

An Indian-Australian research partnership

**Project Title:** **Application of Biochar-metal plasmonics approach for water treatment**
**Project Number** **IMURA1184**
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## Research Clusters:

## Research Themes:

Highlight which of the Academy's CLUSTERS this project will address? (Please nominate JUST <u>one</u> . For more information, see <a href="http://www.iitbmonash.org">www.iitbmonash.org</a> )		Highlight which of the Academy's Theme(s) this project will address? (Feel free to nominate more than one. For more information, see <a href="http://www.iitbmonash.org">www.iitbmonash.org</a> )	
1	<b>Material Science/Engineering (including Nano, Metallurgy)</b>	1	Artificial Intelligence and Advanced Computational Modelling
2	Energy, Green Chem, Chemistry, Catalysis, Reaction Eng	2	<b>Circular Economy</b>
3	Math, CFD, Modelling, Manufacturing	3	Clean Energy
4	CSE, IT, Optimisation, Data, Sensors, Systems, Signal Processing, Control	4	Health Sciences
5	Earth Sciences and Civil Engineering (Geo, Water, Climate)	5	<b>Smart Materials</b>
6	Bio, Stem Cells, Bio Chem, Pharma, Food	6	<b>Sustainable Societies</b>
7	Semi-Conductors, Optics, Photonics, Networks, Telecomm, Power Eng	7	Infrastructure
8	HSS, Design, Management		

## The research problem

### *Define the problem*

The sustainable development goals as set by the United Nations, is a wholistic approach that the global societies want to achieve by 2030. Among such goals, clean water and sanitation, safeguarding life below water and above ground are the ones which connect with the environmental, human and biota's health. Till the last decade, such health was considered in a siloed approach but the paradigm is changing fast now with better analytical and genomic techniques. Recent development in the understanding of the inter-relationship of human, animal and environment health (clubbed together under the banner of 'one-health' concept) has led to a global movement for better sanitation, animal and health practices and wastewater management. While the concept of one-health' is the bigger umbrella that eventually the societies want to achieve, a major focus from source-based mitigation point of view is the implementation of effective disinfection technologies for wastewater treatment. This is fuelled by the logic of making the water safe and pathogen free prior to discharge for reducing the pathogen load on the water bodies.

Treatment of wastewater for removal of pathogens involves different disinfection strategies. Among these, oxidation using oxidative species, UV radiation, thermal sterilization, ultrasonication have been extensively used. Chemical oxidation processes are time tested and deliver excellent results all the while being lower in cost and are already standardized chemical processes that can be easily implemented. However, chemical oxidation processes are not target specific and the highly reactive nature of the produced free radicals are prone to forming carcinogenic disinfection by-products (DBP). Formation of such DBPs reduces the environmental viability of such processes all the while increasing the cost of treatment due to requirement of further post treatment. This statement shifts the focus towards understanding the alternative disinfection strategies or namely, the physical disinfection strategies such as UV radiation, thermal treatment or ultrasonication.

One of the most popular disinfection strategies implemented both at household as well as industrial level among the physical disinfection strategies is the application of UV-C radiation. This technology has limitation in terms of energy requirement as well as the performance issues such as shielding effect due to high turbidity etc. Ultrasound tech again has high energy demand as well as very narrow application bandwidth and suffers from high energy loss from interfering factors such as poor hydrodynamics, inefficient energy transfer due to material properties limitation etc. Other strategies might include thermal treatment and sterilization which are again not applicable for mass scale. Over years, research has focussed on complementing chemical + Physical processes to deliver better results. Such combination helps reduce the limitations of each process and increase disinfection efficiency. Such combined technologies are also known as hybrid technologies.

Hybrid treatment systems are hence now being developed more extensively for such contaminant removal purpose. In this context, application of biochar has been well documented in water treatment as an adsorbent and as a support matrix for photocatalyst. For photocatalytic applications, biochar doped with different metal oxides have been experimented successfully. Such composites/doped materials function in combination of adsorption + photocatalysis. Adsorption onto the biochar surface is the first step of this degradation process. Hence, the properties of biochar play a significant role in this step. Biochar is reported to have high specific surface area, ion exchange capacity and high abundance of oxygen functional groups. The carbon structure of the biochar surface and the high conductivity also prevent the recombination of the hole-electron pair. As the target pollutant adsorbs onto the biochar surface, the higher porosity of the surface enables the diffusion of the pollutant over the surface as well as migration to the inner pores. Such sorption provides a higher chance of interaction between the target pollutant and the oxidative species created. Similar to usual photocatalyst processes, in this case, the generated hole electron pair react with water and hydroxyl ions to produce superoxide anion and hydroxyl free radical species. These oxidative species now react with the adsorbed target molecule and cleave the strong covalent bonds by donating the free radical electrons. This discussion provides a clear idea about the crucial role biochar plays in such a biochar-photocatalyst hybrid system.

In continuation to the above discussion, we propose a new type of disinfection and emerging contaminant treatment technique. In this technique, metal nano-particles are doped onto the biochar surface for contaminant removal through enhanced adsorption-thermal cleaving facilitated through plasmonic resonance effect. The biochar surface adsorbs the target contaminant molecule which is further degraded by the reactive action of the plasmonic metallic resonance. To understand this mechanism, it is important

to understand the plasmonic effect of such noble nanoparticle.

In this research, a plasmonic metallic nano particle -biochar system will be developed to degrade target pollutants from the as well as to render potability by providing disinfection. Thus, the scope of work would involve design and synthesis of a plasmonic nanoparticle as well as testing the developed nano particle for plasmonic resonance. To enhance the performance of this plasmonic nanoparticle, it will be doped onto the surface of biochar. Biochar will be prepared from different sources for this application. Ideally, food waste and agricultural waste residues will be utilized for the work. Biochar activation can lead to excellent adsorptive properties as demonstrated in different past investigations. Such activation not only enhances the biochar porosity and the specific surface area, but also enhances the density of the surface functional groups of biochar which further aid in chemisorption and provides valence electrons as an energy source for degradation of organic molecules. Hence the investigation will also include a comparison of performance between the two types of materials viz. biochar and activated biochar doped with plasmonic nano particles. Such comparison can be answer the hypothesis whether such an activation would be beneficial for degradation experiments. Both materials will be used in batch investigations of contaminant degradation and the same would be Upon successful demonstration of batch studies, a semi-continuous mode reactor will also be developed for testing the scale-up feasibility of this technology. The research thus would involve the following broad objectives:

- 1) To synthesize, characterize and functionalize/activate biochar from agricultural and food waste.
- 2) To fabricate/prepare plasmonic nanoparticles doped biochar materials and conduct initial testing of the plasmonic resonance phenomena.
- 3) Performance evaluation and comparison of the two different biochar-plasmonic nanoparticles for degradation of target contaminant in batch studies.
- 4) Fabrication and demonstration of semi-continuous mode reactor for studying the scale feasibility of the developed technology.

## Project aims

Based on the above problem statement and research objectives, the following project aims are proposed:

1. Development of a standardized protocol for biochar production and activation from agricultural and food waste.
2. To understand the plasmonic behaviour of the nanoparticles doped on biochar surface
3. To demonstrate the application of such composite plasmonic-adsorption mechanism for enhanced removal of target pollutants.
4. Demonstration of a continuous reactor for the scale-up study feasibility.

## What is expected of the student when at IITB and when at Monash?

*Highlight how the project will gain from the students stay at IITB and at Monash*

The project has three distinct research verticals.

- 1) **Synthesis and activation of biochar:** Includes initial screening of biowaste, production and activation of biochar as well as initial physico-chemical characterization of the material
- 2) **Synthesis/fabrication of biochar-metallic nanoparticles as adsorptive-plasmonic materials:** This includes the complete gamut of synthesis, physico-chemical characterization and testing for plasmonic resonating effects. Also includes initial investigations to understand how this effect can be engineered to degrade contaminants.
- 3) **Application of the composites for the water treatment:** This research vertical includes the batch experiments to study the contaminant degradation kinetics, effect of different interfering ions and other environmental factors etc. it also includes the fabrication of the semi-continuous reactor with the developed material for understanding the scale-up feasibility.

The first research vertical is connected to the of the work will be conducted at IIT Bombay in the IITB PI (Prof. Indrajit Chakraborty's lab). The lab of the IIT B PI is well equipped with tubular furnace and other laboratory equipment for the synthesis, activation and post processing of biochar material. The student will be given hands-on training for this objective by the IITB PI for successfully conducting the related lab experiments and the synthesis of both biochar and activated biochar. The second research vertical would be conducted at Monash University for further modification of the synthesized biochar and activated biochar by doping metallic nanoparticles. Further testing to understand the feasibility of plasmonic effect of the synthesized materials will also be conducted at Monash University under the guidance of the Monash University PI (Prof. Murali Sastry). This would also include hands on training on the state-of-the art equipment for material characterization and guidance to the student for standardization of the synthesis protocol. The expertise of

the Monash University PI, Prof. Sastry in this regard will be invaluable for shaping out concrete outcomes from this part of the research plan. The last part of research will be partly conducted at Monash University and IITB. For instance, the initial batch experiments can be partly be conducted at Monash and based on the results obtained in Monash University, the fabrication of the semi-continuous reactor and deployment of the same for demonstration purpose can be conducted at IITB.

The research verticals are curated with care to compliment the expertise of the two faculty members involved in this project with an objective to maximize the research exposure of the enrolled student and to provide support with the best of the two research environments.

## Expected outcomes

*Highlight the expected outcomes of the project*

Based on the above discussed objectives and project aim, the following deliverables are expected from the project:

- i) Protocol development for the standardization of biochar-metallic nanoparticle materials for degradation of target contaminants.
- ii) Development of novel biochar-metallic nanoparticle incorporated reactor/column for the water treatment and disinfection
- iii) Patenting of the developed prototype for further field-scale applications.

## How will the project address the Goals of the above Themes?

*Describe how the project will address the goals of one or more of the 6 Themes listed above.*

The proposed proposal addresses multiple issues in parallel. The utilization of waste material for producing biochar and its subsequent usage promotes *circular practice*. The application of the plasmonic resonance theory is intended to use minimal energy for efficient degradation of organic compounds. Such an approach would again reduce the energy burden. A special feature of the plasmonic materials is that excitation of these materials is possible using visible light. Such a feature reduces the energy burden of disinfection and contributes to directly to *sustainable societies* and also indirectly to efficient *infrastructure*. As the central theme of research is to treat and disinfect water sustainably to be used for potable purposes, hence this research directly connects to improved *health practices* also.

## Potential RPCs from IITB and Monash

*Provide names of the potential research progress committee members (RPCs) and describe why they are most suited for the proposed project*

IITB RPC members:

1. Prof. Tabish Nawaz: Prof. Nawaz has worked with biochar and other adsorbent materials for removal of PFAs from the wastewater and water sources. Prof. Nawaz also has experience of working with storm water runoff etc.
2. Prof. V. S. Vamsi Botlaguduru: Prof. Vamsi has research experience advanced oxidation and advanced reduction processes for degradation of emerging contaminants. He has been guiding students in the topics of emerging contaminant fate and transport as well as the degradation of emerging contaminants present in runoff and surface water.

Monash RPC member:

1. Prof Mainak Majumder: Prof Majumder is well known for his work on graphene membranes for water treatment.

## Capabilities and Degrees Required

*List the ideal set of capabilities that a student should have for this project. Feel free to be as specific or as general as you like. These capabilities will be input into the online application form and students who opt for this project will be required to show that they can demonstrate these capabilities.*

Candidates meeting either criteria 1 or 2 as well as **all three criteria (3-5)** eligible to apply:

1. M.Sc. in Chemistry/Physics/Environmental Science/Materials Science

**OR**

2. Masters in Environmental Engineering/Civil Engineering with Environmental Engineering specialization/Chemical Engineering/Materials Science
3. Should have secured 60% or equivalent CPI in Class 10, 10+2, graduation and post-graduation examinations.
4. The medium of instruction of the candidate's education should have been English for undergraduate and post-graduation degrees.

The student should be motivated and proactive with excellent problem-solving skills. A general proficiency in English is also desirable since the student would have to spend a considerable time at Monash University.

## Necessary Courses

*Name three tentative courses relevant to the project that the student should complete during his/her coursework at IITB (the student will require to secure 8 point in these courses)*

ES-631- Environmental Chemistry  
ES-307- Wastewater engineering  
ME-6110- Nanomanufacturing process

## Potential Collaborators

*Please visit the IITB website [www.iitb.ac.in](http://www.iitb.ac.in) OR Monash Website [www.monash.edu](http://www.monash.edu) to highlight some potential collaborators that would be best suited for the area of research you are intending to float.*

**Keywords** relating to this project to make it easier for the students to apply.

**Adsorption, Biochar, Emerging contaminants, Water treatment, Hybrid materials**