Biological Contamination in Direct Air Capture Systems

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PCCC-8

IEAGHG 8th Post Combustion Capture Conference
16th to 18th September 2025 Marseille, France

Outline

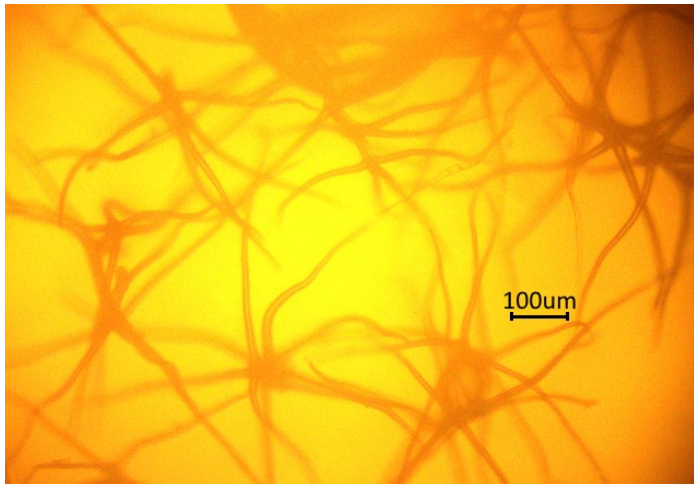
- UK DAC System

- Ambient Air Contaminants

- Particles and Fungal Growth

- Experience/Recommendations

- Conclusions



DAC and H_2 Production

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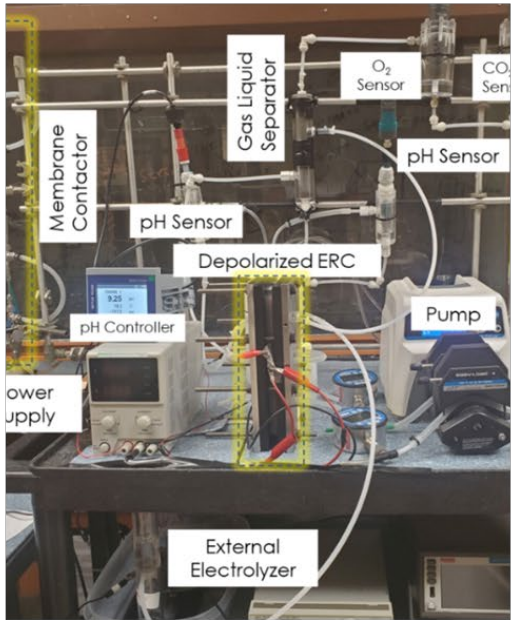
DAC 1.0, proof-of-concept

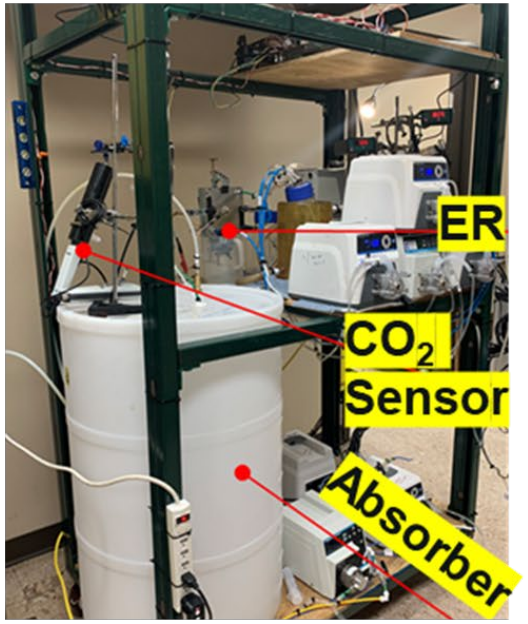


2020 - 2021

- 30 W regenerator
- 2 L min^{-1} air contactor
- <1 kg yr^{-1} CO_2 capture process
- <1 kg yr^{-1} H_2 production

- Standard operation and explored depolarized operation

DAC 2.0, scale-up



2021 - 2023

- 210 W regenerator
- 10 cfm air contactor
- 200 kg yr^{-1} CO_2 capture
- 10 kg yr^{-1} H_2

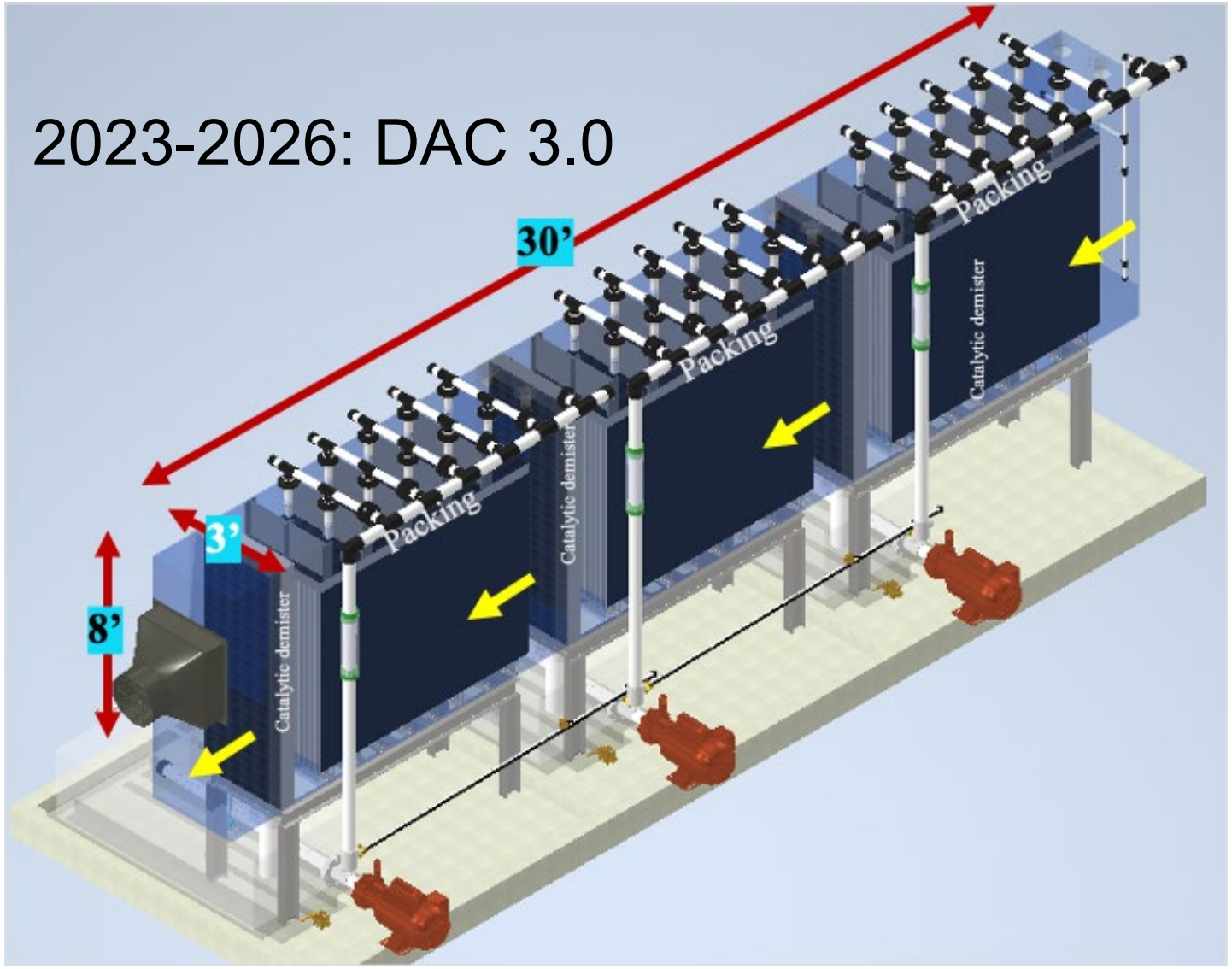
- Zero-gap cell design, electrode material selection
- ~500 kJ mol^{-1} regeneration energy

DAC 2.5, point-source integration

2022 - 2023

- 600 W regenerator
- 14 cfm gas with 4,000 ppm CO_2 contactor
- Negative Emissions, Integrated with point source capture (3-5% CO_2) as polisher
- Carbon polisher, 1700 kg yr^{-1} process
- H_2 production at 77 kg yr^{-1}

DAC and H_2 Production

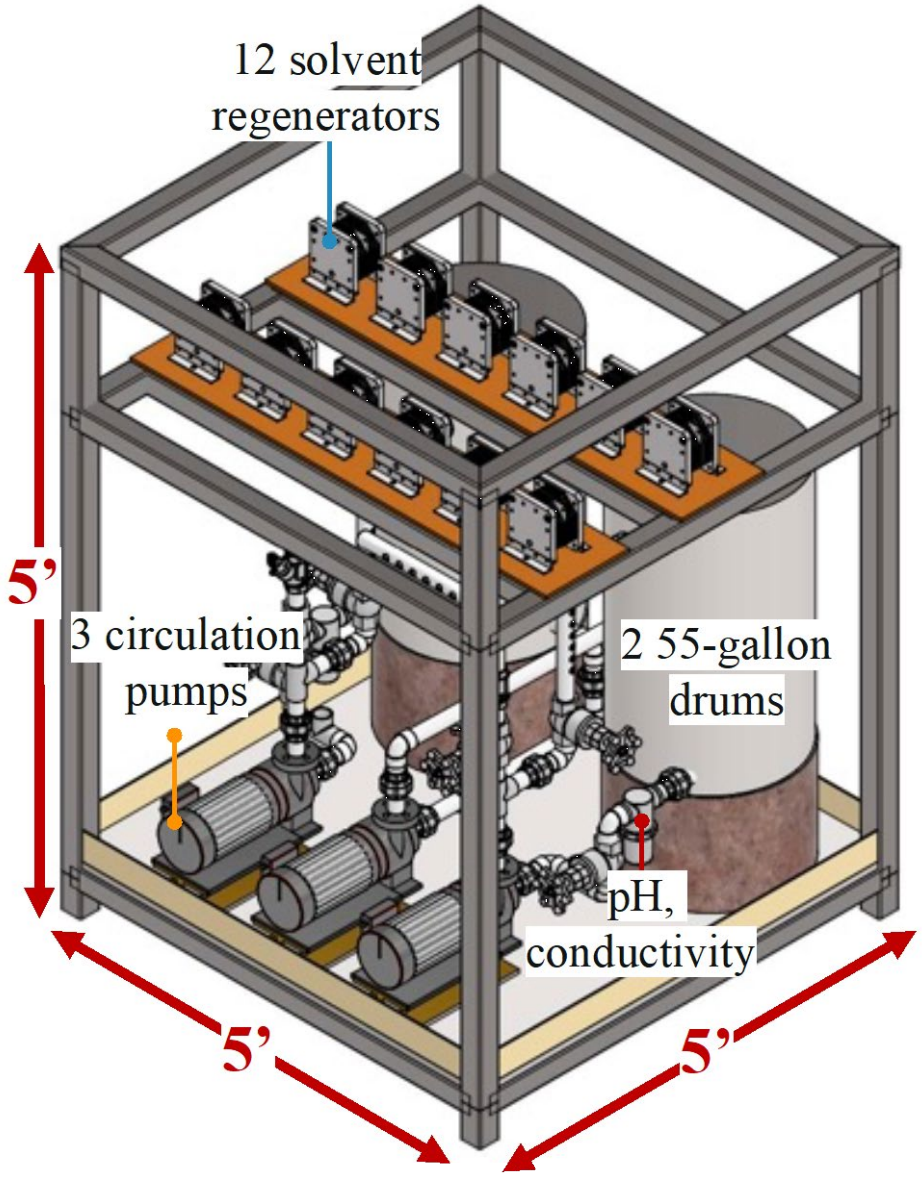


Goal: Capturing kiloton scale of CO_2 per year from air

Approach: Packing assisted cross-flow absorber with KOH.

Performance will be controlled across 3 segments by adjusting the local pH

DAC and H_2 Production

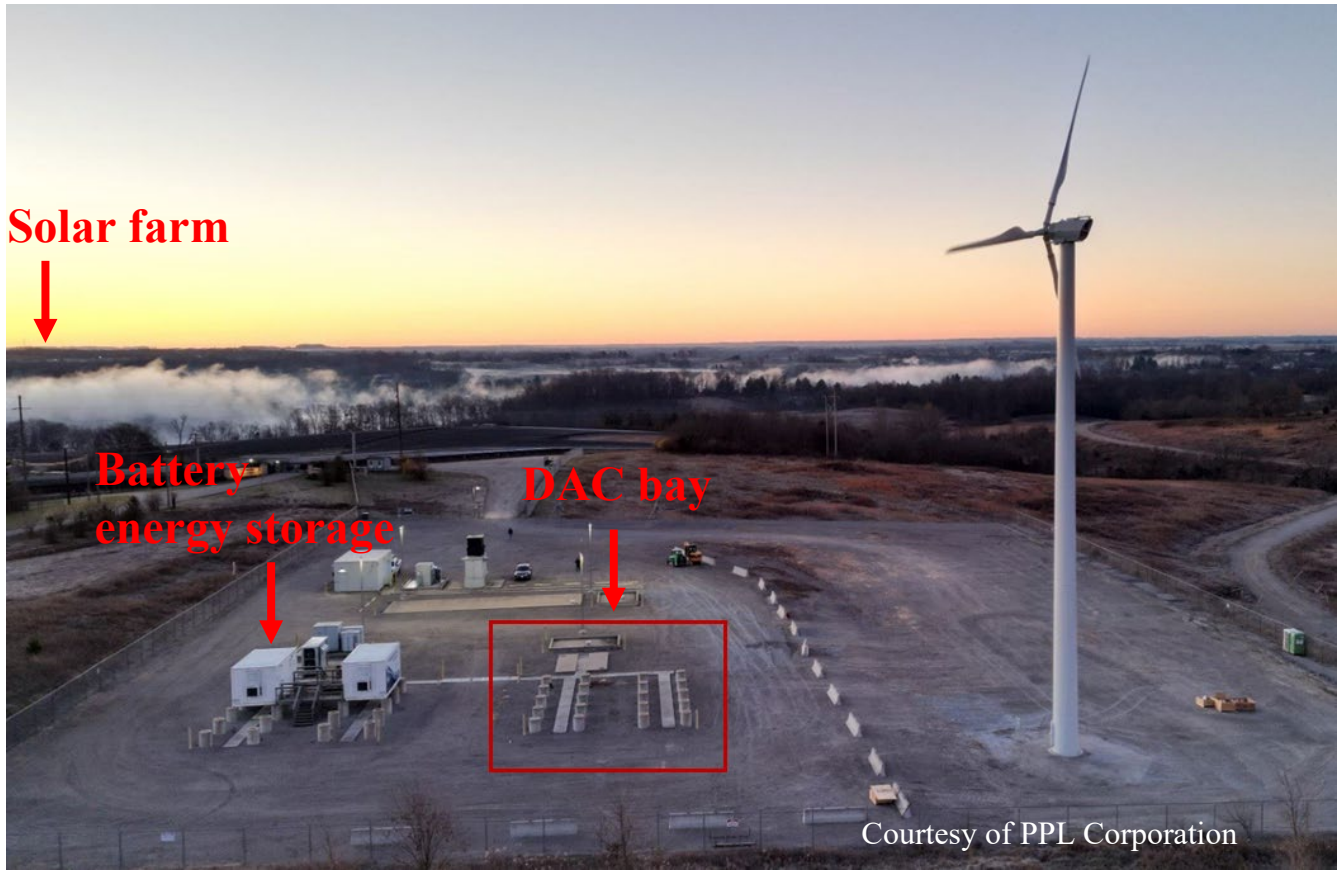


2023-2026: DAC 3.0

Solvent Regeneration Unit

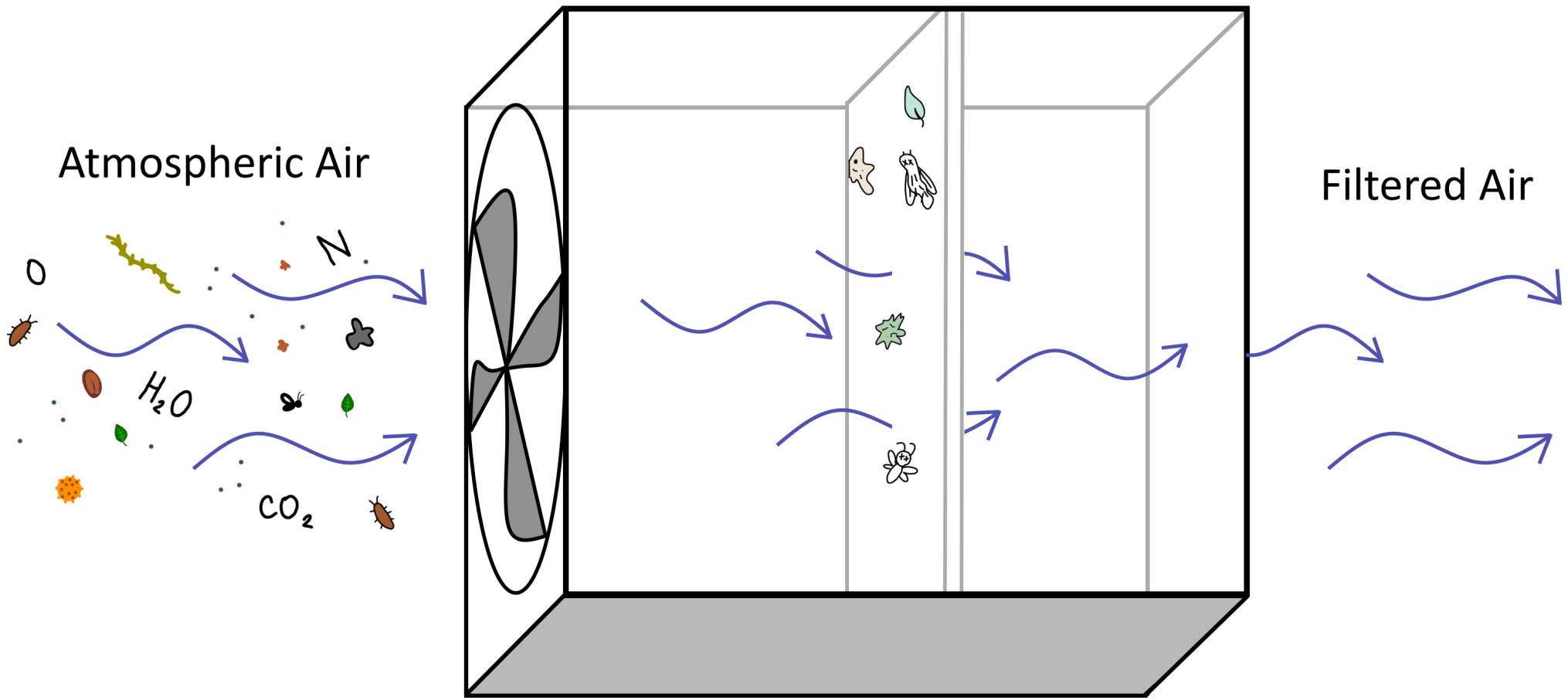
- 12 stacked solvent regenerators, 3 circulation pumps, 2 solvent tanks, pH and conductivity sensors.
- Nominal power for KOH regeneration is 7.2 kW, and total power is 8.5 kW.
- Daily operation: 53 kg of KOH regenerated and 13 kg of H_2 produced

Renewable Powered at PPL R&D



The DAC3 unit will be installed later in 2025 at the PPL Renewable Integration Research Facility, located at E.W. Brown Power Generation Plant, and will be powered by renewable energy coupled with battery energy storage.

DAC – Air Contaminants



DAC – Local Conditions

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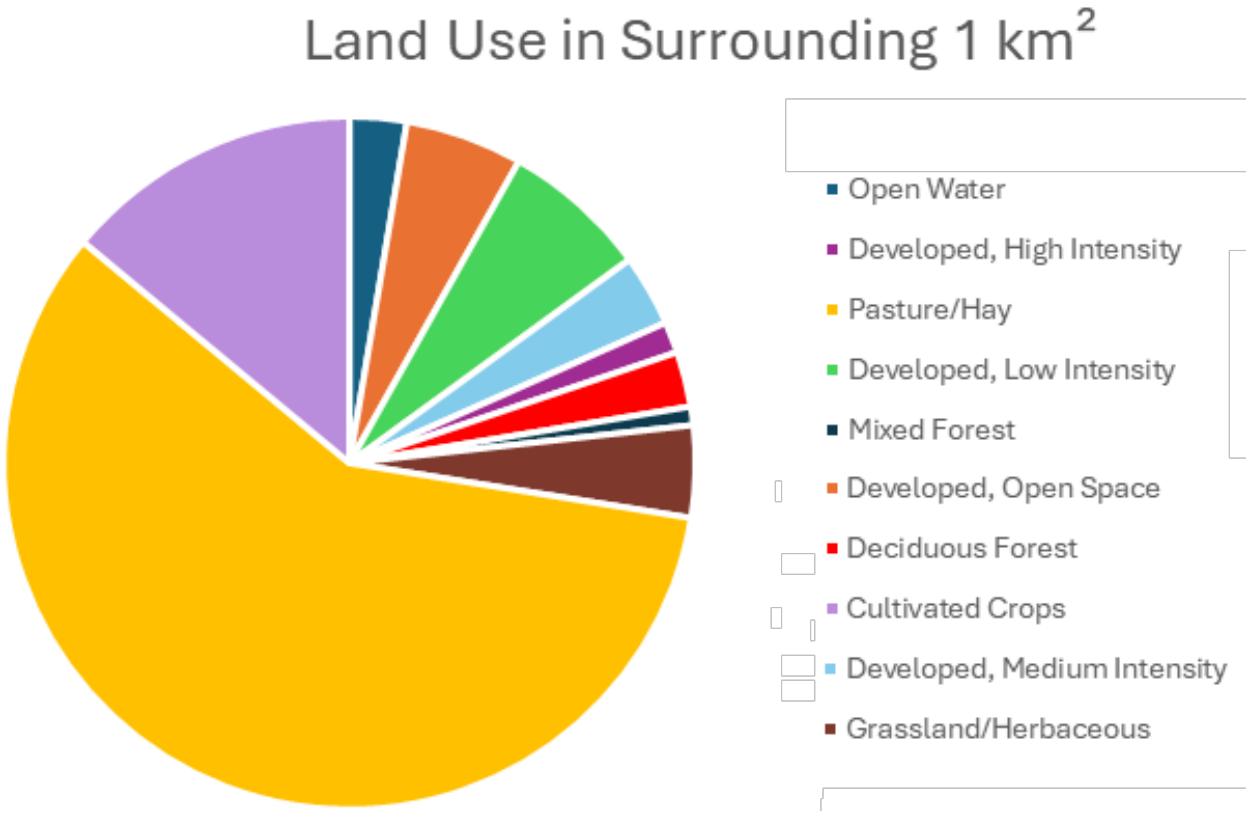
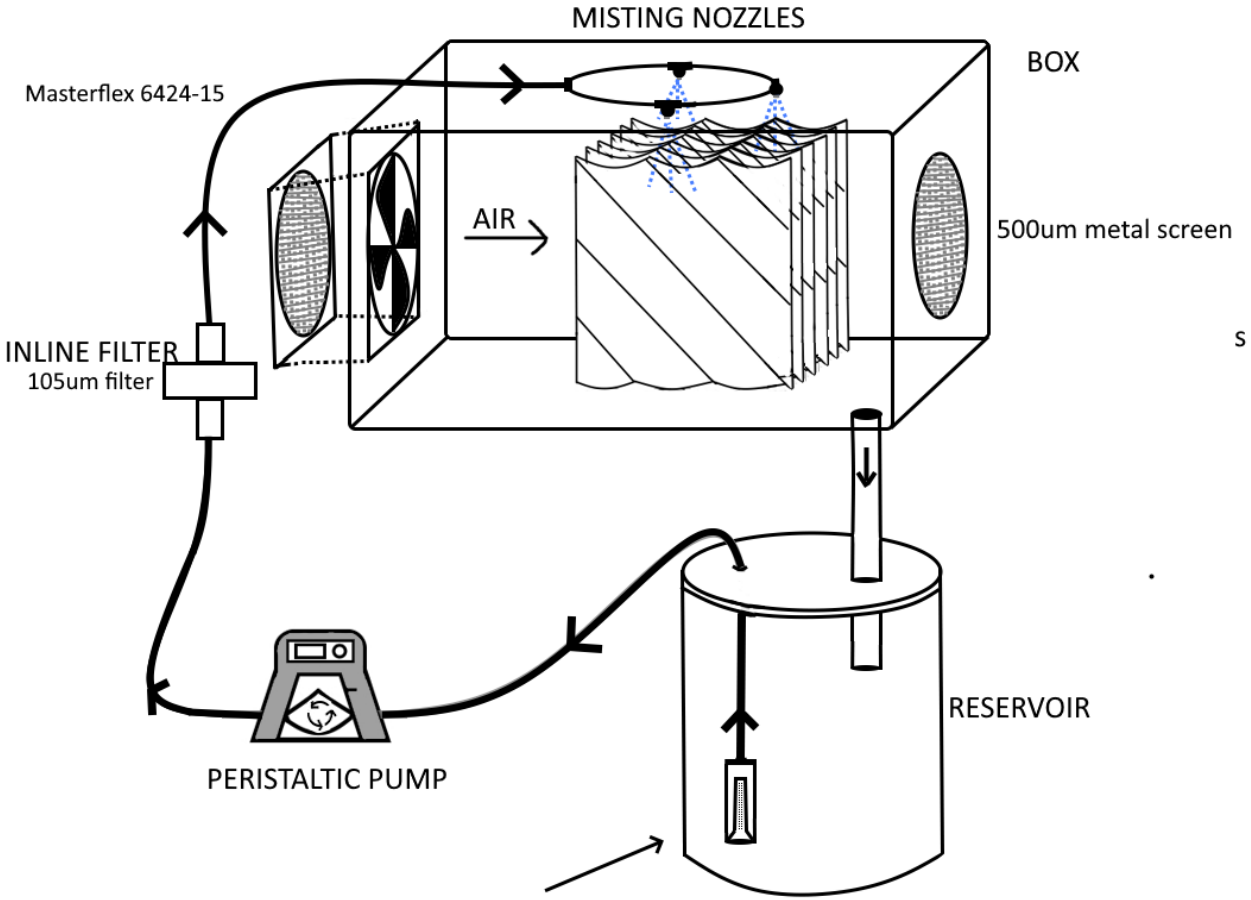


DAC – Testing Apparatus



green very fine mesh filter screen, 0.010 in x 0.013 in (included) to prevent clogging

DAC – Testing Conditions

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- Every 100 hours the fan screens and particulate filters were cleaned, and the solution was plated on potato dextrose agar (72 hr incubation) for bacterial and fungal growth

- The experiment was performed across three 500-hour testing phases.
  - Phase I (tap water control) - May
  - Phase II (0.3M KOH) - June/July
  - Phase III (tap water and 0.3M KOH) - July/August

- At the end of each phase, the H_2O and KOH solutions were filtered, and the filters were weighed to calculate a weight and contamination profile.

Slime Growth in Tubing

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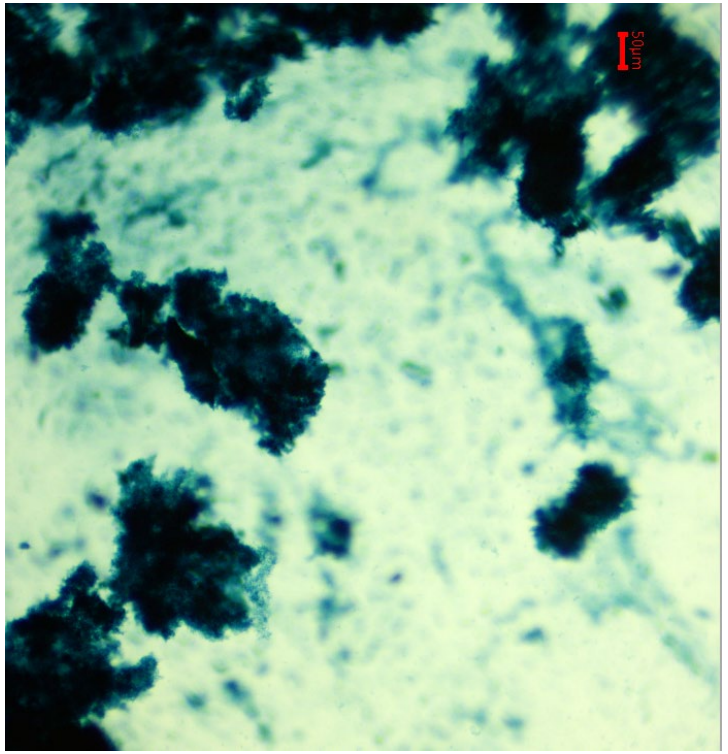
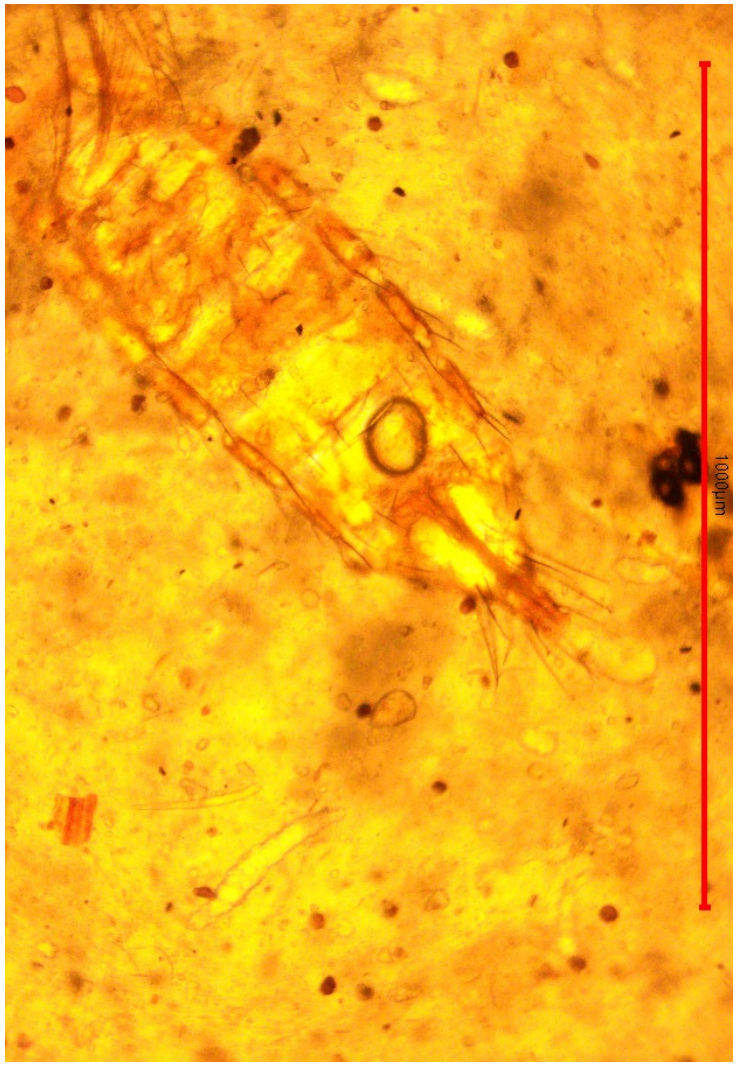
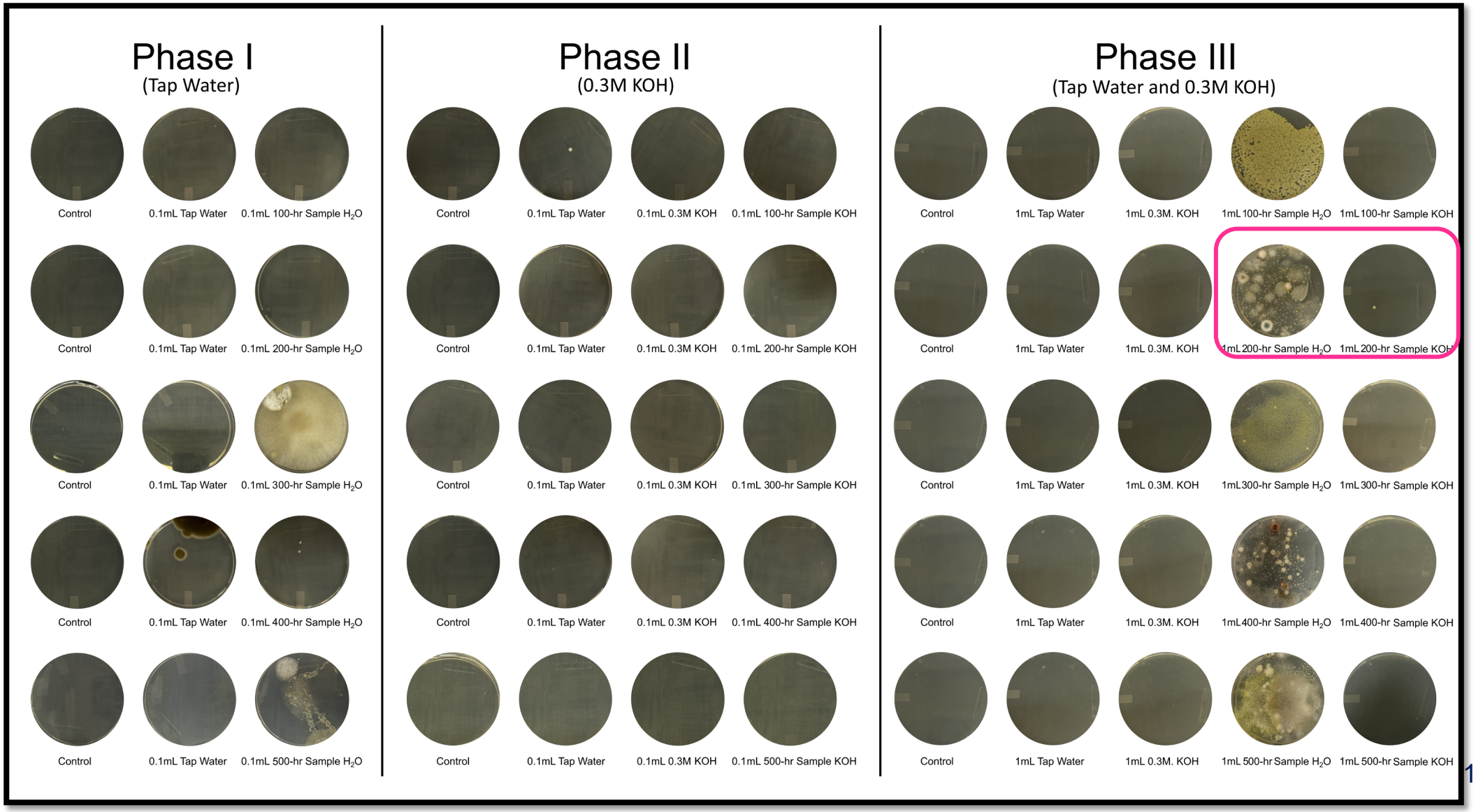
Slime growth within tubing and microscopic images taken after plating (likely zooplankton)



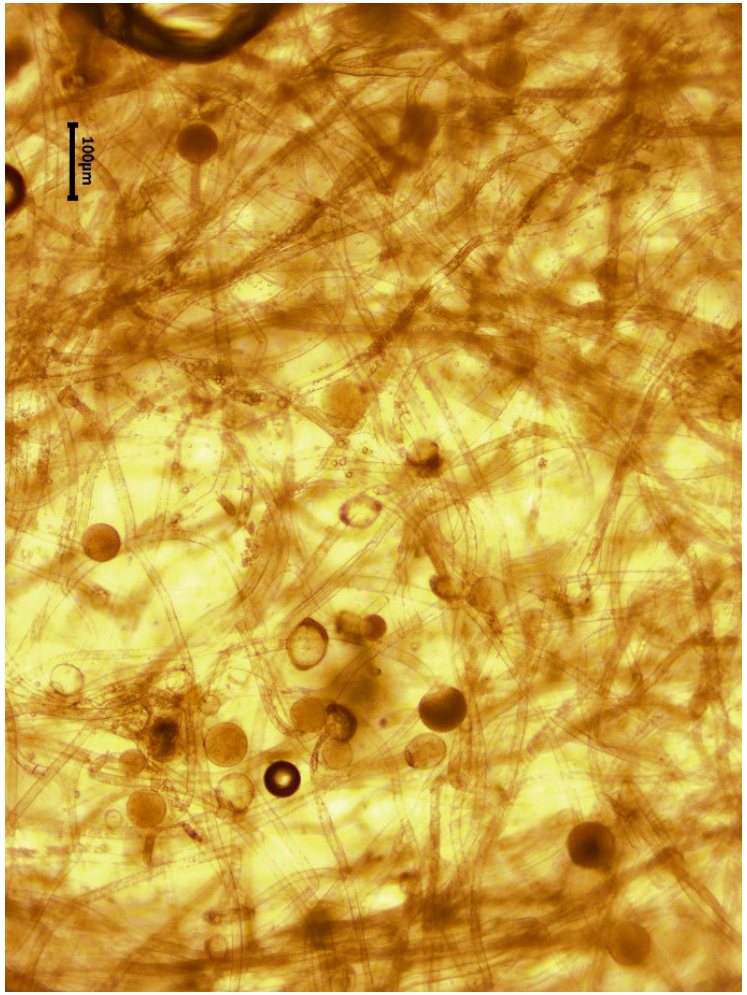


Bacteria and Fungal Growth

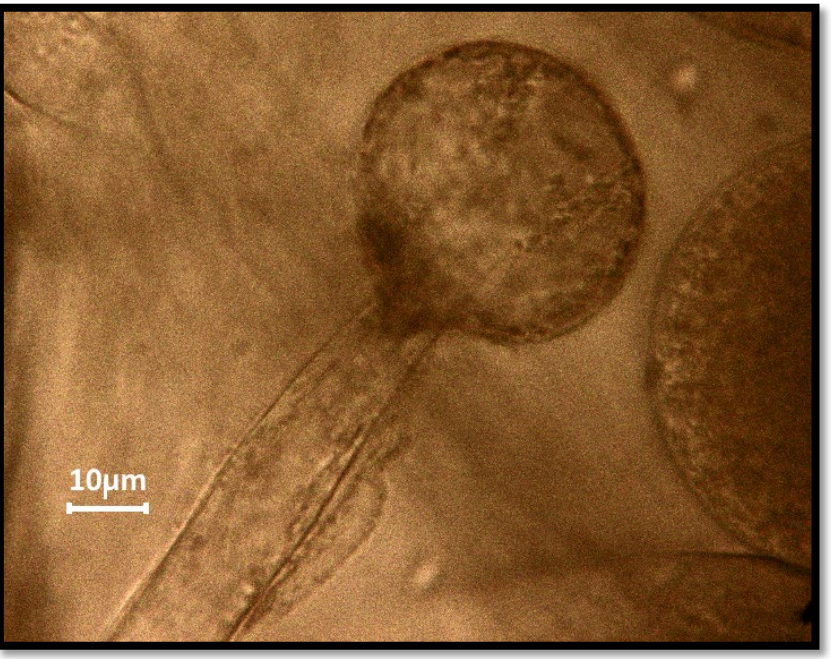
80% of H_2O samples showed bacteria or fungal growth. KOH showed fungal growth at 200 hours of runtime

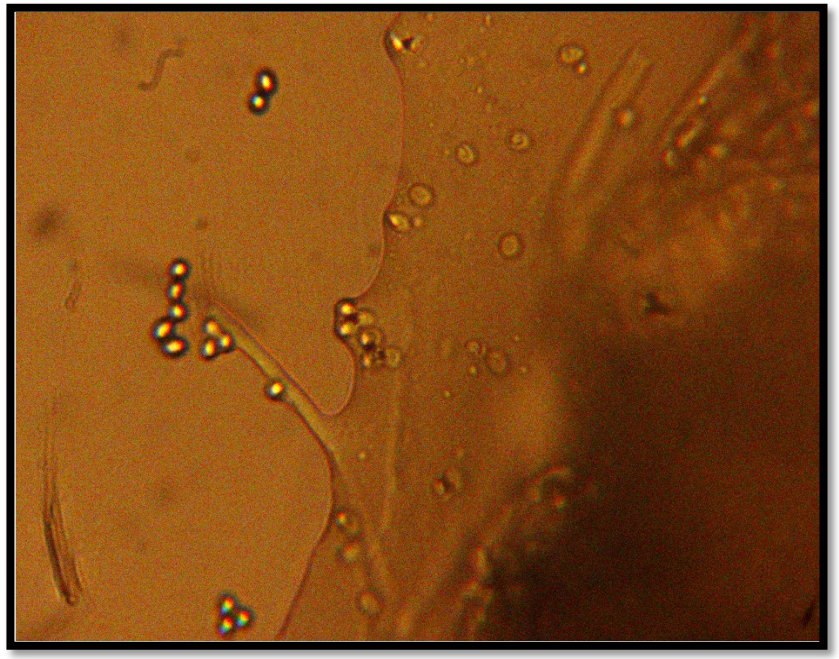


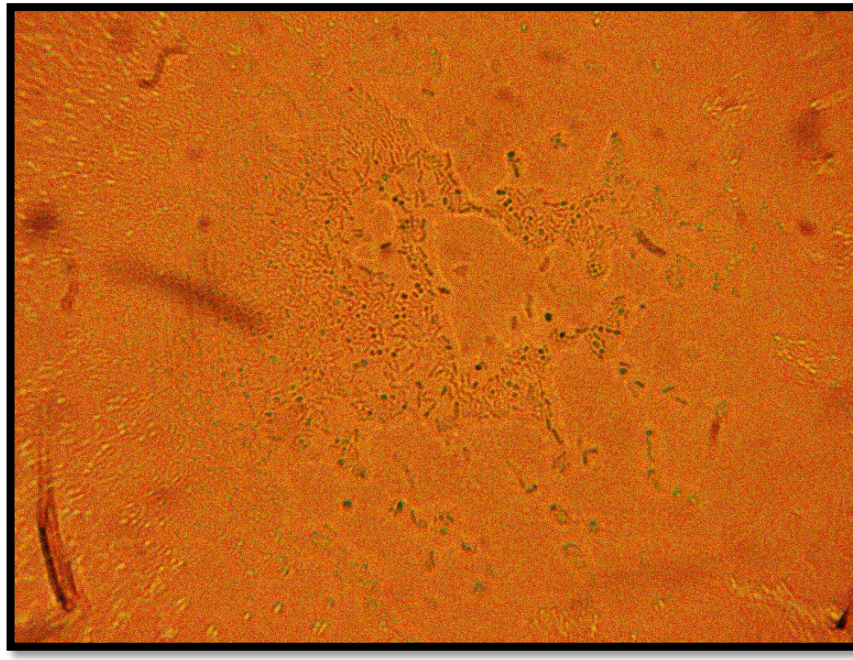
Bacteria and Fungal Growth



Bacteria and Fungal Growth

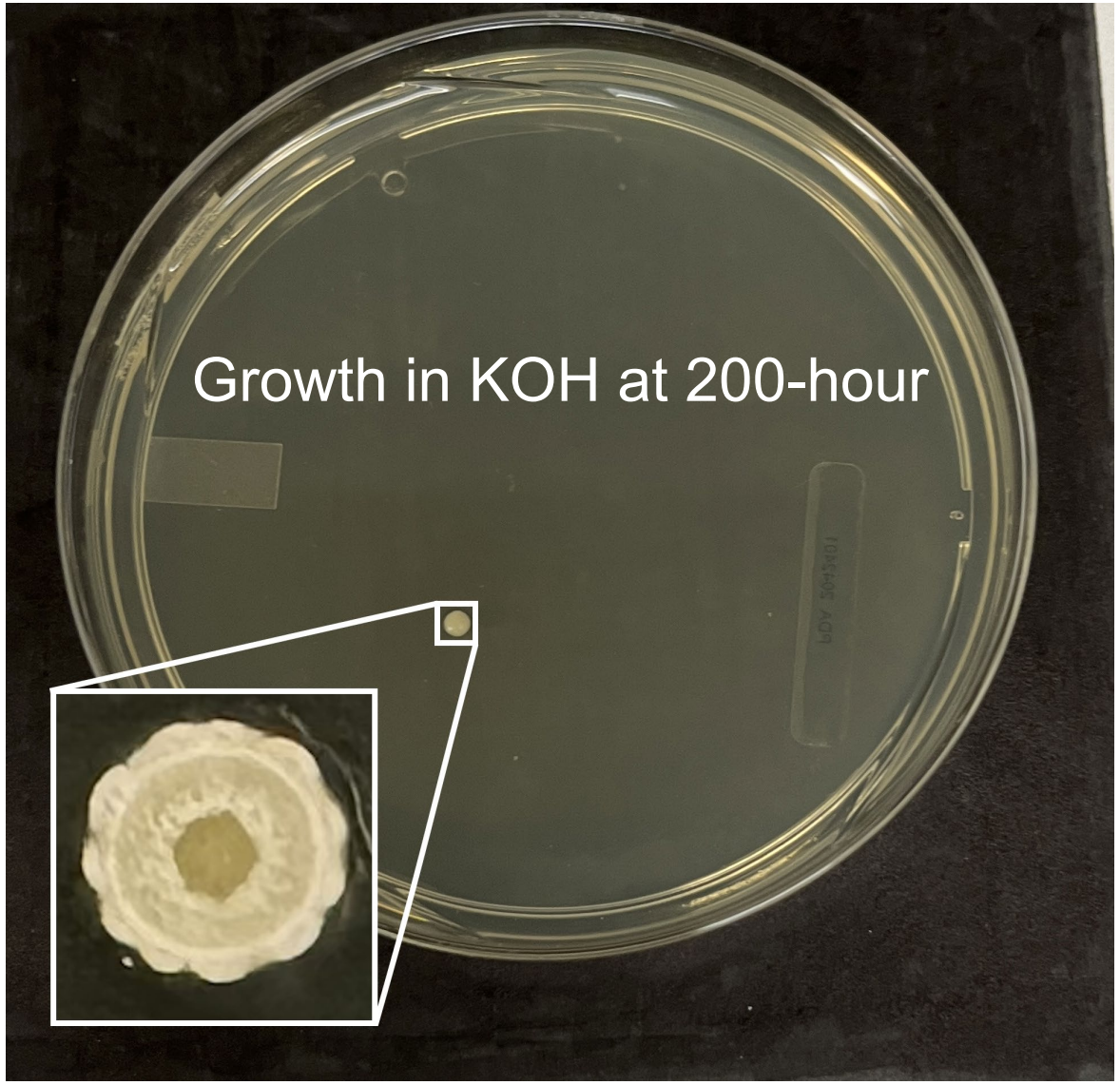






Sporangium, spores, and bacterial growth were visible under microscope

Bacteria and Fungal Growth



Fan Screen - Large Particles

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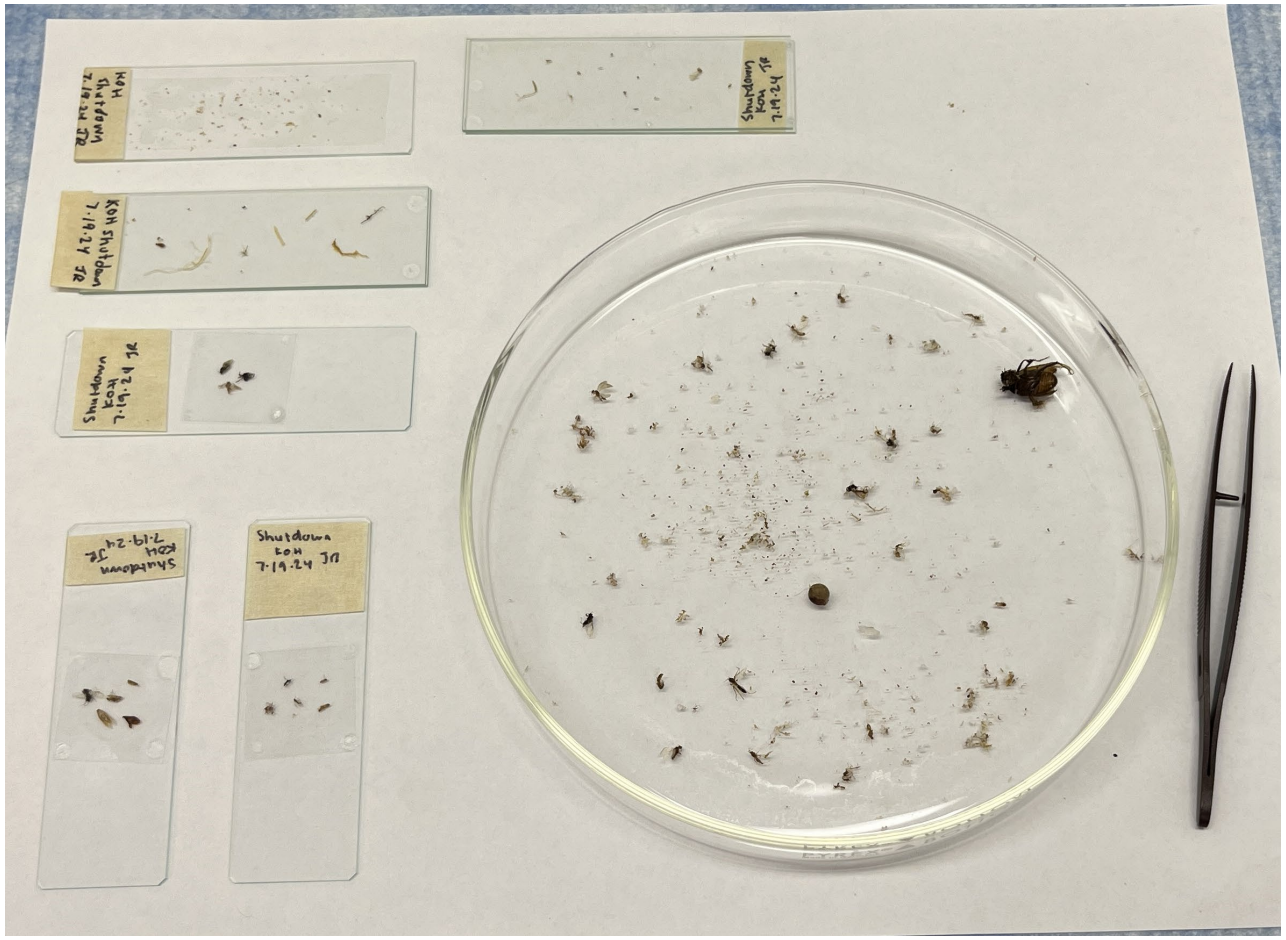
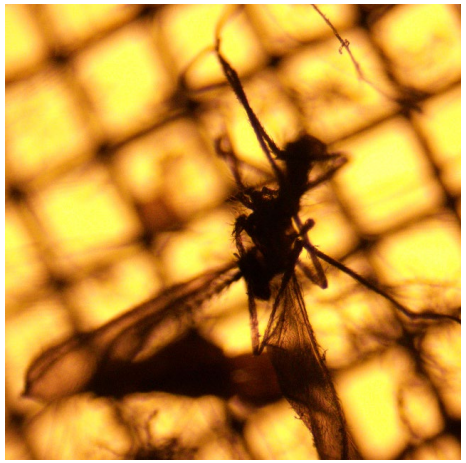
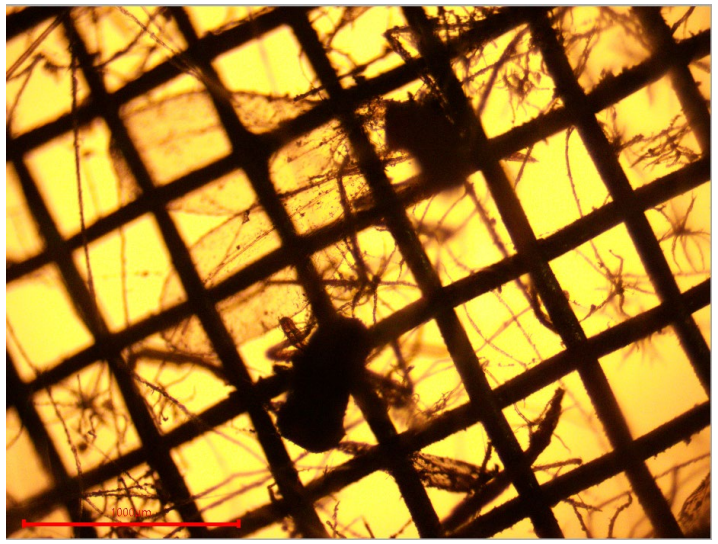
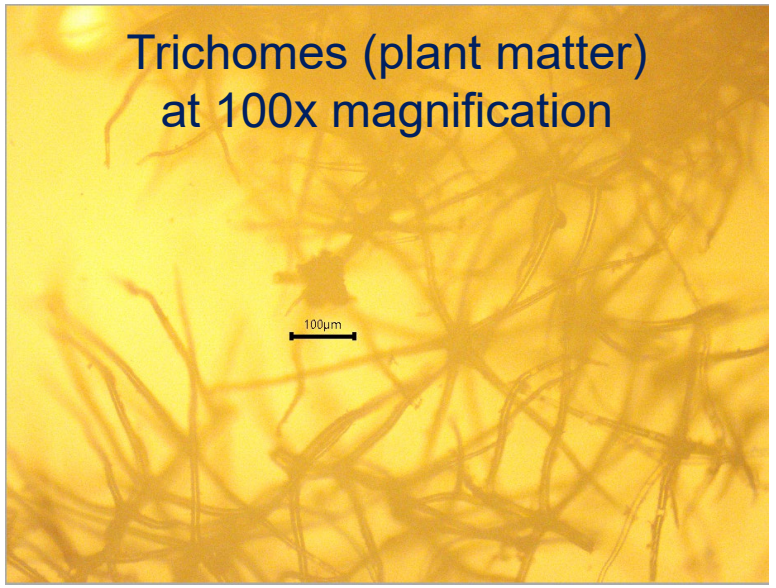
Inlet Fan Screen

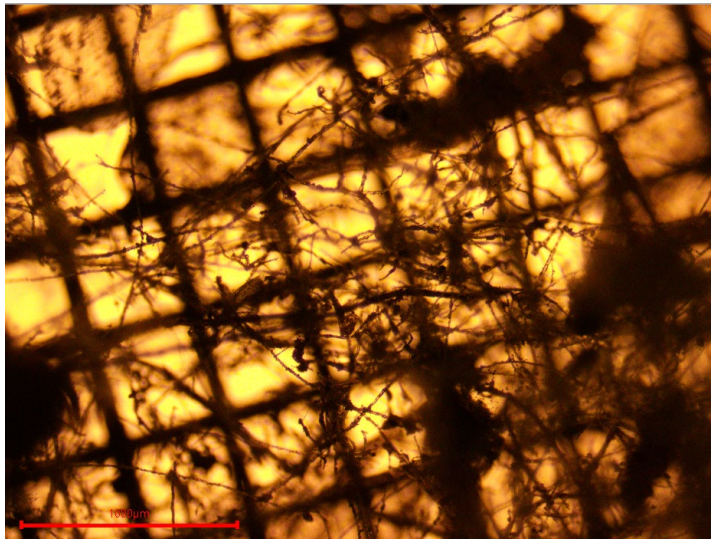


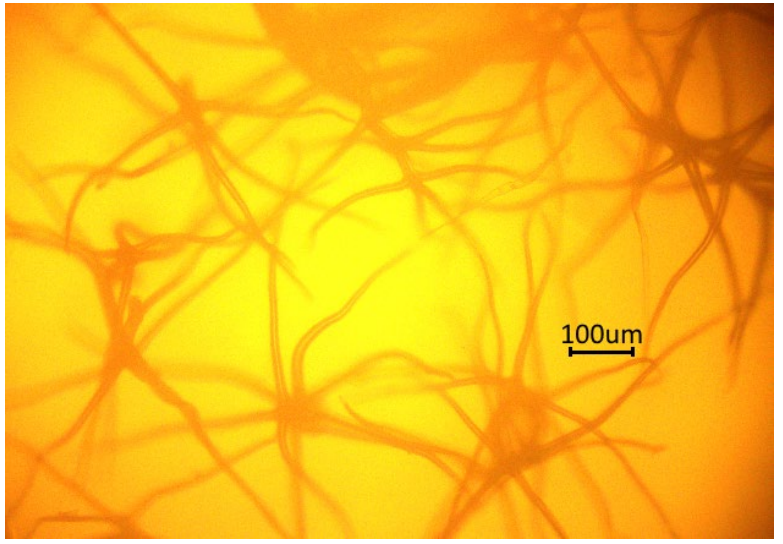
Fan Screen - Large Particles











Within DAC Reservoir - Insects

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Thrips measured to be 1.5 mm long and 0.25 mm wide

Within DAC Reservoir – More Insects

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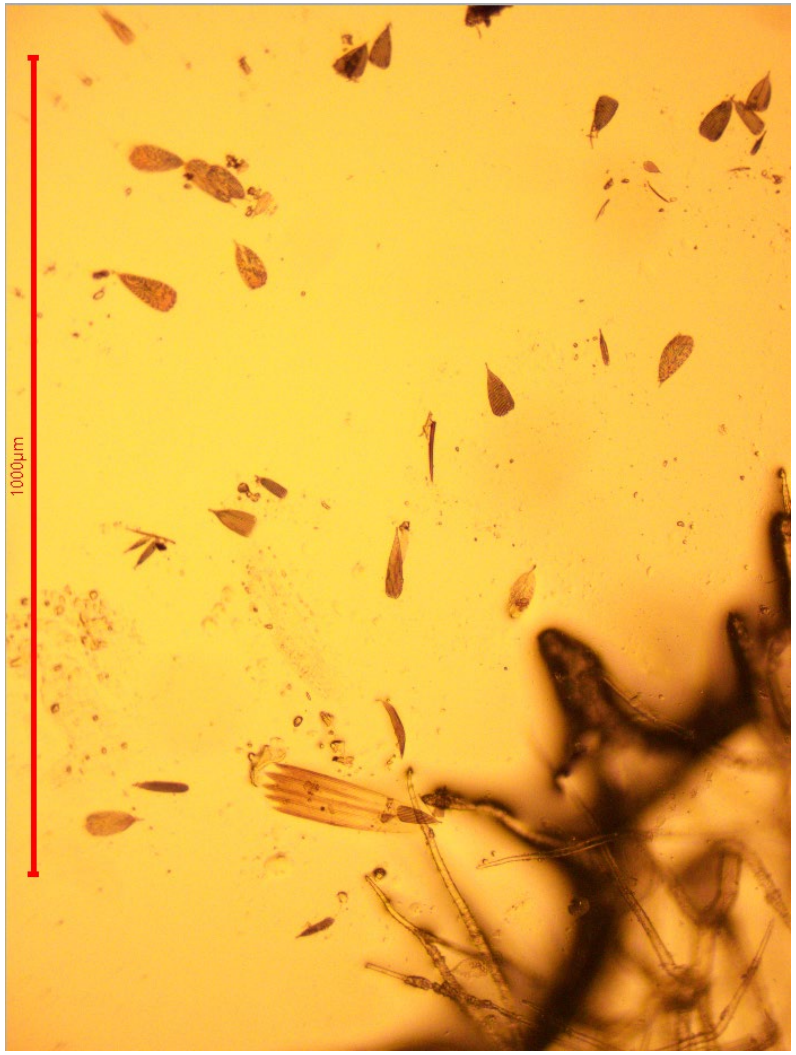
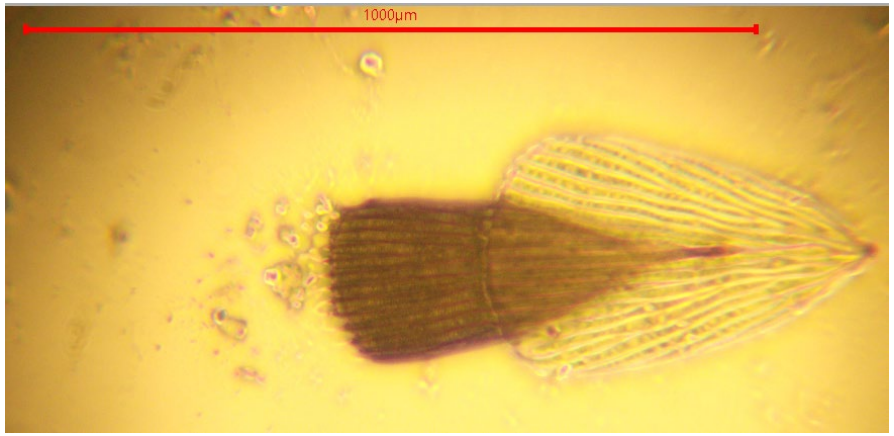
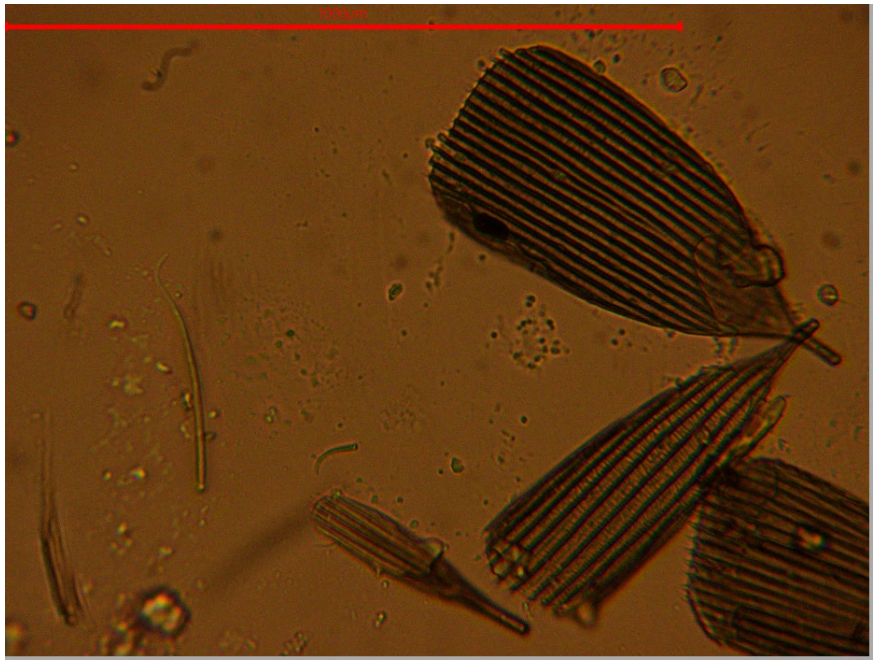
Lepidopteran (winged insect) scales found







Within DAC Reservoir – More Insects

Within DAC Reservoir – Spiders

Arachnid collected from inside DAC absorber

Filtering of Smaller Particles

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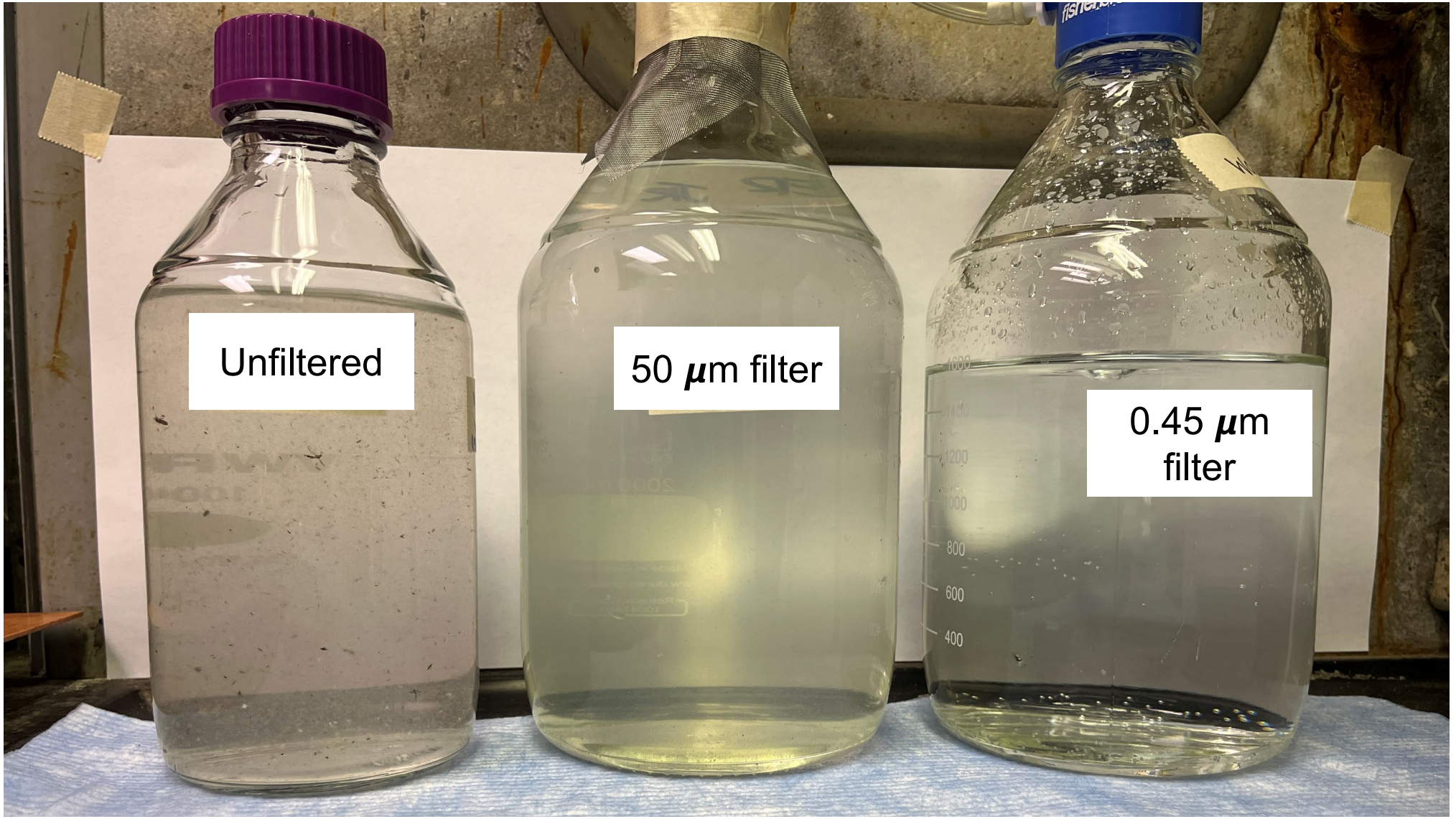

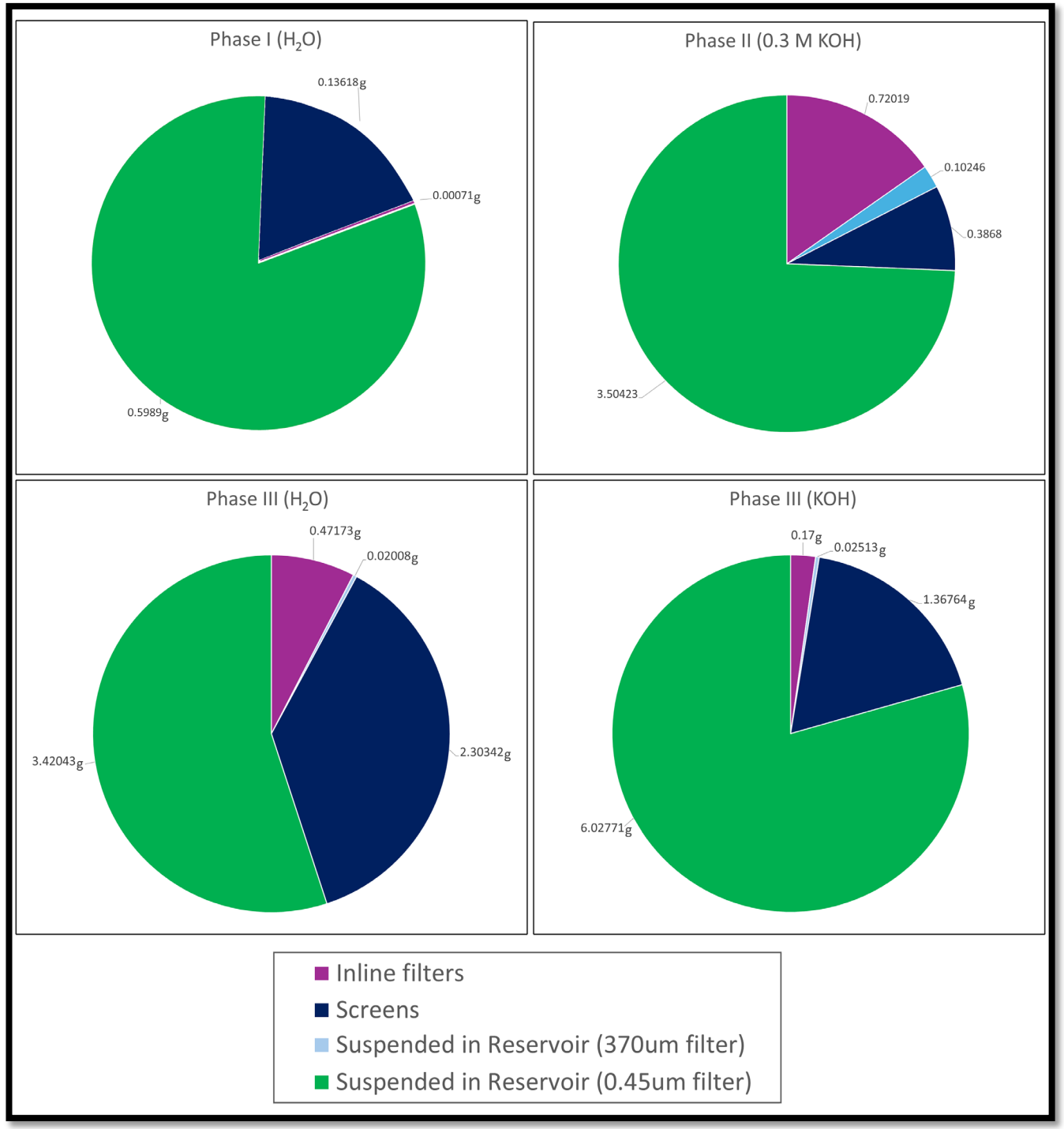

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External screens: large bulk material

Inline filters: particles > 105 μm

Reservoir filter: particles > 370 μm

Reservoir filter: particles > 0.45 μm

Majority of biological mass collected was from within the DAC reservoir and below 370 μm in size.

Filter down to 0.45 μm was needed to remove all biological contamination

Conclusions

- Macroscopic and microscopic biocontamination can occur in DAC systems leading to plugging of filters and spray nozzles

- Fungal growth is possible even in higher pH systems

- Multiple stages of filtration in DAC systems will likely be necessary to mitigate biocontamination and allow for sustained capture and will be impacted by local conditions and seasonal changes.

- *Nature will find a way . . . to get inside your DAC*

Acknowledgements

- DOE-NETL : DE-FE0032255
- UK: Xin Gao
- PPL