Environment and Natural Resources Trust Fund
2017 Request for Proposals (RFP)

Project Title: **ENRTF ID: 041-B**

Green Technology for Harmful Algal Bloom Remediation

Category: B. Water Resources

Total Project Budget: $ 549,967

Proposed Project Time Period for the Funding Requested: 3 years, July 2017 - June 2020

Summary:

We propose to develop a novel green technology based on electrical discharge plasma in water to simultaneously inactivate harmful blue-green algal blooms and their toxins without non-target effects.

Name: Peter Bruggeman

Sponsoring Organization: U of MN

Address: 111 Church St SE

Minneapolis MN 55455

Telephone Number: (612) 626-8391

Email pbruggem@umn.edu

Web Address

Location

Region: Statewide

County Name: Statewide

City / Township:

Alternate Text for Visual:

Schematic of plasma discharge technology and how to implement it for HAB remediation in lakes

_____ Funding Priorities	_____ Multiple Benefits	_____ Outcomes	_____ Knowledge Base
_____ Extent of Impact	_____ Innovation	_____ Scientific/Tech Basis	_____ Urgency
_____ Capacity Readiness	_____ Leverage	_____ TOTAL	_____%

PROJECT TITLE: GREEN TECHNOLOGY FOR HARMFUL ALGAL BLOOM REMEDIATION

I. PROJECT STATEMENT

Harmful blue-green algal blooms (HABs) are occurring with increasing frequency worldwide. They have an impact on landscape beauty and significantly reduce the recreational value of lakes. These blooms consist of cyanobacteria that can be beneficially used to fix atmospheric nitrogen in soil to provide added value to agriculture. However some cyanobacteria produce toxins that are a major concern for fisheries, wild mammals, livestock, pets, and public health. Microcystin, one of the most frequent, well-studied and hazardous HAB toxins has been measured in high risk concentrations in sampled Minnesota lakes by Heiskary *et al*[1]. The occurrence of HABs in Minnesota and their underlying causes are currently the subject of research supported by the Environment and Natural Resources Trust Fund.

HABs can be treated chemically or biologically but these processes are complex and often have a negative impact on the lake ecosystem. An additional challenge is that often-used oxidation techniques tend to induce cell lysis of cyanobacteria potentially leading to an increased release of toxins in water, which is particularly challenging in the context of drinking water.

We propose to develop a novel green technology based on electrical discharge plasmas in water that produce shockwaves, UV radiation and short-lived free radicals. Plasma discharges have the potential to ***simultaneously inactivate harmful algal blooms and reduce related water-based toxins.*** As plasma discharges in water do not require any addition of chemicals, the treatment could be performed ***without any non-target effects***. The novel technology could also lead to flocculation of cyanobacterial cells enabling an easier removal of cyanobacteria from water.

While a proof of concept study is proposed, we envision that the proposed green technology to remediate HABs in lakes can be designed as an autonomous pontoon-like structure powered by solar energy. The technology is mobile and could be easily deployed in lakes when these harmful algal blooms occur.

II. PROJECT ACTIVITIES AND OUTCOMES

Activity 1: Optimization of Plasma Discharge Technology for Algal Bloom Treatment Budget: $288,298

Plasma discharges in water are typically generated by nanosecond or microsecond high voltage pulses. The energy consumption is of the order of 1 Joule per pulse for lab scale reactors. Preliminary results on non-toxin producing cyanobacteria obtained by a Japanese research team have illustrated the huge potential of plasma discharge technology in this area. The outcomes of this study suggest that the produced shockwaves reduce the number of air vesicles in cyanobacterial cells leading to sedimentation of these cells. In addition, it has been shown that gas bubble injection can significantly enhance the effects of plasma discharges on decomposition of organics in wastewater and we anticipate a similar effect for HABs treatment.

We propose to study the efficacy of the plasma discharge HAB treatment in two reactors with a volume of 0.1 gallon with and without gas bubble injection. This study will lead to a set of optimized conditions for HAB treatment. For this first activity we will use (non-toxin producing) *Anabaena variabilis* and *Synechocystis spp*. The analyses will involve measurement of flocculation and reduction in chlorophyll, turbidity and viability and structure of cyanobacterial cells.

Outcome	Completion Date
1. Liquid phase plasma discharge reactor	Dec. 31, 2017
2. Bubbling plasma discharge reactor	June 30, 2018
3. Optimized reactor conditions for HAB treatment	Dec. 31, 2018

[1] Heiskary *et al*., Lake and Reservoir Management 30 (2): 268-272 (2014),

Activity 2: Optimization of Plasma Discharge Technology for Toxin Treatment **Budget: $97,058**

The effect of plasma discharges on toxin-producing HABs has to date not been evaluated in detail. The optimized treatment conditions for the two reactors found in activity 1 will be used to assess the effect of this technology on microcystin-LR toxin. This is an extremely toxic compound and has been found in Minnesota lakes. The Minnesota Department of Health has derived a guidance value of a maximum of 1µg/l in drinking water. The analysis will be performed with an enzyme-based assay (ELISA) and liquid chromatography. This study will be complemented with the treatment of two toxin-producing cyanobacteria: *Microcystis aeruginosa* and *Anabaena circinalis*. This will allow assessing the possible impact of cell lysis on the toxin release during treatment.

Outcome	Completion Date
1. Optimized conditions for toxin reduction with the 2 reactors	June 30, 2019
2. Optimized conditions for combined toxin and algae reduction	June 30, 2019

Activity 3: Scaled Up Treatment of Algal Blooms by Plasma Discharge Technology **Budget: $164,611**

The optimized conditions obtained in activities 1 and 2 will be used to scale up the treatment to a 30 gallon aquarium. We will take water samples from Minnesota Lakes to perform this treatment. The technology will be implemented as a floating device on the water surface as would be the case for the treatment of a lake. In addition, we will assess the impact on water quality after the treatment (pH, dissolved oxygen and micro-organisms) before and after the treatment.

Outcome	Completion Date
1. Scaled up plasma discharge reactor	Sept. 30, 2019
2. Proof of principle treatment of algae in 30 gallons aquarium and impact on water quality	June 30, 2020

III. PROJECT STRATEGY

A. Project Team/Partners

This project brings together three *University of Minnesota* researchers with complementary expertise:

- Prof. Dr. Peter Bruggeman (Department of Mechanical Engineering) an expert in plasma discharge technology – *project manager*;
- Prof. Dr. Sagar Goyal (Department of Veterinary Population Medicine) an expert in environmental microbiology; and
- Prof. Dr. Brett Barney (Department of Bioproducts and Biosystems Engineering) an expert on cyanobacteria and algae.

The plasma discharge technology will be developed in the lab of Professor Bruggeman. The cyanobacteria will be grown in the lab of Professor Barney and the treatment and analysis (including toxins) will be performed in the lab of Professor Goyal under biosafety level 2 conditions.

B. Project Impact and Long-Term Strategy

The proposed technology could be an important future asset in the state of Minnesota`s efforts to guarantee the recreational and natural value of our lakes for future generations. We envision that the technology can be designed as an autonomous pontoon-like structure powered by solar energy that can be easily deployed by staff of the Department of Natural Resources on lakes when harmful algal blooms occur. The successful outcomes of the proposed work could hold great prospect for commercialization. The further scale up of the proof-of-principle setup would require future investment for which national and state funding will be sought. In addition, we anticipate investments of private sponsors with interest in commercialization of the proposed technology.

C. Timeline Requirements

The project will require 3 years to complete with milestones explained above.

2017 Detailed Project Budget

Project Title: GREEN TECHNOLOGY FOR HARMFUL ALGAL BLOOM REMEDIATION

IV. TOTAL ENRTF REQUEST BUDGET 3 years

BUDGET ITEM	AMOUNT
Personnel: prof. dr. Peter J. Bruggeman - project management/supervision - 8.33% FTE - 3 years - $48,692 (fringe 33.7%) (summer salary) prof. dr. Sager M. Goyal - supervising treatments and analysis 4.17% FTE - 3 years - $36,027 (fringe 33.7%) prof. dr. Brett Barney - supervising algae growth - 4.17% FTE - 3 years - $15,569 (fringe 33.7%) (summer salary) RA - technology development and algae treatments (Bruggeman group) - 50% FTE - 3 years - $141,438 (fringe and tuition 70.87%) postdoc -biological analysis and toxin treatment (Goyal group)- 50 % FTE - 3 years - $90,798 (fringe 22.4%) Junior scientist - (Barney group) - 50% FTE - 3 years - $66,943 (fringe 27.4%)	$ 399,467
Equipment/Tools/Supplies: High voltage pulsed power supply (50 kV) with variable pulse width from 100 nanoseconds to 100 microseconds - $40,000 Plasma discharge reactor materials, electronical components, machining of components, compressed air, oxygen, high voltage and current probes to measure power deposition - $20,000 Culturing and titration of algae - $30,000 chlorophyll fluorescence device - $10,000 Analysis of algae treatment - $30,000 Setup toxin test and analysis - $15,000	$ 145,000
Additional Budget Items: Liquid chromatography of toxins - University of Minnesota Analysis Facility ($24/hour - 125 hours) - includes 25 hours of calibration and approximately 200 samples - $3000 Water quality assessment - University of Minnesota Analysis Facility ($25/sample - 100 samples) - $2500	$ 5,500
TOTAL ENVIRONMENT AND NATURAL RESOURCES TRUST FUND $ REQUEST =	$ 549,967

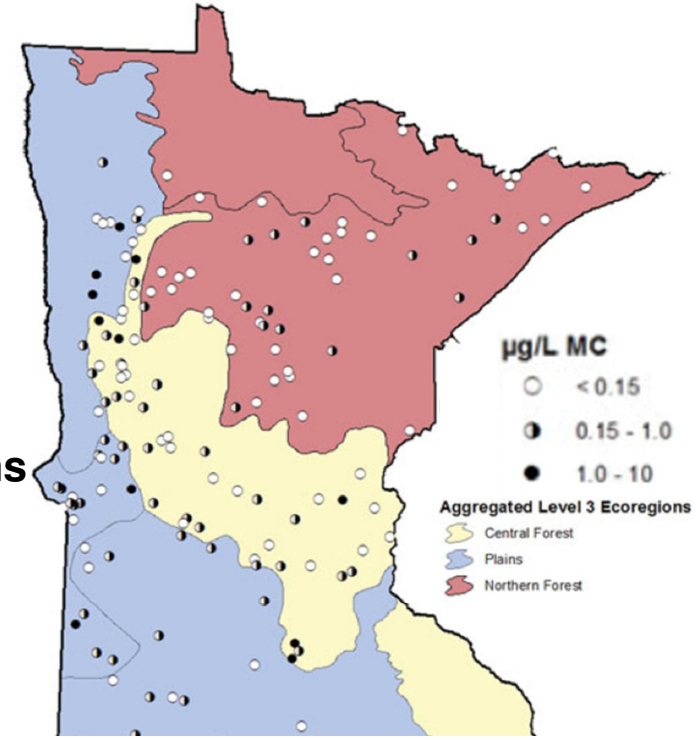
V. OTHER FUNDS

SOURCE OF FUNDS	AMOUNT	Status
Other Non-State $ To Be Applied To Project During Project Period: National Science Foundation: project 1500135 "Unraveling the unique properties of transient discharges in bubbles and liquid water". The results of this project will be invaluable to optimize plasma discharge conditions for harmful algal bloom treatment. PI: prof. Peter Bruggeman, 3 year project: 07/01/15 - 06/30/18. This is for informational purposes only and is not intended as a UMN cost share committment.	$ 342,000	ongoing
Other State $ To Be Applied To Project During Project Period: N/A	N/A	N/A
In-kind Services To Be Applied To Project During Project Period: University of Minnesota does not charge overhead of 52% of budget (without tuition for RA)	$ 263,282	
Funding History: N/A	N/A	N/A
Remaining $ From Current ENRTF Appropriation: N/A	N/A	N/A

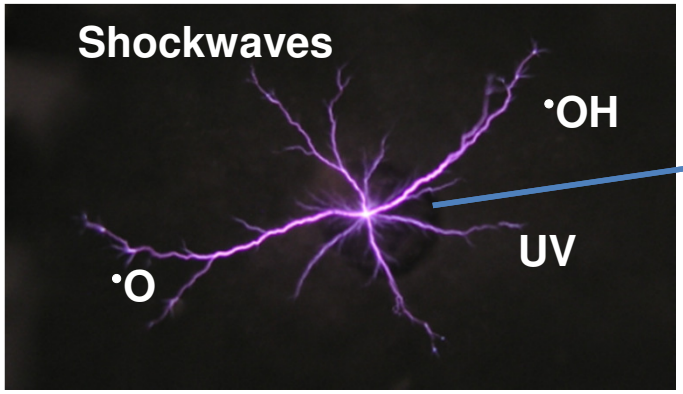
GREEN TECHNOLOGY FOR HARMFUL ALGAL BLOOM (HAB) REMEDIATION

(photo credit wikemedia commons)

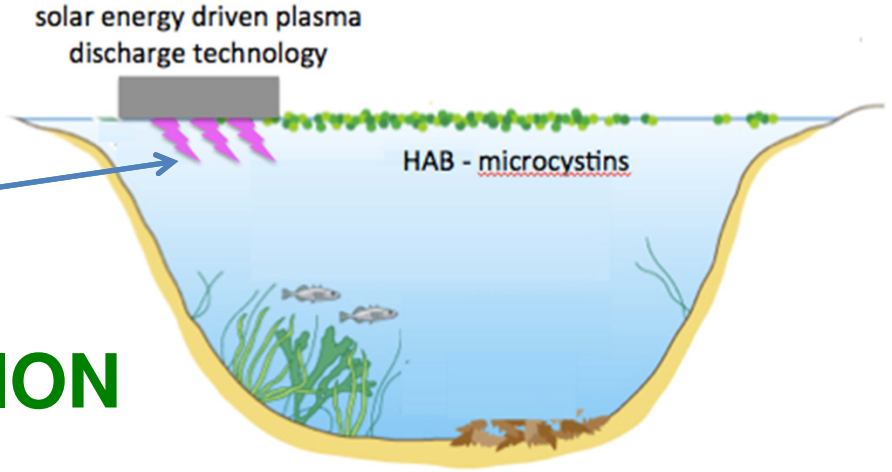
Lakes with elevated Microcystin (HAB toxin) concentrations
(Heiskary et al 2014)



Plasma discharge in liquid



OUR SOLUTION



In situ production of free radicals, UV and shockwaves from electrical energy to simultaneously inactivate cyanobacteria and reduce toxin levels without non-target effects.

Bruggeman, Barney and Goyal – University of Minnesota

ENRTF: **A Green Technology for Harmful Blue-Green Algal Bloom Remediation**

Project Manager Qualification: PETER J. BRUGGEMAN
Richard and Barbara Nelson Associate Professor – University of Minnesota

1. Education
Ph.D. in Applied Physics (2008), MS in Engineering and Physics (2005), BS in Engineering and Physics (2002, 2004) from Ghent University, Belgium

2. Positions

University of Minnesota	Richard and Barbara Nelson Associate Professor	2013-
Eindhoven Univ. of Technology, NL	Assistant Professor of Applied Physics	2009-2013
Ghent University/FWO, Belgium	Research fellow	2009
Loughborough University, UK	Postdoctoral researcher	2008-2009
Ghent University/FWO, Belgium	Research fellow	2005-2008

3. Expertise: Professor Bruggeman`s work involves plasma discharge technology for water and gas treatment, disinfection, wound healing, material processing, chemical synthesis and advanced combustion. He has 12 years of experience in plasma discharges in liquids with a strong emphasis for the last 6 years on biological applications of plasma discharges. He has directed research projects in Europe and US and collaborated with researchers and industrial partners in more than 10 countries on 3 different continents. Prof. Bruggeman is a member of the board of directors of the International Plasma Chemistry Society and serves on the editorial board of 5 journals in his research field.

Professor Goyal and Barney provide complementary expertise in cyanobacteria and environmental biology. Professor Bruggeman has an ongoing collaboration with professor Goyal on the development and testing of plasma devices for the disinfection of fresh foods.

4. Selection of Relevant Publications (total more than 70)

- K. Wende, P. Williams, J. Dalluge, W. Van Gaens, H. Aboubakr, J. Bischof, T. von Woedtke, **S. M. Goyal**, K.-D. Weltmann, A. Bogaerts, K. Masur and **P.J. Bruggeman,** Identification of the biologically active liquid chemistry induced by a non-thermal atmospheric pressure plasma jet, Biointerphases (2015) 10, 029518 ***(2015 Journal Highlight)***
- H. Aboubakr, P. Wiliams, U.Gangal, M. Youssef, S. Al-Sohaimy, **P.J. Bruggeman**, and **S.M. Goyal**, Virucidal effect of cold atmospheric gaseous plasma against feline calicivirus, a surrogate to human norovirus, Appl. Environ. Microbiol. (2015) 81 (11) 3612-3622
- C.A.J. van Gils, S. Hofmann, B.K.H.L. Boekema, R. Brandenburg and **P.J. Bruggeman**, Mechanisms of bacteria inactivation in the liquid phase induced by a remote RF cold atmospheric pressure plasma jet, J. Phys. D: Appl. Phys. 46 (2013) 175203 ***(2013 Journal Highlight)***
- **P.J. Bruggeman** and C. Leys, Non-thermal plasmas in and in contact with liquids, invited topical review paper, J. Phys. D: Appl. Phys., 42 (2009) 053001 ***(2009 Journal highlight)***

5. Organizational Description: The University of Minnesota supports this research project with laboratory space, infrastructure, administrative support in the departments of Mechanical Engineering, Bioproducts and Biosystems Engineering and Veterinary Population Medicine. The University is dedicated to promoting research that directly benefits society, especially the state of Minnesota and its citizens.