**PROJECT TITLE: Cellulosic Carbon Fiber-Intensified Capture and Biodegradation of Airborne VOCs**

**I. PROJECT STATEMENT:**

Volatile organic compounds (VOCs) constitute a significant threat to environment and human health. VOCs are commonly generated through anthropogenic activities in agriculture and manufacturing industries including animal farming, paper, paint, wood product, biofuel, food and pharmaceutical manufacturing that contribute to a large portion of Minnesota economy. VOCs include a variety of organic compounds ranging from small molecules such as methane, formaldehyde and toluene, to more complicated compounds especially polycyclic aromatic hydrocarbons (PAHs). Small molecules such as methane from agricultural industry contribute in a significant way to greenhouse gas emission in MN, while aromatic compounds especially PAHs are increasingly concerned for respiratory health issues including irritation and lung cancer. People can even be exposed to airborne VOCs and PAHs from site-specific sources like tobacco smoke, wood smoke, and smoke from prescribed incineration sites, or through human activities in even more open environments such as vehicle operation and road construction. Oxidation of such airborne VOCs can also lead to generation of particular matters in air (smog) or acidic rains. Minnesota Pollution Control Agency has actively involved in monitoring the airborne of VOCs and PAHs; however, there is essentially a lack of effective measures and technologies for mitigation of airborne VOCs [1].

Collect and destroy airborne VOCs at major emissions sites is probably still the most effective strategy for mitigation of air pollution in Minnesota. Biodegradation of organic chemicals, i.e. transforming the chemicals as carbon and energy source into environmentally friendly biomass, can be a “green” alternative to traditional approaches such as incineration which is also concerned with pollution emission. Over the past decades, research has identified numerous strains of bacteria, fungi and algae capable of degrading VOCs and PAHs[2,3]. The degradation efficiency has been largely limited, however, by several factors including low concentration of VOCs in air for collection, and low aqueous solubility of VOCs. All of that make it particular challenging for biodegradation of airborne VOCs, even though microbial digestion has been applied widely for treatment of waste water and agricultural wastes[4].

The overall goal of the proposed project is to explore a nano carbon-facilitated VOC capture and concentration strategy for intensified biodegradation. Specifically we will examine the electrically-switchable adsorption/desorption behaviors of VOCs and volatile PAHs on hierarchical nano carbon matrices, which can produce concentrated VOCs as substrates for biodegradation. The bioreactor will be intensified at the same time with packed nano carbon matrices that carry biofilms of microbial strains capable of degrading VOCs. The synergistic effects of concentrated VOC substrate feeding and the improved reaction kinetics of the biofilm reactors (with optimized porosity for improved gaseous substrate retention, adsorption and bioavailability) will be investigated with respect to the biodegradation efficiency for eventually large scale air cleanup applications.

**II. PROJECT ACTIVITIES AND OUTCOMES**

This is a new project evolved from our previous work on development of hierarchical nano carbon electrodes, i.e. carbonized cellulose with surface-patterned carbon nanotubes (see SEM Visual Map). Nano carbon materials offer high specific surface areas, ideal for adsorption and capture of VOCs and PAHs [5,6]. In our recent studies on biosensors using the hierarchical CC-CNT electrodes [7-9], we observed that highly volatile chemicals such as ethylene, methane and benzene, can be absorbed by the material from a very diluted gas phase (in the order of PPM or lower). The adsorption capacity could be improved further when CC-CNT was prepared via a reductive carbonization process (in the presence of hydrogen that helps to remove oxygenated groups). More excitingly, the adsorption capacity decreased sharply when electrical current was applied, with the adsorbed VOCs released quickly and completely from the carbon materials [9]. It implies that the VOCs can be absorbed and accumulated on the surface of CC-CNT under ambient conditions, can then be released and collected for further treatment by applying electricity. If applied as support for biodegrading biofilms, CC-CNT may also help to absorb and retain gaseous substrate for enhanced availability for biodegradation. One important concept to be tested in this research is therefore the feasibility of using such an electrically-switchable adsorption/desorption on CC-CNTs for capture and concentration of VOCs; and along with that, evaluation of the efficiency of nano carbon-supported biofilms for biodegradation. In addition to the observation of VOC adsorption/desorption, we have also demonstrated previously the feasibility of constructing bacterial biofilms on CC-CNT matrices for biofuel cells (SEM picture in Visual Map) [10, 11]. Specific activities include:

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| |  |  | | --- | --- | | **Activity 1 Title:** Adsorption Behaviors and Limiting Factors of VOCs on CC-CNT |  |   *Description:* This work will examine the adsorption and concentration capacity of typical VOCs (methane, bezene, formaldehyde, toluene as major model compounds) and volatile PAHs (using benzo-pyrene as a representative PAH); The efficiency of nano carbon-supported biofilm reactor will be examined with a model bacteria strain, *Pseudomonas putida* (ATCC 700007), which has known capable of degrading aromatic compounds [4].  ***ENRTF Budget:*** *$98,000*   |  |  |  | | --- | --- | --- | | **Outcome** | **Completion Date** | | | *1. Adsorption/desorption capacities and CC-CNT structural optimization* | *7/1 ~ 12/31, 2020* | | | *2. Limiting factors (humidity and temperature) for VOCadsorption* | *1/1 ~ 3/31, 2021* | | | *3. Biofilm growth and reactor construction with CC-CNT support* | *4/1 ~ 6/30, 2021* | | | **Activity 2:** Lab Scale CC-CNT Supported Biodegradation of Air-borne VOCs | |  | |   *Description:* A lab scale continuous adsorption/desorption unit, integrated with a biofilm reactor of microbial consortium capable of degrading multiple VOCs and PAHs, mimicking composition and environments at typical emission sites, will be examined.  ***ENRTF Budget:*** *$91,000*   |  |  | | --- | --- | | **Outcome** | **Completion Date** | | *1. Optimal column adsorption and bio-film reactor reaction efficiency with different VOCs when operated separately* | *7/1 ~ 12/31, 2021* | | *2. Effects of operational factors on integrated biofiltration and biodegradation of VOCs (humidity, temperature and flow rate), and from that, overall application potential of the technology* | *1/1 ~ 6/30, 2022* | |  |

***References*:** **[1]** <https://www.pca.state.mn.us/air/air-monitoring-polycyclic-aromatic-hydrocarbons-urban-and-rural-sites>. **[2]** Juhasz et al, *Intern Biodeteri Biodegrad* 2000(45): 57-88. **[3]** Bergara-Fernandez et al., *Chem Eng J* 2018(332): 702-710. **[4]** Estrada et al, *Biotech Bioeng* 2014(112): 263-271. **[5].** Avouris et al, *Nat Photo* 2008(2): 341-350; **[6].** Wu et al, *Water Res* 2016(88): 492-501; **[7].**Zhao et al, *Bios Bioelectron* 2010 (25): 2343-2350; **[8].** Zhao et al, *ACS Appl Mater Interface* 2013(5): 8853-8856. **[9]** J Wang, MS Thesis of Microbial Eng. (ongoing research on biosensors), UMN (Expected 12/2018). **[10]** B Tang, MS Thesis of BBE, UMN (2017, research on microbial biofuel cells with nano carbon electrodes). **[11]** YJ Wang, MS Thesis of Microbial Engineering, UMN (2019, research on nano carbons for chemical adsorption).

**III. PROJECT PARTNERS AND COLLABORATORS:** One postgraduate research scientist will be hired and supported through the requested fund for this project. Part time graduate and undergraduate students (2~4 totally) will be recruited to participate the research through educational programs at UMN.

**IV. LONG-TERM IMPLEMENTATION AND FUNDING:** This project is a proof-of-concept demonstration work for the proposed biodegradation strategy. Future fund will be sought at the end of the project from both Federal and State agencies for scale-up development, toward eventually commercialization of the technology.

**V. SEE ADDITIONAL PROPOSAL COMPONENTS:**

**A. Proposal Budget Spreadsheet**

**B. Visual Component or Map**

**F. Project Manager Qualifications and Organization Description**