

Session E Abstracts

Validation of cryolite as a proxy porous media for bacterial models

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Ammonia fertilizer production through the traditional Haber-Bosch process relies on methane combustion, which releases harmful amounts of carbon dioxide into the atmosphere. This motivates the development of alternative methods for efficient and scalable ammonia production based on nitrogen-fixing soil bacteria. However, visualizing bacterial activity to optimize porous media models, including in soil and fixed-bed reactors, presents challenges due to the media's opaque characteristics. To overcome this, we are working to validate the use of cryolite as a proxy porous media for quasi 2D modeling in bacterial systems. Embedding microbial communities in a cryolite-rich environment represents a drastic difference in the physiochemical composition in regard to what the microbes have been subjected to for years of evolution. In particular, we are working on characterizing the spatiotemporal and metabolic activity of bacteria in modified cryolite scaffolds through confocal microscopy. As a first-order approximation, we are characterizing growth differences in two lab-grown strains: *Escherichia coli* and *Bacillus subtilis* in wet environments, as well as quantification of growth in soil-like structures. Future research will include utilizing the pre-existing enzymatic machinery in *Azotobacter vinelandii*, a free-dwelling, methanogenic, and nitrogen-fixing soil bacterium, to develop an ammonia bioreactor model.

Enhancement of heat transfer in porous materials with polymer solution flows

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Convective heat transfer plays a vital role in energy, industrial, and environmental processes, many of which depend on fluid flow through porous materials. Chaotic, turbulent flows can enhance heat transfer, but small length scales and low fluid velocities suppress conventional turbulence in confined geometries characteristic of porous media. Polymer solutions, however, have been shown to increase solvent mixing in porous materials, as stretching and coiling of dissolved polymers generate elastic instabilities that drive turbulent-like chaotic flow fluctuations despite pore-scale confinement. Therefore, we hypothesize that this elastic turbulence may also enhance convective heat transfer in confined systems. In our study, we prepare a thermo-responsive dye to fluorescently probe the temperature distribution in flow channels representative of porous materials. Paired with confocal fluorescence microscopy, we directly observe thermal gradients in situ while varying the geometry, fluid properties, and imposed heat flux at the boundaries of our devices. Thus, we aim to establish viscoelastic fluid flows as an alternative approach to enhance heat transfer with elastic turbulence in confined environments.

Visualizing and understanding spatial microbial dynamics of free-living vs. symbiotic nitrogen-fixing bacteria in a novel cryolite soil proxy system

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Understanding spatial microbial dynamics in opaque media limits our ability to directly observe and quantify these important metabolic processes including nitrogen fixation. Directly visualizing nitrogen-fixation of free-living and symbiotic bacteria can provide direct optical imaging of microbial activity in three dimensions. Cryolite is a transparent soil proxy with a refractive index similar to water, with the potential of enabling the visualization of microbial dynamics in three dimensions. We have characterized the physical, chemical, and optical properties of various cryolite forms including rocks,

powder, and wet-granulated particles through pH testing, optical density measurements, and confocal microscopy and put it in contrast against natural soils. Cryolite demonstrated transparency in water and nutrient media, with cryolite dust maintaining optical clarity even at higher densities. Although attempts to produce soil-like textures via sintering and granulation were unsuccessful due to structural instability and safety concerns, cryolite dust and crushed particles proved most effective for imaging. Initial fluorescence microscopy confirmed imaging depths of up to 2 micrometers, across multiple grains of material. These findings establish cryolite as a viable transparent medium for real-time microbial ecology and lay the groundwork for studying soil-microbe interactions in structured environments.

Developing systems for multi-modal measurements of microbial activity

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Soil plays a significant role in housing complex interactions between plants, their roots, and microbes. The rhizosphere, the region surrounding plant roots, represents increased microbial activity driven by the secretion of root exudates and their transport through complex media. Avoiding limits due to soil opacity, a transparent soil proxy, cryolite, can be used for direct observation of microbial dynamics alongside different textures and pore sizes. For both growth of microbial samples and non-invasive microscopy capabilities, we designed a custom resin-printed enclosure. It uses suction and reverse osmosis membrane filtration to separate water, exudates, and excess media from soil for later chemical analysis and simulates wetting and drying cycles. Future work will target complementary measurements such as gas sensors for carbon dioxide and oxygen consumption and water potential sensors to fully characterize the microbial metabolism.

PdCu catalyst engineering for electrochemical transformation of 1-butene to 2-butanone

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The oxidation of 1-butene yields 2-butanone, an industrially relevant chemical with applications ranging from pharmaceuticals to plastics. 2-butanone, with its high knock-resistance, octane-like enthalpy of vaporization, and high-octane rating, has the potential to be a greener alternative to traditional fossil fuels if manufactured using energy-efficient methods. Electrochemical synthesis avoids the high pressures, temperatures, and dangerous oxidants traditionally required in thermochemical 2-butanone synthesis. Herein, we reported an electrochemical system using PdCu alloy as an efficient electrocatalyst for ketonization with water as the O-atom source at ambient pressure and temperature. We investigated the effects of Pd:Cu molar ratio on the catalytic performance by systemically synthesizing a variety of PdCu catalysts which were evaluated using x-ray diffraction (XRD). It was found that catalysts with equimolar palladium and copper ratio were the most effective. In addition, the influence of additives, such as sodium bromide, were studied to gain insights into the reaction mechanism.

Measuring energy usage in research labs towards reducing Caltech's energy consumption

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At Caltech, research centers and labs account for as much as 75% of the Institute's total energy costs. A significant amount of energy waste exists due to inefficient equipment management. To find opportunities to save energy, we first need to accurately measure lab equipment energy usage. We conducted lab walkthroughs to build a detailed inventory of over 600 pieces of lab equipment across various labs. From this inventory, we installed 20 energy monitoring sensors onto frequently used equipment to collect real-time energy consumption data. Early findings have revealed discrepancies between estimated and actual energy usage. To address this, we developed a less invasive prototype sensor to measure, analyze, and visualize equipment-level energy consumption. We determined that some ideal targets include freezers and deployed our prototype to estimate potential energy savings. Data collected from these sensors formed the foundation for a targeted education campaign to reduce energy consumption at Caltech.

Enhancing Motion and Sash Height (MASH) alarms to increase fume hood energy efficiency

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Mentors: Julia A. Kornfield, Dennis L. Ko, Maximilian Christman, and Tasha Cammidge

Fume hoods account for 40-70% of a laboratory's total energy consumption, with each unit consuming the same amount of energy as 3.5 households in the US per year. Furthermore, when fume hoods are left open without a user present, energy usage increases unnecessarily. To address this problem, others developed the Motion and Sash Height (MASH) sensor, a fume hood monitoring device with active feedback to alert lab users when a fume hood has been left open and unused for a set amount of time, which helped labs save energy. Our work addresses limitations in the original design by improving performance, data transfer, visualization, design, and scalability. These enhancements not only streamline deployment and usability but also support educational outreach to reinforce best practices among fume hood users. Upon the deployment of the improved sensor, we observed a measurable decrease in average sash height and overall energy consumption. These results suggest that this advancement lays a strong foundation for reducing energy usage across laboratories worldwide.

Utilizing nuclear magnetic resonance spectroscopy and machine learning for tree health monitoring

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Trees play a crucial role in maintaining the health of Californian ecosystems but have been impacted by natural disasters such as forest fires and droughts, and there does not exist a reliable method to quantitatively measure their health, which is representative of climate health. We aim to utilize Nuclear Magnetic Resonance Spectroscopy (NMR) to understand how the molecular composition of tree resin, a terpene-rich compound that trees emit due to an external stress, correlates with the environmental stresses the tree is subject to. We collected tree resin samples from over sixty trees across forests all over California, subjected to varying drought and wildfire exposure, and performed 1D Proton NMR and 2D Correlation Spectroscopy (COSY) experiments on each of the samples. We fed the 1D and 2D results into separate neural networks, where both successfully classified the trees' environmental exposure based on their spectra. The activations from these models were then inputted into a Principal Component Analysis (PCA), and we observed clustering of different trees exposed to the same level of environmental stress. This clustering is indicative of the connection between tree health and tree resin composition and showcases how NMR serves as a reliable method for future climate health monitoring.

Ultrasonic control of ion channel functions via a sonogenetic redox switch

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Abstract withheld from publication at mentor's request.

Building cell radios for deep-tissue wireless detection of biochemical factors

Sudarshanagopal Kunnavakkam

Mentors: Mikhail G. Shapiro and William Benman

Abstract withheld from publication at mentor's request.