. Additionally, these findings should inform research into alternative stabilization approaches. We anticipate that this manuscript will be ready for GMOB review early in 2021.

Experimental research focused on Sb substitution for As in As_2O_3 has also been ongoing since laboratory access was reinstated. Sb-bearing As_2O_3 materials have been successfully synthesized using modified low temperature methods, and solubility experiments using these solids are underway. We submitted a "special request" proposal to the Brockhouse beamlines at the Canadian Light Source synchrotron to perform high energy X-ray diffraction and pair distribution function (PDF) analyses. We will couple these results to laboratory-based XRD analyses. These data are being modelled to gain insight into As-Sb bonding characteristics and identify structural changes initiated by incorporation of Sb into the As_2O_3 crystal structure. This information will be incorporated with solubility experiment results to constrain the relationship between Sb substitution and As_2O_3 solubility.

In addition to material synthesized at low temperatures, experiments have also been conducted experiments to assess solid-state methods for synthesis of As_2O_3 with a wider range of Sb contents. These experiments were initiated to produce material comparable to Giant Mine As_2O_3 phases generated from roasting at high temperatures. These materials will be used for solubility experiments examining the impact of variable Sb concentrations on As_2O_3 solubility. Jullieta has carried out kinetic solubility experiments on pure As_2O_3 and Sb_2O_3 phases under anoxic conditions.

Recent efforts have been focused on finalizing the first manuscript and will resume solubility experiments using synthesized phases and ATRW samples in January 2021.

1.2 Deviations from research plan

During the period of COVID-19 associated laboratory access restrictions (approximately March 2020 to July 2020), research activities were re-aligned to prioritize data processing and experimental planning to minimize the impacts of laboratory closures. On-campus research resumed in July 2020. During the access restricted period processing of XRD, XRF, and XAS data was completed. Interpretations ensuing from this work have been presented at the Goldschmidt 2020 conference (June 2020, virtual), the Annual Users' Meeting of the Canadian Light Source (November 2020), and the NSERC TERRE-NET Annual General Meeting (December 2020).

1.3 Budget update

The total proposed budget for this research in Year 2 is $93,960, including $75,168 for direct research costs plus 25% overhead ($18,792) charged by the University of Saskatchewan (Table 1).

Table 1. Summary of budget proposed and actuals for Year 2.

	Year 2 Budget	Year 1 C'fwd	Total available Year 2	Y2 Q1 Actuals Apr1-Jun30	Y2 Q2 Actuals Jul1-Sep30	Y2 Q3 Actuals Oct1-Dec31	Y2 Q4 Actuals Jan1-Mar31	Year 2 Actuals Total	Total unspent Year 2
Salaries and Benefits	**$ 40,200**	**$ 28,528**	**$ 68,728**	**$ (2,327)**	**$ 16,632**	**$ -**	**$ -**	**$ 14,305**	**$ 54,423**
a) PhD students	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
b) Master's students	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
c) Undergraduate students	$ 5,450	$ 4,800	$ 10,250	$ (2,327)	$ 414	$ -	$ -	$ (1,913)	$ 12,163
d) Postdoctoral fellows	$ 31,000	$ 16,228	$ 47,228	$ -	$ 16,218	$ -	$ -	$ 16,218	$ 31,010
e) Technical/Professional Assistants	$ 3,750	$ 7,500	$ 11,250	$ -	$ -	$ -	$ -	$ -	$ 11,250
Equipment	**$ 26,120**	**$ 23,743**	**$ 49,863**	**$ 340**	**$ 383**	**$ -**	**$ -**	**$ 723**	**$ 49,140**
a) Purchase or rental	$ 2,400	$ 2,368	$ 4,768	$ -	$ -	$ -	$ -	$ -	$ 4,768
b) Operation and maintenance costs	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
c) User Fees	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
d) Analytical Costs	$ 23,720	$ 21,376	$ 45,096	$ 340	$ 383	$ -	$ -	$ 723	$ 44,373
Materials and Supplies	**$ 4,298**	**$ 1,293**	**$ 5,591**	**$ 467**	**$ (2,299)**	**$ -**	**$ -**	**$ (1,832)**	**$ 7,423**
a) Laboratory supplies, reagents	$ 4,298	$ 1,293	$ 5,591	$ 467	$ (2,299)	$ -	$ -	$ (1,832)	$ 7,423
b) Machining costs	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Travel	**$ 4,550**	**$ 4,550**	**$ 9,100**	**$ -**	**$ 387**	**$ -**	**$ -**	**$ 387**	**$ 8,713**
a) Conferences and Workshops	$ 2,550	$ 2,550	$ 5,100	$ -	$ 387	$ -	$ -	$ 387	$ 4,713
b) Field Work	$ 2,000	$ 2,000	$ 4,000	$ -	$ -	$ -	$ -	$ -	$ 4,000
Dissemination	**$ -**	**$ -**	**$ -**	**$ -**	**$ -**	**$ -**	**$ -**	**$ -**	**$ -**
a) Publication costs	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
b) Communication costs (teleconference)	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Subtotal	**$ 75,168**	**$ 58,114**	**$ 133,282**	**$ (1,520)**	**$ 15,103**	**$ -**	**$ -**	**$ 13,583**	**$ 119,699**
University Overhead (25%)	**$ 18,792**	**$ 14,529**	**$ 33,321**	**$ (380)**	**$ 3,776**	**$ -**	**$ -**	**$ 3,396**	**$ 29,925**
Grand Total	**$ 93,960**	**$ 72,643**	**$ 166,603**	**$ (1,900)**	**$ 18,879**	**$ -**	**$ -**	**$ 16,979**	**$ 149,624**

1.4 Deviations from budget

Primary deviations from the budget include a lower level of salary and equipment disbursements due to the slightly delayed start of the project. A 6-month extension for Project 1 has been requested (revised end date: June 30, 2021).

Project 2: Sulfidation of As_2O_3 to form low-solubility As_2S_3

Investigator:
Tom Al (University of Ottawa)

2.1 Research update

The purpose of this project is to explore methods to transform As_2O_3-rich dust to a low solubility As_2S_3 material that is stable in an anaerobic environment such as deep in the mine. One goal is to identify a sulfide source for sulfidation; the considered sources are $Na_2S{\cdot}9H_2O$, H_2S gas, and elemental sulfur (S^0). The second goal is to investigate the dissolution rate of As_2O_3. Because of the required large-scale implementation, optimal reaction conditions are being explored to allow for full conversion of the As_2O_3-rich dust to As_2S_3. The work is being conducted by two researchers: Evelyn Tennant (MSc) and Erika Revesz (PhD chemist).

To evaluate the use of S^0 and suitable reagents and experimental conditions to generate H_2S, a reliable quantitative method for the determination of sulfide is being investigated. Uncertainties with the potentiometric method (using a sulfide ion – selective electrode) due to differences in ionic strength, the presence of interfering ions, and non-linearity of the calibration curve prompted investigation of other methods for the determination of sulfide. Two other methods, including the Cline method (involving the formation of a methylene-blue sulfide complex followed by the spectrophotometric measurement of the absorbance) and a gravimetric method (involving the precipitation of sulfide as CuS with subsequent isolation and weighing) have been investigated.

Quantitative experiments were carried out with Na_2S and HCl to compare the spectrophotometric and the potentiometric methods.

Methods for generating H_2S are being investigated simultaneously with the above-described sulfide measurement methods. Reactions to generate H_2S from S^0 and organic forms of carbon include methane (CH_4) as a necessary reactant. The industrial production of CH_4 from C (*e.g.*, charred sawdust) is feasible because the transformation at high temperature is efficient; however, where CH_4 (*i.e.*, natural gas) is readily available in large quantities it is a more direct approach for production of H_2S. Sulfide production experiments using charred sawdust and S^0 reacted in an acidic system to create a CH_4 intermediate, followed by generation of H_2S have been conducted. To date, experiments with sawdust have resulted in only trace amounts of H_2S. Work is continuing to optimize the conditions and test other catalysts to achieve a higher H_2S yield.

Initially, the second objective of this project was to react aqueous sulfide directly with As_2O_3 to create a low-solubility As_2S_3 reaction product. The results indicated that the reaction rate was very slow due to the formation of a passivating surface coating. In response, the second objective was revised to investigate methods to rapidly dissolve the As_2O_3-rich dust in preparation for subsequent reaction with sulfide. The following specific tasks are underway:

- Characterization of the composition of the Giant Mine ATRW that will be used for ongoing experiments (sample B233-P9)
- Determine the dissolution rate of the Giant Mine ATRW under variable temperature, pressure, time, and pH conditions using a microwave digestion system
- Isolate and characterize residues remaining after attempts to dissolve the Giant Mine ATRW

Sample B233-P9 was selected because it has anomalously high Sb content, which has been shown to lower the solubility and perhaps also the dissolution rate; sample B233-P9 should provide a worst-case assessment of the challenges to be overcome to effectively dissolve the Giant Mine ATRW. Characterization of sample B233-P9 is underway using ICP-OES and SEM. Reagent-grade As_2O_3 represents a benchmark for comparison; the initial experiments have been conducted to determine the

extent of dissolution of reagent-grade As_2O_3 at elevated temperatures. Similar experiments will follow using Giant Mine material.

2.2 Deviations from research plan

Access to laboratory facilities at University of Ottawa has been restored and laboratory experiments are continuing. As documented in Section 2.1, the initial second objective of this project was to react aqueous sulfide directly with As_2O_3 to create a low-solubility As_2S_3 reaction product. The results indicated that the reaction rate was very slow due to the formation of a passivating surface coating. In response, the second objective was revised to investigate methods to rapidly dissolve the As_2O_3-rich dust in preparation for subsequent reaction with sulfide.

2.3 Budget update

The total proposed budget for this research program in Year 2 is $51,100, including $36,500 for direct research costs plus 40% overhead ($14,600) charged by the University of Ottawa (Table 2).

Table 2. Summary of budget proposed and actuals for Year 2.

	Year 2 Budget	Year 1 C'fwd	Total available Year 2	Y2 Q1 Actuals Apr1-Jun30	Y2 Q2 Actuals Jul1-Sep30	Y2 Q3 Actuals Oct1-Dec31	Y2 Q4 Actuals Jan1-Mar31	Year 2 Actuals Total	Total unspent Year 2
Salaries and Benefits	**$ 21,000**	**$ 10,096**	**$ 31,096**	**$ 11,783**	**$ 7,288**	**$ -**	**$ -**	**$ 19,071**	**$ 12,025**
a) PhD students	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
b) Master's students	$ 21,000	$ 21,000	$ 42,000	$ 3,500	$ 5,523	$ -	$ -	$ 9,023	$ 32,977
c) Undergraduate students	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
d) Postdoctoral fellows	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
e) Technical/Professional Assistants	$ -	$ (10,904)	$ (10,904)	$ 8,283	$ 1,765	$ -	$ -	$ 10,048	$ (20,952)
Equipment	**$ 4,000**	**$ (22,374)**	**$ (18,374)**	**$ -**	**$ 615**	**$ -**	**$ -**	**$ 615**	**$ (18,989)**
a) Purchase or rental	$ -	$ (26,374)	$ (26,374)	$ -	$ -	$ -	$ -	$ -	$ (26,374)
b) Operation and maintenance costs	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
c) User Fees	$ 2,500	$ 2,500	$ 5,000	$ -	$ -	$ -	$ -	$ -	$ 5,000
d) Analytical Costs	$ 1,500	$ 1,500	$ 3,000	$ -	$ 615	$ -	$ -	$ 615	$ 2,385
Materials and Supplies	**$ 7,000**	**$ 5,955**	**$ 12,955**	**$ 540**	**$ 327**	**$ -**	**$ -**	**$ 867**	**$ 12,088**
a) Laboratory supplies, reagents	$ 5,000	$ 3,955	$ 8,955	$ 540	$ 327	$ -	$ -	$ 867	$ 8,088
b) Machining costs	$ 2,000	$ 2,000	$ 4,000	$ -	$ -	$ -	$ -	$ -	$ 4,000
Travel	**$ 2,500**	**$ 2,500**	**$ 5,000**	**$ -**	**$ -**	**$ -**	**$ -**	**$ -**	**$ 5,000**
a) Conferences and Workshops	$ 2,500	$ 2,500	$ 5,000	$ -	$ -	$ -	$ -	$ -	$ 5,000
b) Field Work	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Dissemination	**$ 2,000**	**$ -**	**$ 2,000**	**$ -**	**$ -**	**$ -**	**$ -**	**$ -**	**$ 2,000**
a) Publication costs	$ 2,000	$ -	$ 2,000	$ -	$ -	$ -	$ -	$ -	$ 2,000
b) Communication costs (teleconference)	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Subtotal	**$ 36,500**	**$ (3,823)**	**$ 32,677**	**$ 12,323**	**$ 8,230**	**$ -**	**$ -**	**$ 20,553**	**$ 12,124**
University Overhead (40%)	**$ 14,600**	**$ (1,529)**	**$ 13,071**	**$ 4,929**	**$ 3,292**	**$ -**	**$ -**	**$ 8,221**	**$ 4,850**
Grand Total	**$ 51,100**	**$ (5,352)**	**$ 45,748**	**$ 17,252**	**$ 11,522**	**$ -**	**$ -**	**$ 28,774**	**$ 16,974**

2.4 Deviations from budget

This project is currently on budget in Year 2. Slight overspending in Equipment – User Fees has been off set by under-spending in other categories. A 3-month extension for Project 2 has been requested (revised end date: September 30, 2022).

Project 3: Stabilization of As_2O_3 dust in cemented paste backfill

Investigators:
Isabelle Demers (UQAT)
Nick Beier (University of Alberta)
Mostafa Benzaazoua (UQAT; collaborator)

3.1 Research update

To evaluate the effectiveness of As stabilization through incorporation within cemented paste backfill (CPB), Amirhossein Mohammadi (PhD) has been recruited and started at UQAT in May 2020. The student is currently conducting a literature review and developing an experimental plan. As_2O_3 dust samples and tailings samples from the Giant mine were received at UQAT and UA (tailings only) during the summer 2020. Initial characterization was initiated and should be completed by the end of 2020. Preliminary CPB recipes are in preparation with inert material (silica), As_2O_3 dust and binders to assess the interaction between As_2O_3 and binders.

The University of Alberta components of this project are scheduled to start in Year 3.

3.2 Deviations from research plan

The laboratory facilities at UQAT were closed due to COVID-19 restrictions until mid-summer 2020, while the experimental portion of the project was planned to begin on May 1. A project delay of 4 to 6 months is expected; due to slower laboratory work practices and delays in shipment of binders and laboratory reagents. Amirhossein Mohammadi is currently advancing in his required course load; received all health and safety training, and began working on characterization and preliminary CPB recipes.

3.3 Budget update

The total proposed budget for this research in Year 2 is $60,548, including $52,650 for direct research costs plus 15% overhead ($7,898) charged by UQAT (Table 3).

Table 3. Summary of budget proposed and actuals for Year 2.

	Year 2 Budget	Year 1 C'fwd	Total available Year 2	Y2 Q1 Actuals Apr1-Jun30	Y2 Q2 Actuals Jul1-Sep30	Y2 Q3 Actuals Oct1-Dec31	Y2 Q4 Actuals Jan1-Mar31	Year 2 Actuals Total	Total unspent Year 2
Salaries and Benefits	**$ 28,900**	**$ 24,713**	**$ 53,613**	**$ 9,407**	**$ 10,362**	**$ -**	**$ -**	**$ 19,769**	**$ 33,844**
a) PhD students	$ 24,000	$ 19,813	$ 43,813	$ 9,407	$ 7,462	$ -	$ -	$ 16,869	$ 26,944
b) Master's students	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
c) Undergraduate students	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
d) Postdoctoral fellows	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
e) Technical/Professional Assistants	$ 4,900	$ 4,900	$ 9,800	$ -	$ 2,900	$ -	$ -	$ 2,900	$ 6,900
Equipment	**$ 20,000**	**$ 6,250**	**$ 26,250**	**$ -**	**$ -**	**$ -**	**$ -**	**$ -**	**$ 26,250**
a) Purchase or rental	$ -	$ 1,250	$ 1,250	$ -	$ -	$ -	$ -	$ -	$ 1,250
b) Operation and maintenance costs	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
c) User Fees	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
d) Analytical Costs	$ 20,000	$ 5,000	$ 25,000	$ -	$ -	$ -	$ -	$ -	$ 25,000
Materials and Supplies	**$ 250**	**$ 250**	**$ 500**	**$ -**	**$ 208**	**$ -**	**$ -**	**$ 208**	**$ 292**
a) Laboratory supplies, reagents	$ 250	$ 250	$ 500	$ -	$ 208	$ -	$ -	$ 208	$ 292
b) Machining costs	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Travel	**$ 3,000**	**$ -**	**$ 3,000**	**$ -**	**$ -**	**$ -**	**$ -**	**$ -**	**$ 3,000**
a) Conferences and Workshops	$ 3,000	$ -	$ 3,000	$ -	$ -	$ -	$ -	$ -	$ 3,000
b) Field Work	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Dissemination	**$ 500**	**$ -**	**$ 500**	**$ -**	**$ -**	**$ -**	**$ -**	**$ -**	**$ 500**
a) Publication costs	$ 500	$ -	$ 500	$ -	$ -	$ -	$ -	$ -	$ 500
b) Communication costs (teleconference)	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Subtotal	**$ 52,650**	**$ 31,213**	**$ 83,863**	**$ 9,407**	**$ 10,570**	**$ -**	**$ -**	**$ 19,977**	**$ 63,886**
University Overhead (15%)	**$ 7,898**	**$ 4,682**	**$ 12,579**	**$ 1,411**	**$ 1,586**	**$ -**	**$ -**	**$ 2,997**	**$ 9,583**
Grand Total	**$ 60,548**	**$ 35,895**	**$ 96,442**	**$ 10,818**	**$ 12,156**	**$ -**	**$ -**	**$ 22,974**	**$ 73,469**

3.4 Deviations from budget

This project started January 1, 2020; it is anticipated that underspending in Year 1 will be corrected through the duration of the project. A 1-year extension for Project 3 has been requested (revised end date: June 30, 2023).

Project 4: Geochemical and leaching characterization of vitrified arsenical glass

Investigators:
David Blowes (University of Waterloo)
Carol Ptacek (University of Waterloo)

4.1 Research update

The conversion of hazardous wastes into ceramics or vitrified products has the potential to mitigate contaminant mobility and toxicity. This approach has received significant attention in the research community over recent years. Bench-scale studies have examined the potential utility of vitrification for attenuation of contaminants associated with coal fly ash (Guzmán-Carrillo et al., 2018), metallurgical slag (Guzmán-Carrillo et al., 2018; Karamanov et al., 2018), asbestos-bearing wastes (Iwaszko et al., 2018), and fly ash derived from the incineration of medical wastes (Stoch et al., 2018; Tsakalou et al., 2018). In addition, vitrification has been identified as a solution for the long-term disposal of low- and high-level nuclear wastes (*e.g.*, Kim & Kruger, 2018).

Incorporation of reagent-grade arsenic compounds into vitrified products, including As_2O_3 and sodium arsenate (Na_3AsO_4), has been demonstrated under laboratory conditions (*e.g.*, Shi et al., 2015; Zhao et al., 2016, 2017). However, knowledge gaps exist in the scientific literature surrounding the long-term stability of vitrified arsenical glass, and the vitrification of arsenic-bearing industrial residues that are not derived from pure-phase, reagent-grade compounds.

4.2 Deviations from research plan

The vitrified material required for this project has not been received at UW resulting in a project start delay. In addition, access to laboratory facilities at UW is currently limited due to COVID-19 restrictions. It is not expected that laboratory facilities will be accessible before January 1, 2021 resulting in a Project 4 delay of approximately 1 year.

4.3 Budget update

The total proposed budget for this research in Year 2 is $0 as the Year 2 budget has been deferred to Year 3 (Table 4).

Table 4. Summary of budget proposed and actuals for Year 2.

	Year 2 Budget*	Year 1 C'fwd	Total available Year 2	Y2 Q1 Actuals Apr1-Jun30	Y2 Q2 Actuals Jul1-Sep30	Y2 Q3 Actuals Oct1-Dec31	Y2 Q4 Actuals Jan1-Mar31	Year 2 Actuals Total	Total unspent Year 2
Salaries and Benefits	$ -	$ 45,000	$ 45,000	$ -	$ -	$ -	$ -	$ -	$ 45,000
a) PhD students	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
b) Master's students	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
c) Undergraduate students	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
d) Postdoctoral fellows	$ -	$ 40,000	$ 40,000	$ -	$ -	$ -	$ -	$ -	$ 40,000
e) Technical/Professional Assistants	$ -	$ 5,000	$ 5,000	$ -	$ -	$ -	$ -	$ -	$ 5,000
Equipment	$ -	$ 8,000	$ 8,000	$ -	$ -	$ -	$ -	$ -	$ 8,000
a) Purchase or rental	$ -	$ 2,000	$ 2,000	$ -	$ -	$ -	$ -	$ -	$ 2,000
b) Operation and maintenance costs	$ -	$ 500	$ 500	$ -	$ -	$ -	$ -	$ -	$ 500
c) User Fees	$ -	$ 500	$ 500	$ -	$ -	$ -	$ -	$ -	$ 500
d) Analytical Costs	$ -	$ 5,000	$ 5,000	$ -	$ -	$ -	$ -	$ -	$ 5,000
Materials and Supplies	$ -	$ 10,000	$ 10,000	$ -	$ -	$ -	$ -	$ -	$ 10,000
a) Laboratory supplies, reagents	$ -	$ 10,000	$ 10,000	$ -	$ -	$ -	$ -	$ -	$ 10,000
b) Machining costs	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Travel	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
a) Conferences and Workshops	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
b) Field Work	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Dissemination	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
a) Publication costs	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
b) Communication costs (teleconference)	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Subtotal	$ -	$ 63,000	$ 63,000	$ -	$ -	$ -	$ -	$ -	$ 63,000
University Overhead (30%)	$ -	$ 18,900	$ 18,900	$ -	$ -	$ -	$ -	$ -	$ 18,900
Grand Total	$ -	$ 81,900	$ 81,900	$ -	$ -	$ -	$ -	$ -	$ 81,900

4.4 Deviations from budget

This project has not yet started funding for Year 2 has been deferred by one year. A 1-year extension for Project 4 has been requested (revised end date: June 30, 2023) due to delays in starting experiments and HQP recruitment associated with delays in receiving vitrified product from Dundee. Further delays are probable due to COVID-19 laboratory access and travel restrictions.

Administration

Investigators:
David Blowes (University of Waterloo)
Carol Ptacek (University of Waterloo)

5.1 Budget update

The total proposed budget for this research in Year 2 is $0 as the Year 2 budget has been deferred to Year 3 (Table 5).

Table 5. Summary of budget proposed and actuals for Year 2.

	Year 2 Budget*	Year 1 C'fwd	Total available Year 2	Y2 Q1 Actuals Apr1-Jun30	Y2 Q2 Actuals Jul1-Sep30	Y2 Q3 Actuals Oct1-Dec31	Y2 Q4 Actuals Jan1-Mar31	Year 2 Actuals Total	Total unspent Year 2
Salaries and Benefits	$ -	$ 24,532	$ 24,532	$ -	$ -	$ -	$ -	$ -	$ 24,532
a) PhD students	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
b) Master's students	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
c) Undergraduate students	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
d) Postdoctoral fellows	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
e) Technical/Professional Assistants	$ -	$ 24,532	$ 24,532	$ -	$ -	$ -	$ -	$ -	$ 24,532
Equipment	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
a) Purchase or rental	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
b) Operation and maintenance costs	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
c) User Fees	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
d) Analytical Costs	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Materials and Supplies	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
a) Laboratory supplies, reagents	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
b) Machining costs	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Travel	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
a) Conferences and Workshops	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
b) Field Work	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Dissemination	$ -	$ 1,000	$ 1,000	$ -	$ -	$ -	$ -	$ -	$ 1,000
a) Publication costs	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
b) Communication costs (teleconference)	$ -	$ 1,000	$ 1,000	$ -	$ -	$ -	$ -	$ -	$ 1,000
Subtotal	$ -	$ 25,532	$ 25,532	$ -	$ -	$ -	$ -	$ -	$ 25,532
University Overhead (30%)	$ -	$ 7,660	$ 7,660	$ -	$ -	$ -	$ -	$ -	$ 7,660
Grand Total	$ -	$ 33,192	$ 33,192	$ -	$ -	$ -	$ -	$ -	$ 33,192

5.2 Deviations from budget

The administration portion of the project incurred some costs in Q3 (Year 1) but has not yet fully started and funding for Year 2 has been deferred by one year. A 1-year extension for the administration portion has been requested (revised end date: June 30, 2023).