Environment and Natural Resources Trust Fund
2016 Request for Proposals (RFP)

Project Title: **ENRTF ID:** **054-B**

Engineered Biofilter for Sulfate Removal from Mine Waters

Category: B. Water Resources

Total Project Budget: $ 439,817

Proposed Project Time Period for the Funding Requested: 3 years, July 2016 to June 2019

Summary:

This project will develop an efficient, low-cost, biomass-derived adsorbent material used in bioactive filters to clean mining impacted waters from sulfate and metals for the protection of Minnesota's water resources.

Name: Sebastian Behrens

Sponsoring Organization: U of MN

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Location

Region: NE

County Name: Aitkin, Carlton, Cook, Itasca, Lake, St. Louis

City / Township:

Alternate Text for Visual:

Engineered mineral-biochar composites are an effective adsorbent for heavy metal and metal sulfides that can be used in bioactive barriers to remove sulfate and metals from contaminated mine water. Biochar is a carbon-rich solid obtained by heating biomass, such as wood or manure with little to no oxygen (pyrolysis). Its specific material characteristics make biochar a very efficient absorbent to remove pollutants from aqueous solution. The adsorption characteristics of biochar can be enhanced by blending metals with the feedstock prior to pyrolysis. The addition of biochar to biologically active filters such as bioactive barriers for sulfate and heavy metal removal will increase filter performance by retaining organic carbon, stimulating sulfate reduction, and capturing sulfide metal precipitates and dissolved metals. Metal-loaded biochars can be recycled by desorbing the metals.

_____ Funding Priorities _____ Multiple Benefits _____ Outcomes _____ Knowledge Base

_____ Extent of Impact _____ Innovation _____ Scientific/Tech Basis _____ Urgency

_____ Capacity Readiness _____ Leverage _______ TOTAL ______%

PROJECT TITLE: Engineered biofilter for sulfate removal from mine waters

I. PROJECT STATEMENT

The purpose of this research is to develop an efficient, low-cost bioactive filter to remove sulfate and metals from water. The availability of effective low cost treatment methods for sulfate and heavy metal-rich waters will **lower the environmental impact of mining in Minnesota**. The outcomes of this work will be:

(1) A mineral-enriched, biomass-derived adsorbent material (composite biochar) optimized to stimulate biological sulfate reduction and adsorption of metal sulfides and heavy metals.

(2) An effective and low-cost biochar filter to remove sulfate and toxic metals from mine waters.

(3) Application guidelines for scale-up and field implementation of the new bio-filtration technology.

The addition of engineered biochars (carbon-rich solids obtained by heating biomass with little to no oxygen in a process called pyrolysis) **to bioactive barriers containing mixtures of organic and cellulosic wastes will remove sulfate from solution by promoting microbial sulfate reduction. The produced sulfide will precipitate together with metals onto the mineral enriched-biochar and efficiently be removed from solution and retained in the reactive treatment zone of the filter.** The treatment of mine waters by bioactive filtration systems is a **low cost, broadly applicable approach for non-point source clean-up of sulfate and heavy metals from water.**

Bioactive barriers can be installed directly at mine sites or areas downstream where sulfate and metal-rich waters endanger pristine water resources. **The economic benefit of the biochar filter is that it captures valuable metals from dilute solution which can be recovered by desorption from the filter material**. In the process sulfide precipitates can be re-oxidized to produce sulfuric acid and gypsum. **Iron-enriched biochars have magnetic properties and can be recovered from solution to be re-used as "fresh" adsorbent material.**

Minnesota is currently facing the challenge to balance the economic gain of ongoing and intended mining activities in the Northeast with the potential offset by environmental damage from sulfate and toxic metals in mine discharge waters. Iron mineral mining in the State of Minnesota produces waters with high sulfate concentrations. Currently proposed non-iron, copper-nickel mining activities can even produce waters that contain besides high sulfate concentrations also elevated concentrations of toxic metals. Existing and proposed mining operations in Minnesota are located within the Mississippi River, Lake Superior, and Rainy River watersheds that comprise many pristine wetlands, floodplains, streams and lakes. Elevated heavy metal and sulfide concentrations are toxic to many plants (e.g. wild rice) and animals (e.g. lake trout) living in these impacted areas. **Bioactive barriers with an efficient, low-cost, environmentally-friendly absorbent material (biochar) are a simple solution to prevent sulfate and toxic metals to enter Minnesota's waterways.**

II. PROJECT ACTIVITIES AND OUTCOMES

Activity 1: Production of mineral-biochar composite material for heavy metal and metal sulfide sorption. **Budget: $ 143,510**

We will produce mineral oxide–enriched biochars from different feedstocks by blending waste biomass with metals prior to thermochemical decomposition of the organic material at elevated temperatures in the absence of oxygen. Biochars will be produced from green waste, woods chips, sugar beet pulp, corn stover, and mature enriched with iron and manganese. Production parameters will be optimized to make an efficient adsorbent material for heavy metals and metal sulfides. The sorption/desorption properties of the produced mineral-biochar composite materials will be evaluated.

Outcome	Completion Date
1. Production of mineral biochar composites	Dec 31, 2016
2. Optimal production parameters for most efficient contaminant sorption properties	June 30, 2017
3. Sorption/desorption properties of engineered biochars at various metal sulfide and heavy metal concentrations and temperatures	June 30, 2017

Activity 2: Determine performance of microbial sulfate reduction in the presence of engineered biochar composites. **Budget: $ 148,155**

Cultures of sulfate reducing bacteria (SRB) and anoxic lake sediments containing a mixture of indigenous sulfate-reducing microbial populations will be exposed to the engineered biochar composites in the presence of different natural organic carbon substrates in order to derive optimal conditions for sulfate reduction and metal removal. Sulfate reduction rates will be quantified over a range of biochar, sulfate, and organic carbon concentrations. The most active sulfate reducing microbial populations will be identified and quantified by next generation DNA sequencing and quantitative polymerase chain reaction.

Outcome	Completion Date
1. Determine efficiency of microbial sulfate reduction in the presence of mineral-biochar composites	Dec 31, 2017
2. Best practice to mix organic substrates (food for the bacteria) with the biochar adsorbent material to optimize bioactivity	June 30, 2018
3. Identification and quantification of most efficient sulfate reducing microbial populations	June 30, 2018

Activity 3: Construction of lab-scale bioactive filters for sulfate, heavy metal, and metal sulfide removal from mine waters. Development of field application guidelines and long-term management protocol. **Budget: $ 148,152**

We will construct laboratory scale sulfate-reducing biofilters containing mixtures of organic and cellulosic wastes and the produce engineered biochars to remove sulfate and heavy metals from mine waters. We will optimize filter performance by quantifying filter efficiency at various flow rates, sulfate, and metal concentrations. We will derive critical parameters for biofilter scale-up and field implementation in bioactive barriers. Results will be summarized in a user handbook for guidance on how to use the engineered biochars for the treatment of mine waters.

Outcome	Completion Date
1. Installation of flow-through biofilters	Dec 31, 2017
2. Quantification of filter efficiency at various flow rates, sulfate, and metal concentrations	Dec 31, 2018
3. Sorption data for effective use of engineered biochar in field scale bioactive barriers	Dec 31, 2018
4. Field application handbook on engineered biochars for water treatment	April 30, 2019

III. PROJECT STRATEGY

A. Project Team/Partners

The project team consists of the **Principal Investigator Dr. Sebastian Behrens** (Dept. of CEGE, University of Minnesota) and **project partner Dr. Kurt Spokas** (USDA-ARS; St. Paul, MN). Behrens is an expert on the microbiology of mineral-metal-biochar interactions and Spokas is an expert on the physical sorption/desorption characteristics of engineered biochars. Since Spokas is a federal employee, his participation comes at no cost to the project. The proposed research will be conducted in collaboration with Michael Berndt and Zach Wenz who are geochemists at the Minnesota Department of Natural Resources (MNDNR). The MNDNR will support the proposed project by facilitating the selection of Minnesota mine locations, also at no direct cost to the study.

B. Project Impact and Long-Term Strategy

Results from this research will be key for the MNDNR and the Minnesota Pollution Control Agency (MPCA) to use in support of the decision making process on protecting wild rice from excess sulfate and promote the development of new technologies to remove sulfate and heavy metals from waters impacted by mining operations. The long-term strategy of the project is to lower the environmental impact of mining in Minnesota and to protect Minnesota's water resources and pristine aquatic ecosystems.

C. Timeline Requirements

The proposed project will be completed in the allotted three-year period. Biochars will be produced within the first 6 months of the project followed by (de)sorption analyses and biofilter tests that are time consuming.

2016 Detailed Project Budget

Project Title: Engineered biofilter for sulfate removal from mine waters

IV. TOTAL ENRTF REQUEST BUDGET for three (3) years

BUDGET ITEM	AMOUNT
Personnel: Sebastian Behrens, Assoc. Professor, 9 month appointment, Dept. CEGE, Principle investigator, project coordination, overall technical direction, supervision and training of postdoctoral researcher and gradute student, PI asks for 6 weeks summer salary for each of the 3 years (15%), fringe rate at 33.7%	$68,518
Postdoctoral researcher (to be named), full time (100%) for each of the 3 years, fringe rate 22.4%	$171,938
Graduate student (to be named), 50% position, full time (100%) for each of the 3 years, fringe rate at 92.89% (includes tuition)	$120,316
Professional/Technical/Service Contracts: University of Minnesota Genomics Center (UMGC) - DNA sequencing, quantitative PCR -> identification and enumeration of sulfate reducing bacteria 1680 samples: 210 samples per run = 8 runs x $1500 per run	$12,000
Research Analytical Laboratory at the University of Minnesota - Inorganic chemical analyses for water, biochar composites, filter material - Ion Chromatography and Flow Injection Analysis: ammonia, nitrate, nitrite, phosphorus, sulfate and chloride; Total C/Total N Analysis: TOC, TIC, TN, ICP-OES: metals; average $ 16 per sample per analysis 425 samples x 5 = 2125 x $ 16	$34,000
Equipment/Tools/Supplies: Materials to produce biochars and construct lab-scale biofilters including pumps, tubing, fittings, valves and machining ($ 25,000); chemicals, gases, glass ware for anaerobic cultivation and filter operation ($ 5,000)	$30,000
Travel: Collecting water and sediment samples from aquatic ecosystems in NE Minnesota impacted by high sulfate and heavy metal concentrations (year 1 $1500; year 2 $1545)	$3,045
TOTAL ENVIRONMENT AND NATURAL RESOURCES TRUST FUND $ REQUEST =	$439,817

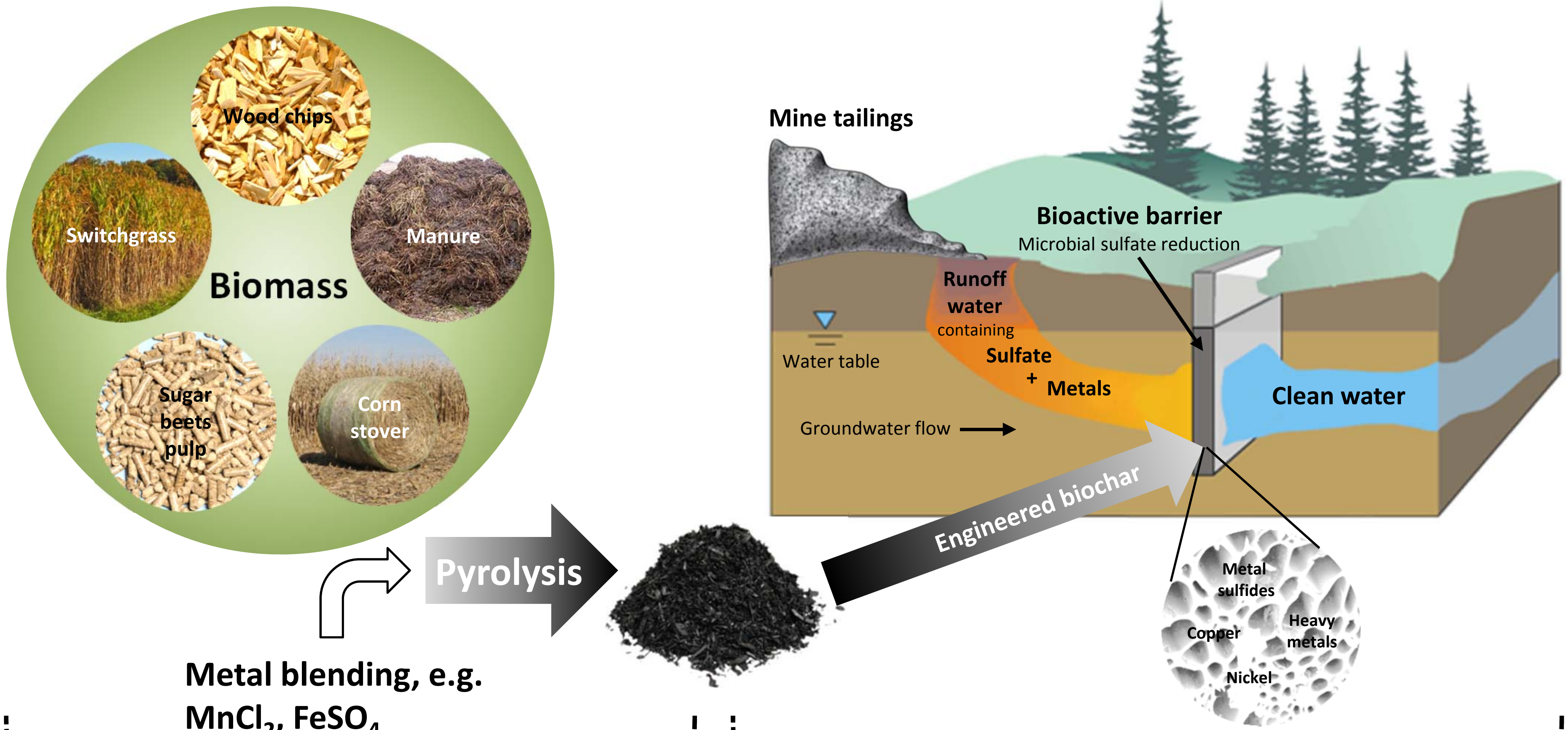
V. OTHER FUNDS

SOURCE OF FUNDS	AMOUNT	Status
Other Non-State $ To Be Applied To Project During Project Period:	N/A	N/A
Other State $ To Be Applied To Project During Project Period: University of Minnesota, OVPR Minnesota Futures Grant Program "Use, detection, and removal of charged molecules and particles for Minnesota water treatment applications"	$250,000	pending
University of Minnesota, Faculty Interactive Research Program "Biochar as In-Situ Sorbent to Reduce Sulfate and Heavy Metal Concentrations in Mining Water Impacted Ecosystems in NE Minnesota"	$52,984	pending
University of Minnesota, OVPR Research Infrastructure Investment Program "High-throughput single cell isolation by fluorescence-activated cell sorting"	$500,000	pending
In-kind Services To Be Applied To Project During Project Period: The University of Minnesota does not charge the State of Minnesota its typical overhead rate of 52% of the total modified direct costs (graduate tuition and academic fringe are excluded).	$201,020	secured
University of Minnesota - MnDrive Start-Up funds to Sebastian Behrens for graduate student (Kipp Sande), 50% position, full time (100%) for 2 years, fringe rate at 92.89% (includes tuition)	$80,210	secured
Funding History: German Science Foundation 2012-2015 "Iron cycling in freshwater sediments under oxic and anoxic conditions"	185,000 €	
German Science Foundation 2011-2014 "Microbial processes and iron-mineral formation in household sand filters used to remove arsenic from drinking water in Vietnam"	307,859 €	
German Science Foundation 2012-2015 "Abundance, activity, and interrelation of phototrophic and chemotrophic microbial iron oxidation in freshwater sediments "	300,775 €	
LGFG Fellowship, State of Baden-Württemberg Germany 2013-2014 "Biochar effects on microbial nitrous oxide formation in soils - composition and activity of the nitrous oxide-forming microbial community"	113,620 €	
German Science Foundation 2011-2014 Research Unit: "Natural halogenation processes in the environment - Direct and indirect formation of organohalogens by microorganisms"	380,644 €	
Remaining $ From Current ENRTF Appropriation:	N/A	N/A

Environment and Natural Resources Trust Fund (ENRTF)
2016 Main Proposal VISUAL
Project Title: Engineered biofilter for sulfate removal from mine waters

- Feedstocks for biochar production

- Metal recovery from biochar
- Recycling of adsorbent



- Carbon sequestration
- Solid waste management
- Invasive plant management

- Sulfate conversion to sulfide
- Biochar use as adsorbent
- Sulfate and heavy metal removal

PROJECT MANAGER QUALIFICATIONS

Sebastian Felix Behrens

a. Professional Preparation.

Institution	Major	Degree	Year
University of Bremen, Germany	Biology	B.S.	1997
University of Bremen, Germany	Microbiology	Diploma	2000
MPI for Marine Microbiology, Germany	Microbial Ecology	Ph.D.	2003

b. Appointments.

Since 2015	Assoc. Professor, Civil, Environmental, and Geo-Engineering, University of Minnesota
2008-2014	Junior Group Leader, Center for Applied Geosciences, University of Tuebingen, Germany
2004-2008	Postdoctoral Researcher, Civil and Environmental Engineering, Stanford University

c. Products.

RECENT PRODUCTS MOST CLOSELY RELATED TO THE PROJECT PROPOSAL

[1] Nitzsche KS, Lan VM, Trang PTK, Viet PH, Berg M, Voegelin A, Planer-Friedrich B, Zahoransky J, Mueller SK, Byrne JM, Schroeder C, Behrens S, Kappler A (2015) Arsenic removal from drinking water by a household sand filter – effect of filter usage practices on arsenic removal efficiency and microbiological water quality. Science of the Total Environment 502: 526-536.

[2] Kappler A, Wuestner ML, Ruecker A, Harter J, Halama M, Behrens S (2014) Biochar as an electron shuttle between bacteria and Fe(III) minerals. Environmental Science & Technology Letters 1: 339-344.

[3] Melton ED, Swanner ED, Behrens S, Schmidt C, Kappler A (2014) The interplay of microbially mediated and abiotic reactions in the biogeochemical Fe cycle. Nature Reviews Microbiology 12: 797-808.

[4] Harter J, Krause HM, Schuettler S, Ruser R, Fromme M, Scholten T, Kappler A, Behrens S (2014). Linking N_2O emissions from biochar-amended soil to the structure and function of the N-cycling microbial community. ISME Journal 8: 660-674.

d. Synergistic activities.

My research focuses on linking environmental processes to the spatial-temporal distribution and metabolic activity of key functional groups of microorganisms. I follow an interdisciplinary approach that combines the disciplines biogeochemistry, microbiology, and molecular biology to understand the basic microbial ecology principles driving the biogeochemical cycling of metals and metalloids, the biodegradation of organic contaminants, and the emission of greenhouse gases from the molecular to the ecosystem scale. The gained knowledge on microbial transformation processes in natural and engineered ecosystems is then implemented in order to optimize microbial remediation approaches, resource recovery, and the biological treatment of water (drinking water, surface water, groundwater, or waste water), thereby spanning the gap between basic and applied research aspects of bioremediation.

ORGANIZATION DESCRIPTION

The University of Minnesota is the State's main research and graduate teaching institution. The University partners with communities and governmental agencies across Minnesota to engage students, faculty, and staff in addressing society's most pressing issues. The Department of Civil, Environmental and Geo-Engineering focuses on collaborative and interdisciplinary research within critical areas such as managing and sustaining water and land-use infrastructure, mitigating disaster of the natural and built environments, engineering and developing earth resources, and designing renewable energy systems.