Jacobs Challenging today. Reinventing tomorrow.

1,4-Dioxane Cometabolic Biological Treatment in a Fluidized Bed Bioreactor: Bench- and Full-Scale Results

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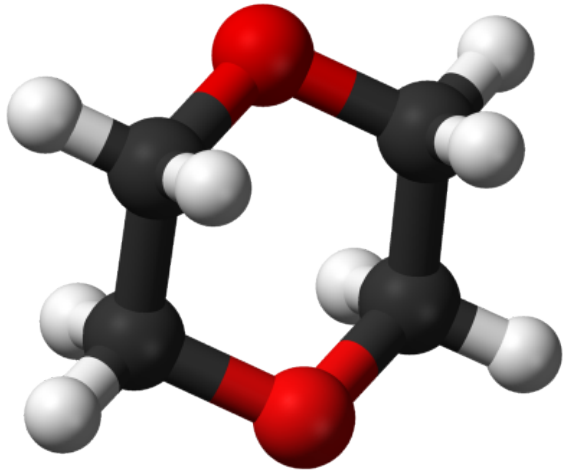
Introduction

- Arnold AFB operates 4 groundwater treatment systems to remove CVOCs from groundwater and control sources of groundwater plumes
- Jacobs is conducting a Corrective Measures Study to add treatment to remove 1,4-Dioxane from system effluent
- Jacobs has conducted bench and pilot scale tests of an aerobic cometabolic bioreactor to remove 1,4-dioxane from system effluents
- This presentation discusses the biological treatment efforts

1,4-Dioxane

- 1,4-dioxane – a cyclic ether, with multiple industrial uses,
  - Added to solvent blends as a sacrificial radical adsorber (stabilizer)
  - Used in cooling oils and cutting oils, and many other uses
  - Industrial waste
- Often associated with TCE and TCA and their degradation products
  - Commonly blended with TCA
  - Metal working
- USEPA Tapwater Regional Screening Level is 0.46 µg/L

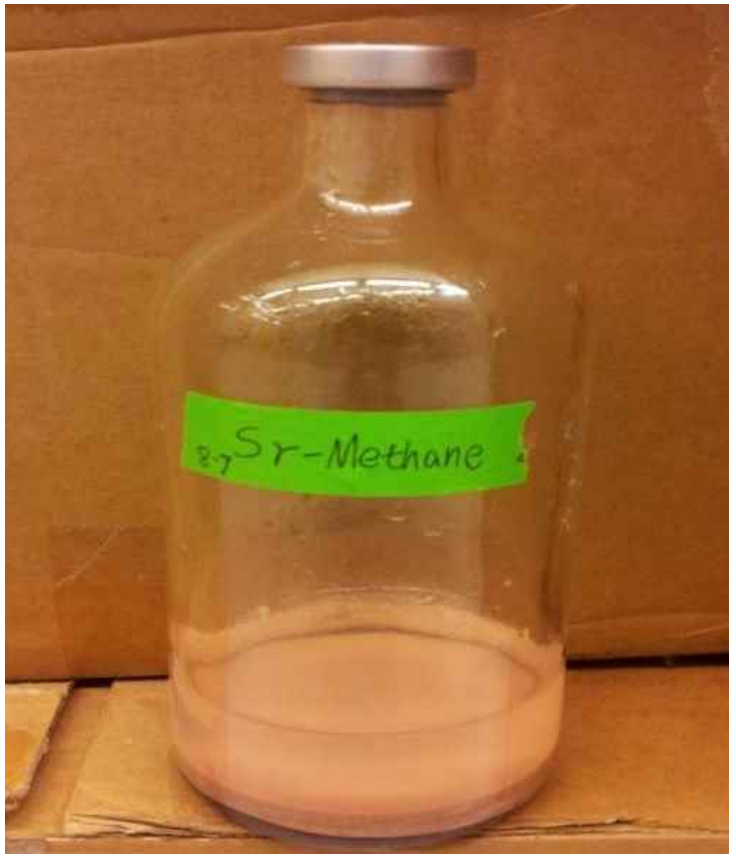


1,4-Dioxane – A cyclic ether that is very stable and entirely miscible

Chemical models are in the public domain, accessed via Wikipedia

1,4-Dioxane Treatment

- Difficult to treat
  - Entirely miscible in water
    - Not well treated by stripping, sparging or SVE
  - Does not adsorb well to most activated carbon
  - Does respond well to oxidation and specialty adsorbent
  - Biological treatment under specific circumstances
    - Intentional biological treatment is relatively new (mostly in the last 5 years)
    - Successful in a few bioreactors
    - In situ biological treatment systems



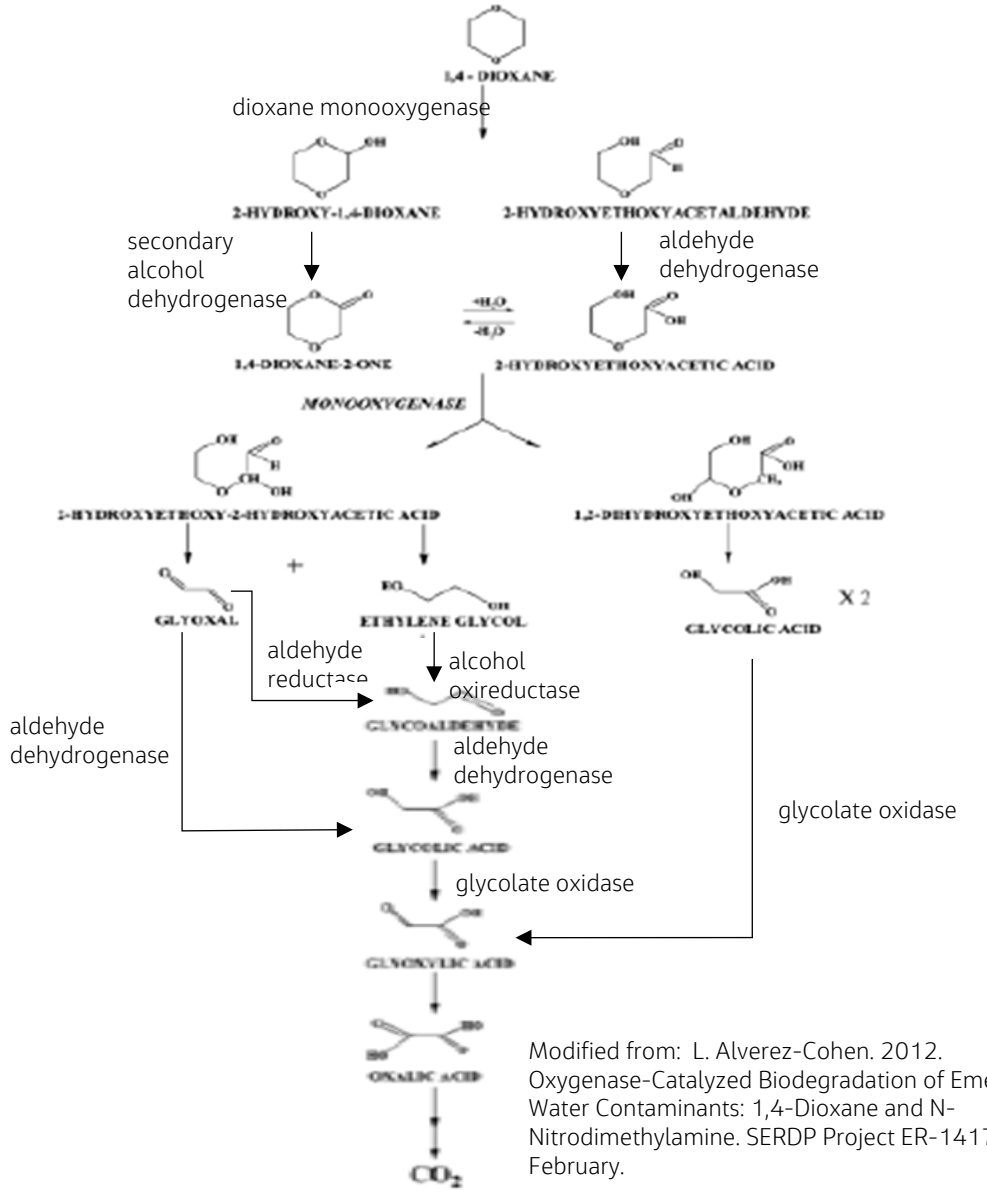
1,4-Dioxane Test Microcosm

Photograph: Rice University

Biological Treatment

Biological Treatment is Specific

- 1,4-Dioxane can be metabolized at higher concentrations (near-ppm and higher) by a small group of organisms
- 1,4-Dioxane can be cometabolized in the presence of the correct substrate
  - Cometabolism – fortuitous degradation of the target compound in the presence of enzymes intended to degrade a different compound
  - A primary substrate is degraded to produce enzymes that degrade the target compound
- Treatment requires the correct enzymes and the enzymes correct primary substrate
- 1,4-dioxane is a less preferred target of cometabolism



Modified from: L. Alverez-Cohen. 2012. Oxygenase-Catalyzed Biodegradation of Emerging Water Contaminants: 1,4-Dioxane and N-Nitrodimethylamine. SERDP Project ER-1417. February.

Arnold AFB

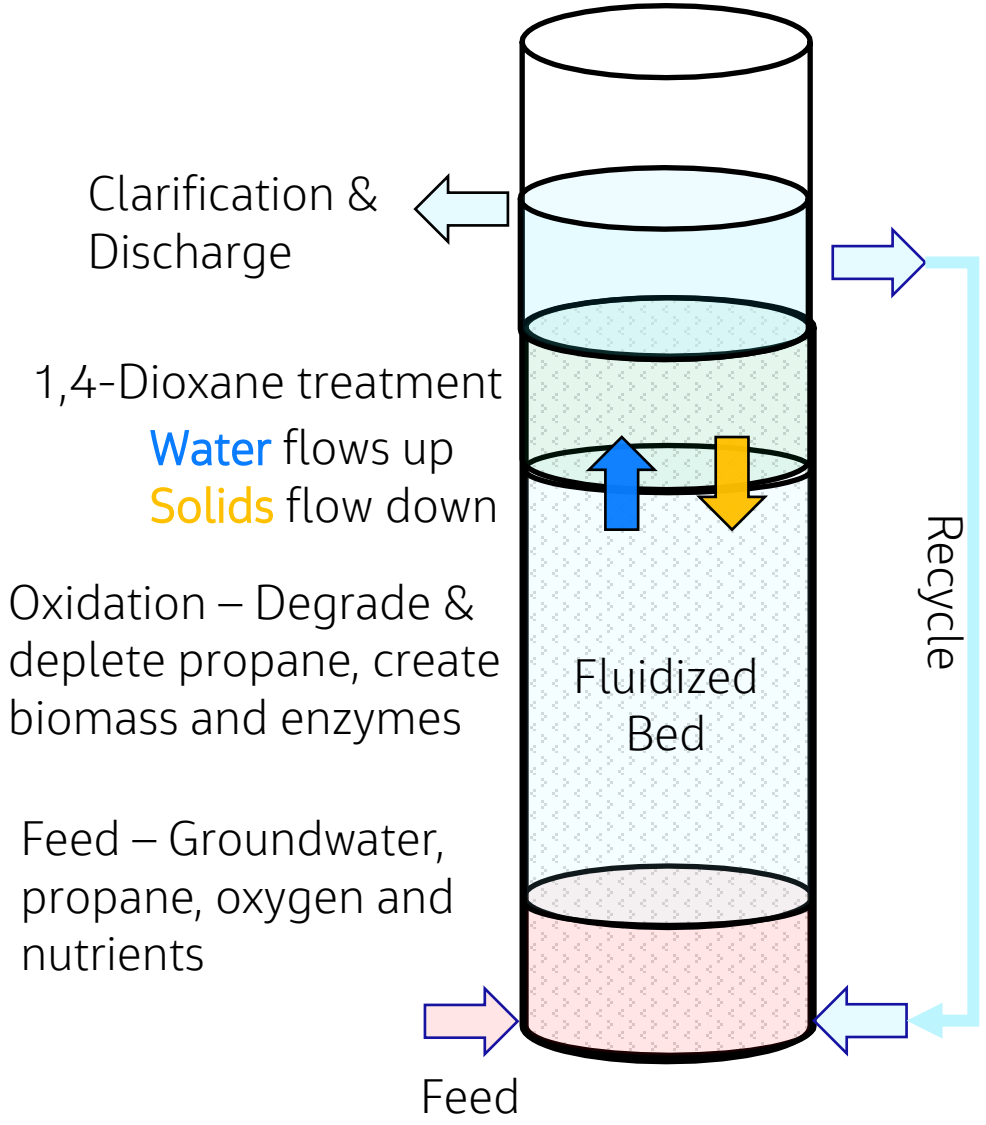
- Arnold AFB, Central Tennessee
  - ~ 1 hour north of Huntsville, Al
- Karst geology
- 4 small (20-200 gpm) groundwater treatment units with air strippers
- 1,4-DX passes through the air strippers at 2-50 µg/L
  - Treatment goal is the RSL of 0.46 µg/L
- Site WP006 (waste pit at old “landfill”)
  - 20-30 gpm
  - <20 µg/L 1,4-dioxane
- Site is remote, at the end of the power line

A Fluidized Bed Bioreactor

Photo courtesy Envirogen

Fluidized Bed Bioreactor (FBR)

- FBR selected because of success treating NDMA using propane cometabolism
- FBR works by recirculating water to fluidize the “bed”, microbes grow on the reactor bed
- The reactor bed is made of granular activated carbon
- Microbes grow and produce enzymes near the bottom of the bed and move up with flow
- As the propane is depleted, the target compound is degraded by excess enzyme
- Clarification occurs at the top of the reactor to conserve solids; clean water is discharged



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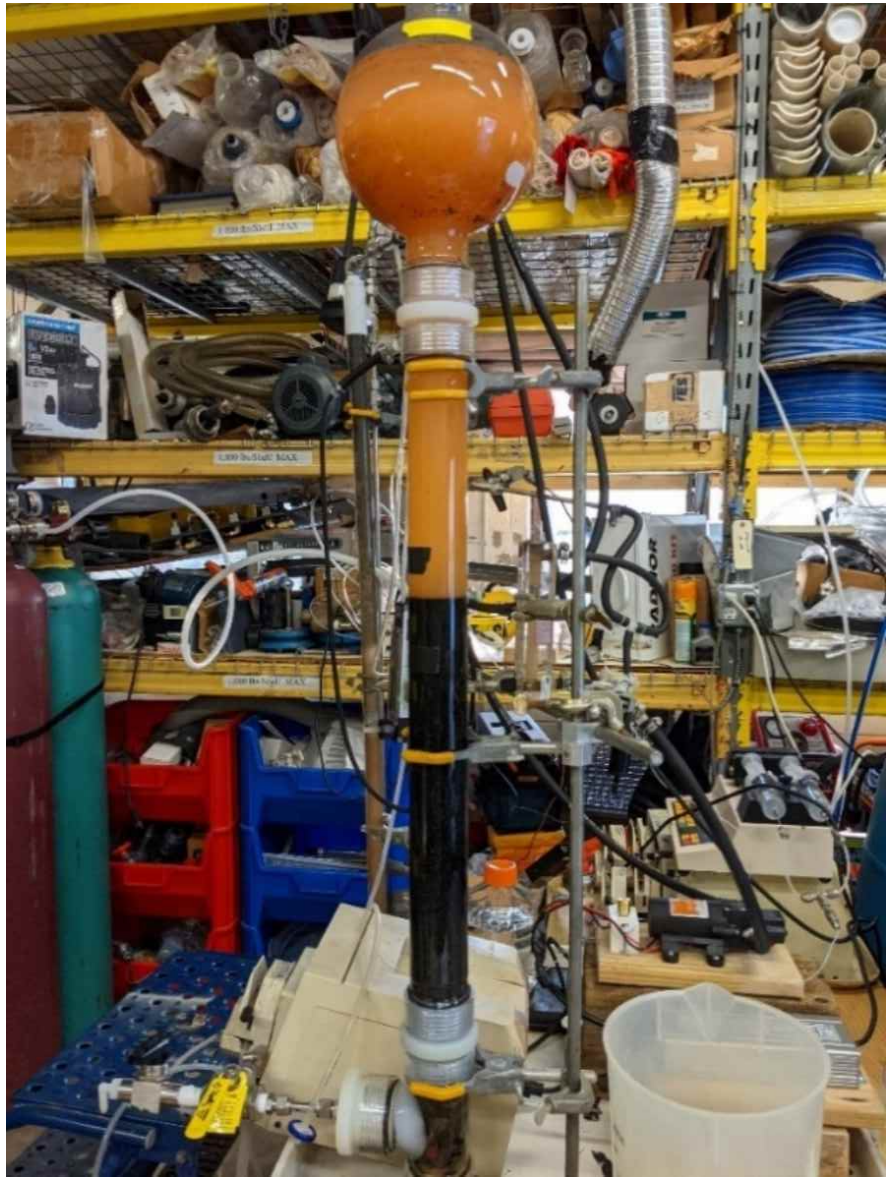
Bench-Scale Lab Testing

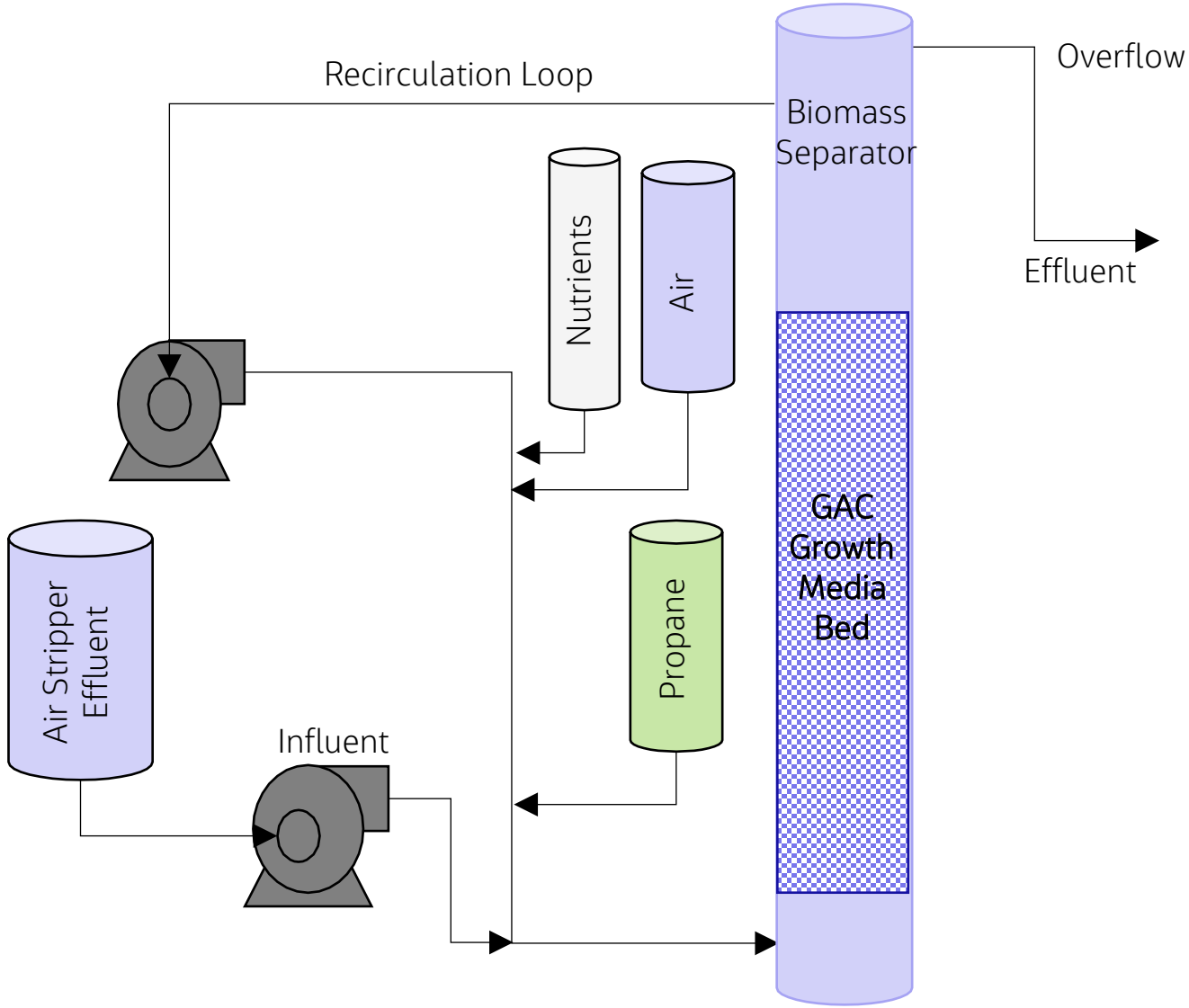
- Set up test in APTIM's Test Laboratory, Lawrenceville, NJ
- Testing was intended as a "proof of concept" and to help understand how the process would work
- Used air stripper effluent that was drummed and shipped to the lab
- System was fed nutrients, propane and oxygen and was inoculated with an ENV 425 (orange material in photo)
  - ENV 425 was selected based on a screening of cultures and because it was used in a prior version of the system
- Propanol was used to supplement the propane, grow the culture and build the biomass
  - Propanol can grow ENV 425 rapidly, but does not lead to production of the correct enzymes (PPO and SCAM)



Laboratory Fluidized Bed Bioreactor

Lab Testing

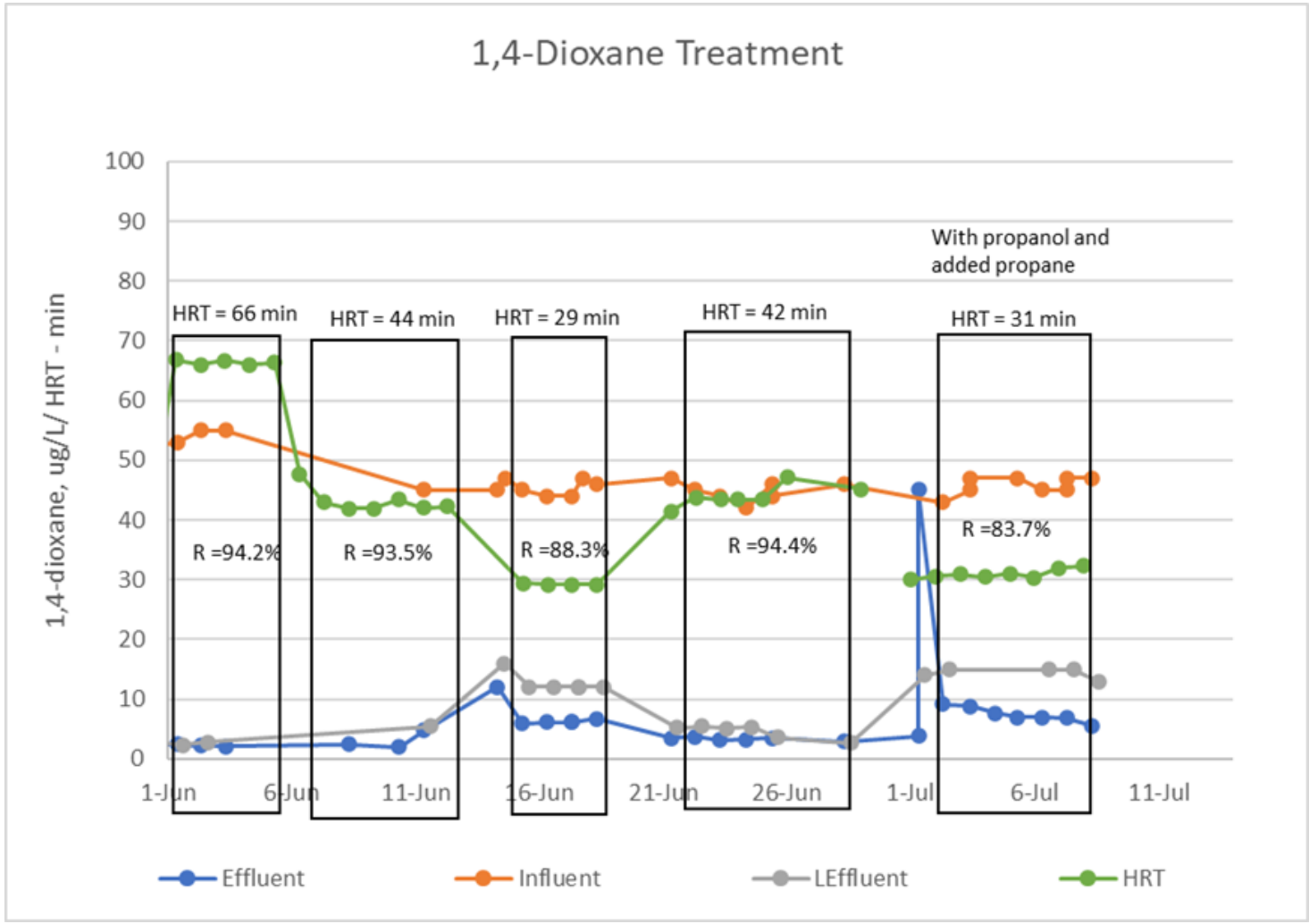
Schematic of Laboratory Fluidized Bed Bioreactor



Lab Testing (2021)

Success!

- ~50 ug/L 1,4-dioxane in the feed
- Removal was consistently 80-90%
- Peak removal was 94%
- Starting the reactor was challenging
  - Difficulties establishing the culture
  - Difficulty maintaining culture
  - Lack of bed growth
  - Media compaction/loss of fluidization
- Treatment similar under starved and fed conditions



Results of 1,4-dioxane treatment in the bioreactor

Field Pilot Test

- Construction Complete January 2022
- System inoculated February 2022
- Similar issues in start-up to the bench scale test, began forward feed in June
- System has run continuously since June
- System attained 80 percent reduction in concentration in September 2022
- But:
  - Typical removal has been 10-30 percent
  - Periods of no removal
  - Propanol use
  - We need better removal to meet treatment goals

Fluidized Bed Bioreactor at site SS006

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Challenges

- Propane
  - Line breaks, explosive gas alarms/shut downs, water backing up into the line
  - Modified the propane feed line and system ventilation, frequent blow-down
- Seasonally frequent power outages
  - System is remote, loses power in storms
- System operations
  - Loss and repair of extraction well caused changes in concentrations and flows
  - Stripper upset allowed CVOCs into the system
- Serious consequences to down-time
  - Outages cause loss of circulation and loss of oxygen, degrade the biomass
  - Recovery time is significant, this biomass builds slowly

Return water, with varying amounts of solids

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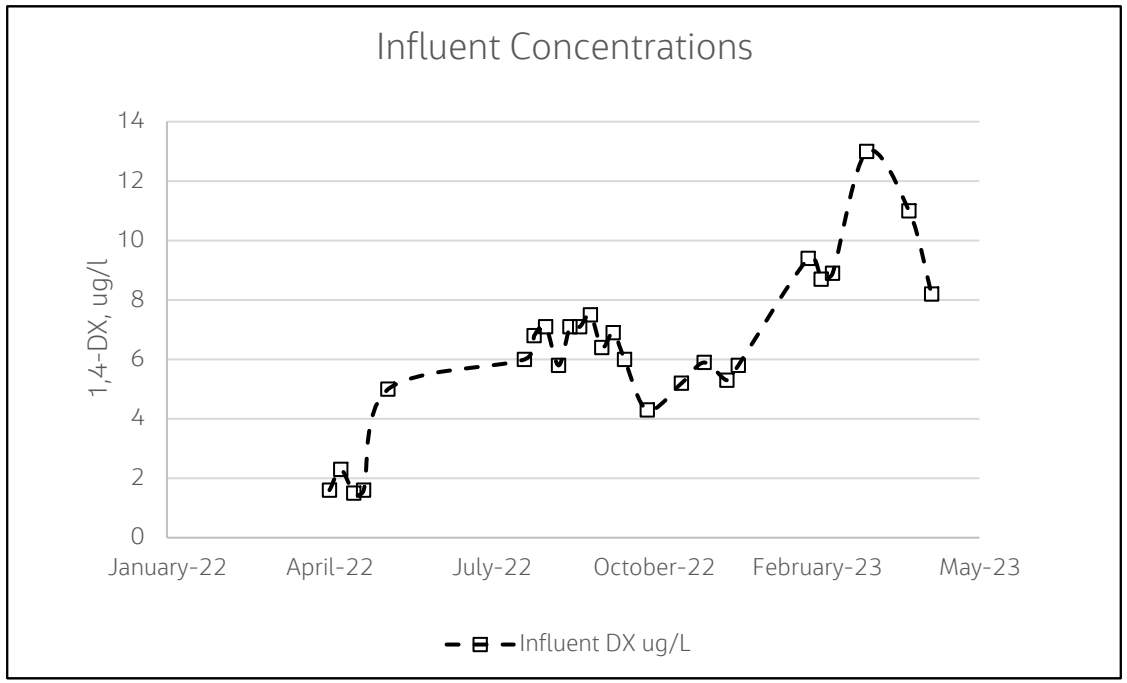
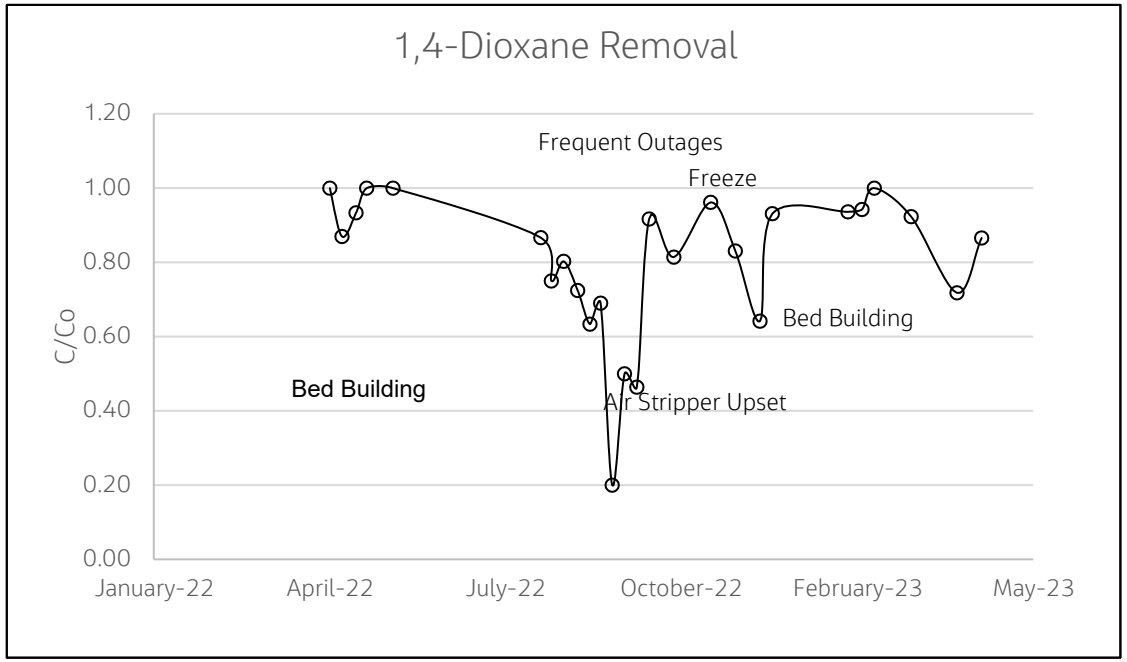
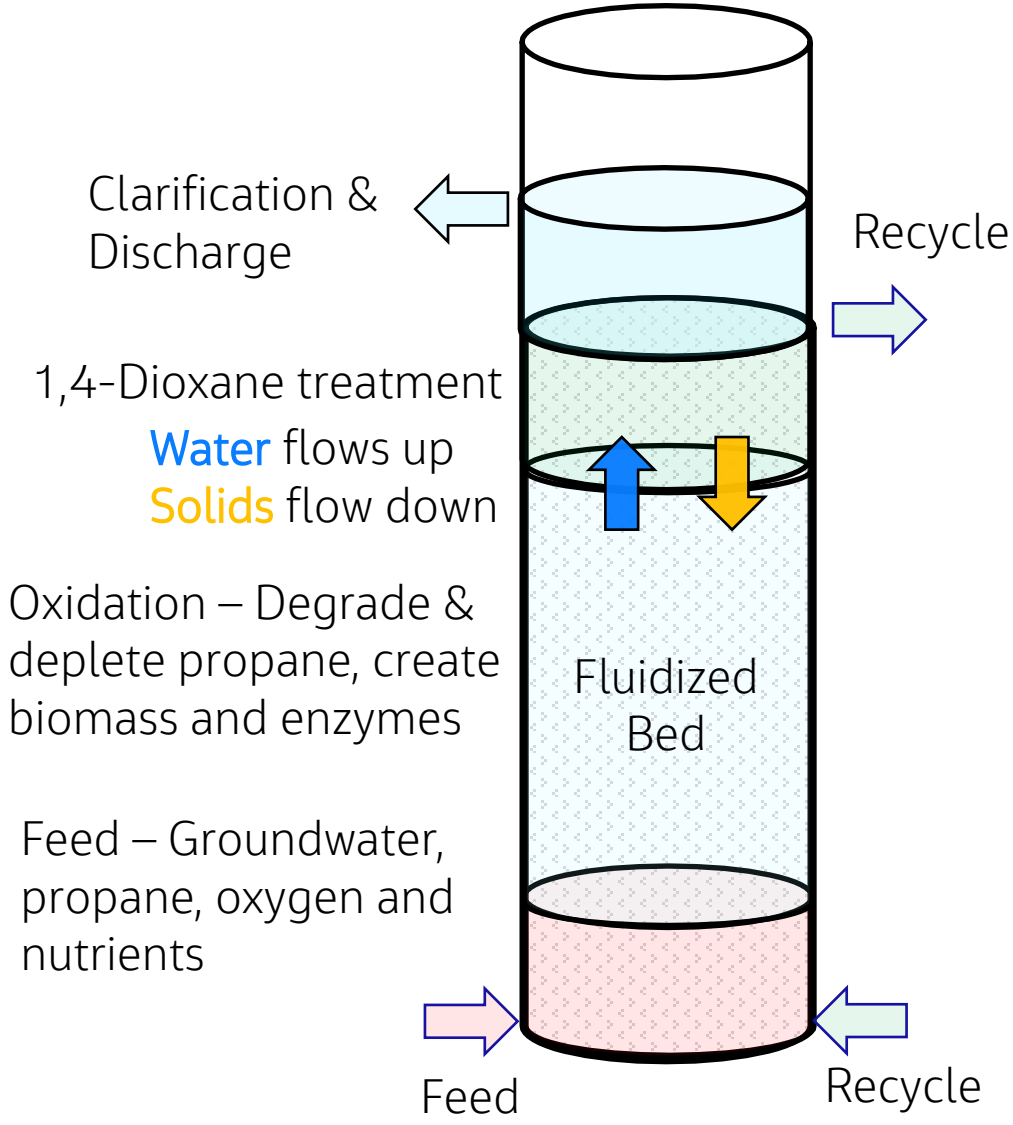
System Performance





Conclusions

- The system is capable of degrading 1,4-dioxane
  - Up to 94 percent at the bench
  - Up to 80 percent in the pilot test
  - Removal with and without propanol
- Propane as a substrate has challenges
- Building and maintaining biomass is critical
  - Start up
  - Consistent operation
  - Response to upsets
- The correct amount of primary substrate sustains the biomass while generating enzymes, but too much substrate can hinder treatment
  - This is a sensitive balancing act



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Path forward

- Carry on!
- Improve up-time through proactive maintenance and response to power outages
- Be aggressive in rebuilding biomass after down time and upsets
  - Use propanol to build biomass
- Continue to tweak the system and evaluate the correct operating conditions/regimes
  - Optimize the continuous propane feed configuration
    - Optimal propane feed
    - Optimal reactor conditions
    - Optimal operating conditions
  - Try intermittent propane feed

System with Insulation

Acknowledgements

- Thanks to co-authors: Todd Webster (Envirogen), Paul Hatzinger (APTIM), Hunter Anderson (AFCEC)
- Thanks to the people and organizations who support this work: Arnold AFB, USACE and USAF; Rachael Barber, JBenny Buice and Jacob Hyde (Jacobs)

Questions?

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Sixth International Symposium on Bioremediation and Sustainable Environmental Technologies
Austin, Texas. May 2023

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