Results from a 1,4-Dioxane Biogeochemical Reactor Field Pilot Test

Claudia Walecka-Hutchison, PhD

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AGENDA

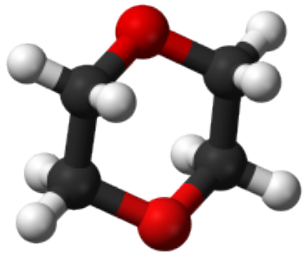
- Site Background
- Subgrade Biogeochemical Reactor (SBGR) Technology Overview
- 1,4-Dioxane SBGR Implementation
  - Design Considerations
  - Construction Lessons Learned
  - Bioaugmentation
  - Initial Results
- Next Steps

Site Background

- Chemical manufacturing facility in North America
- Soil and groundwater impacted primarily by chlorinated volatile organic compounds (CVOCs), benzene and 1,4-dioxane
- Various remedial actions have been implemented to address CVOC and benzene contamination:
  - Air Sparge/Soil Vapor Extraction (AS/SVE) System
  - Aerobic cometabolic biosparging (ACB) System
    - ✓ Total CVOCs and benzene concentrations reduced 97% using these technologies
  - Not surprisingly, concentrations of 1,4-dioxane remain unchanged

Challenges Associated with 1,4-Dioxane

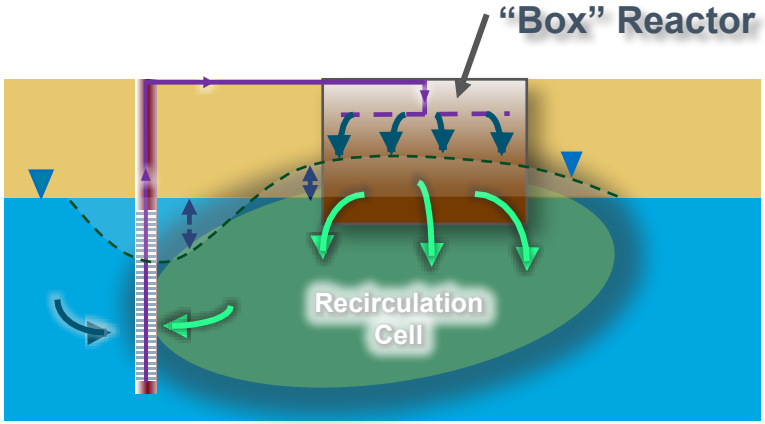
- 1,4-Dioxane was used as a stabilizer for 1,1,1-trichloroethane
- Most treatment options that target CVOCs (e.g., soil vapor extraction, sorption, and biological treatments) are generally not very effective at treating 1,4-dioxane
- Some existing treatment methods for 1,4-dioxane, e.g., advanced oxidation processes, are expensive and can create other problems

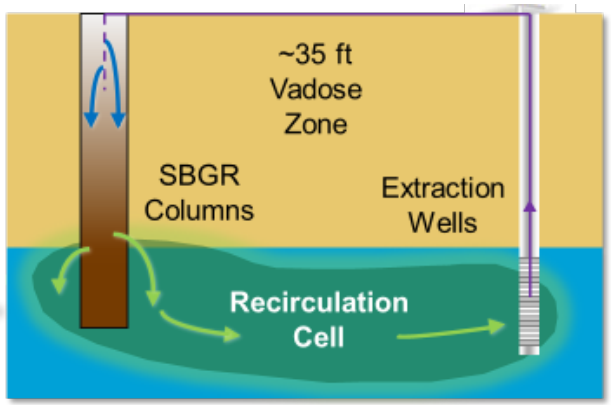


1,4-Dioxane

Technology Overview: Subgrade Biogeochemical Reactors (SBGR)

- SBGRs are a **sustainable treatment technology**
  - Utilize locally-sourced, non-refined carbon sources (such as wood mulch, spent brewery grain, agricultural byproducts, etc.) for establishment of microbial population
  - Site specific media to support treatment of many types of contaminants
- Impacted groundwater is extracted and recirculated through SBGR for treatment
- Different configurations are possible and based on site-specific needs, criteria, or restrictions
  - Box reactor, columns, passive barrier
  - Pumping regimen





"Column" Reactor

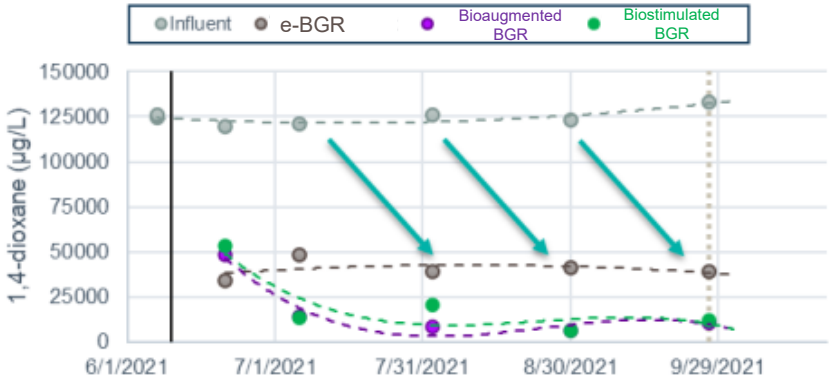
1,4-Dioxane Biogeochemical Reactor Drum-Scale Pilot Test

- Two drum-scale pilots conducted in 2020 and 2021 with three treatment trains to evaluate:
  - Biostimulated Metabolic BGR
  - Bioaugmented Metabolic BGR
    - ✓ UCLA's CB1190 culture (1,4-dioxane specific)
  - e-BGR (electrochemical oxidation) (not topic of this presentation)
- Objectives:
  - Evaluate effectiveness of BGR treatment at concentrations (>100,000 µg/L)
  - Refine design criteria for a full-scale system

1,4-Dioxane Biogeochemical Reactor Drum-Scale Pilot Test

- Influent 1,4-dioxane concentrations ~125,000 µg/L
- **Up to 98% 1,4-dioxane reduction observed**
- Biostimulated metabolic and CB1190 bioaugmented drum-scale BGRs
  - Organic media with air addition
  - Similar performance with and without bioaugmentation
    - ✓ similar microbial profiles
- Hydraulic residence time of 15 days
  - Saw good performance with bioaugmented train at reduced HRTs

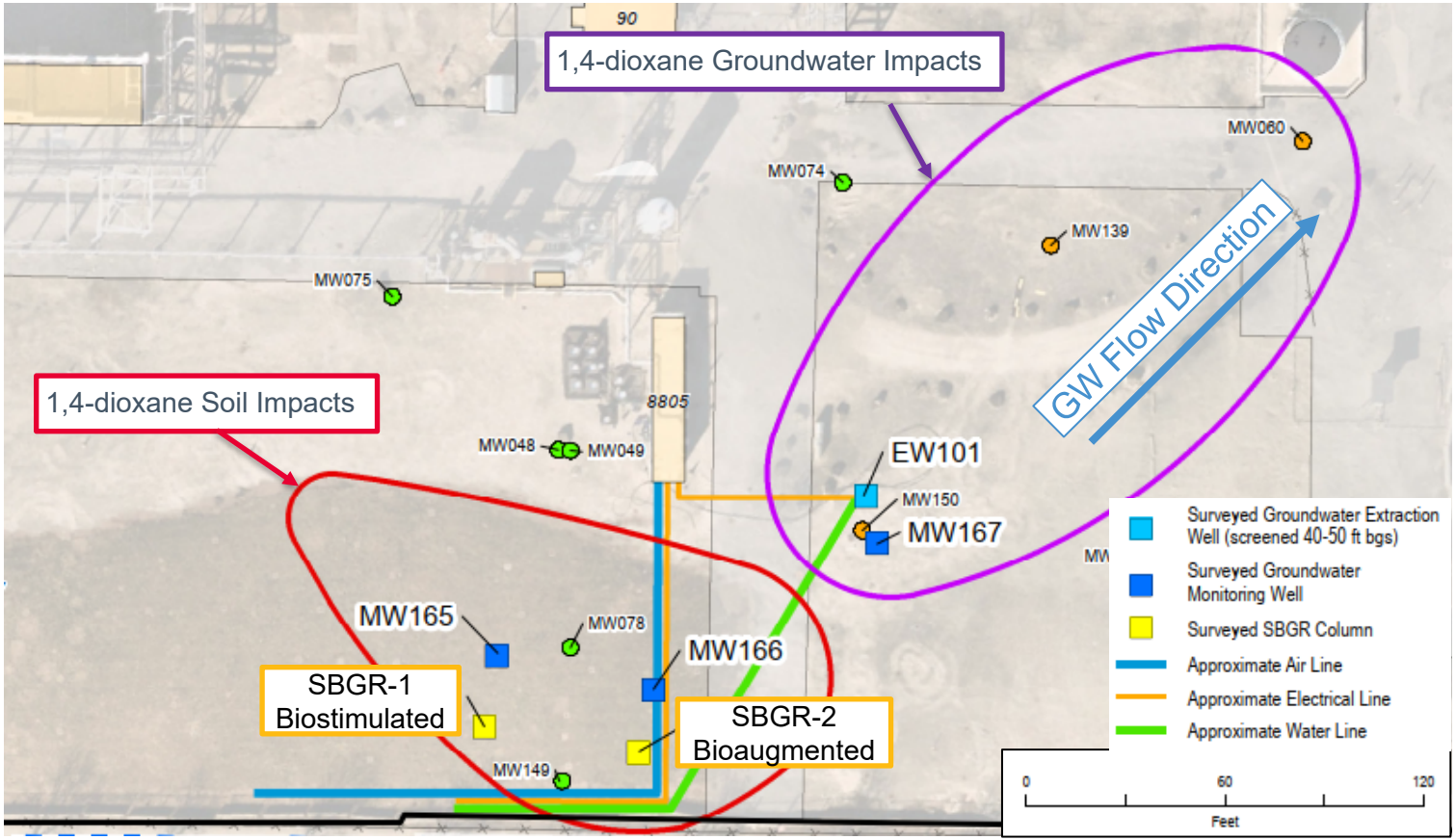
Influent and Effluent Concentrations (15-Day Residence Time)



Basis of Design for SBGR

- Based on drum-scale SBGR findings
- Implement such that system can be expanded to full scale
  - Offers potentially lower life-cycle costs
  - Offers more sustainable solution
- SBGR Design
  - HRT of 15 days
  - Groundwater extracted within core of groundwater impact
  - Infiltrate upgradient of soil source area and groundwater impact
  - Media mixture based on drum scale biostimulated and bioaugmented metabolic drums
  - Column configuration due to aquifer depth
  - Pulsed pumping
- Test both bioaugmentation and native bacteria

In-Situ SBGR Layout



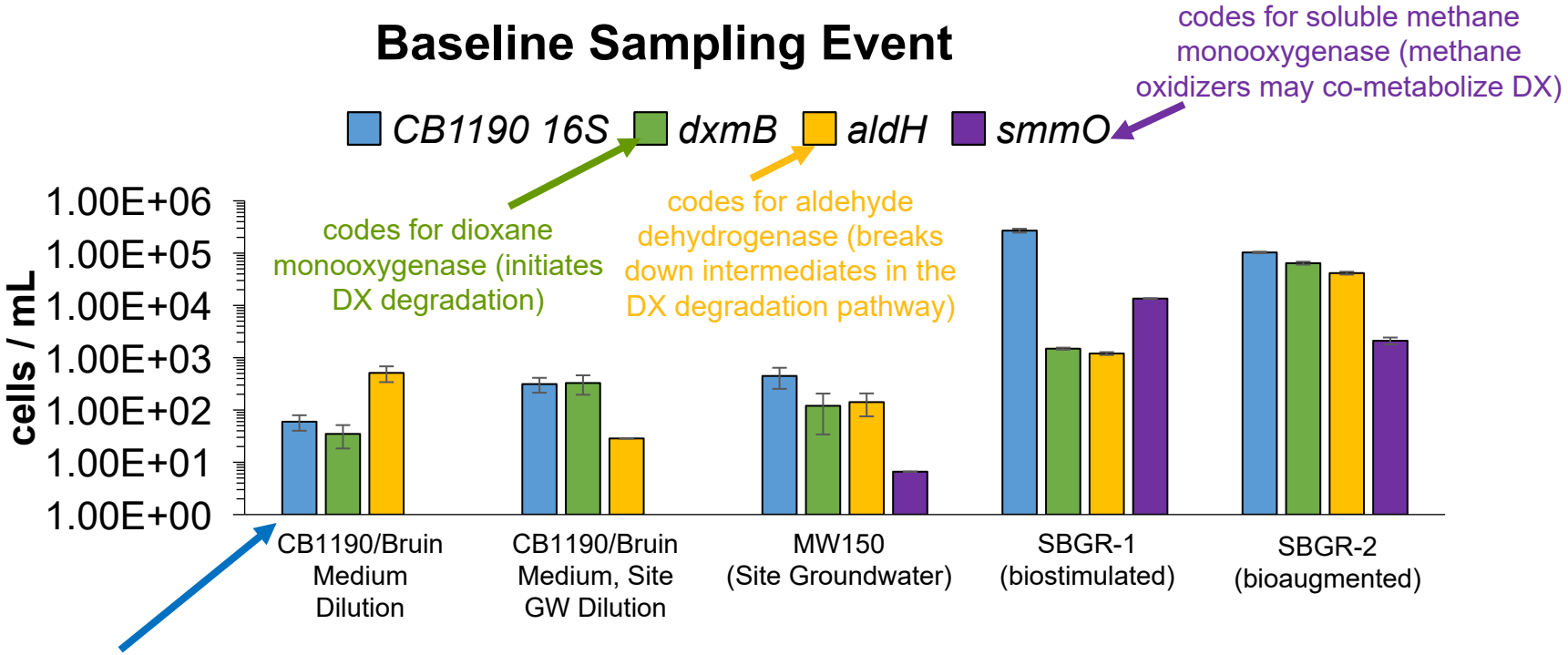
SBGR Construction

- 14 inch diameter SBGR columns installed via sonic drilling to bedrock
  - Monitoring Well, infiltration well, and aeration well within SBGR
- Backfilled with locally sourced media to 5-feet below grade.
- Biochar/gravel mixture installed at top of column to prevent fugitive emissions

Field Pilot Construction

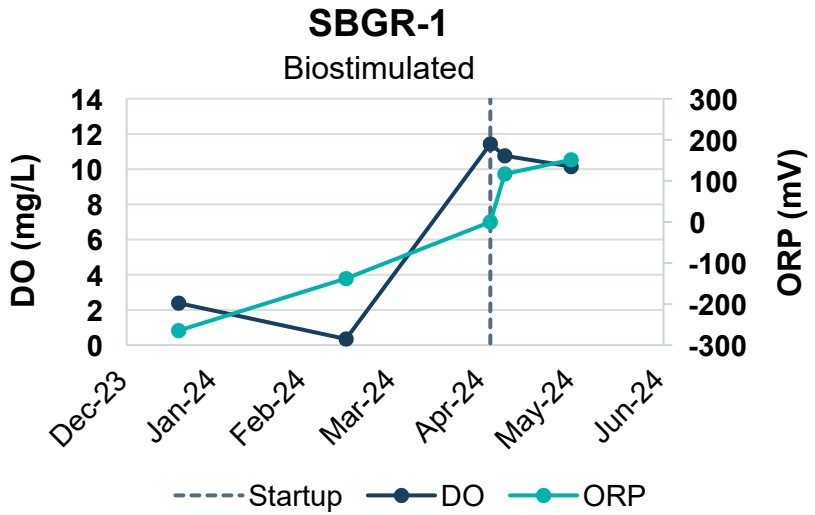
- All infrastructure installed below grade, allowing for utilization of above grade space if needed
- Automated controls require limited O&M and tied back to centrally located control panel

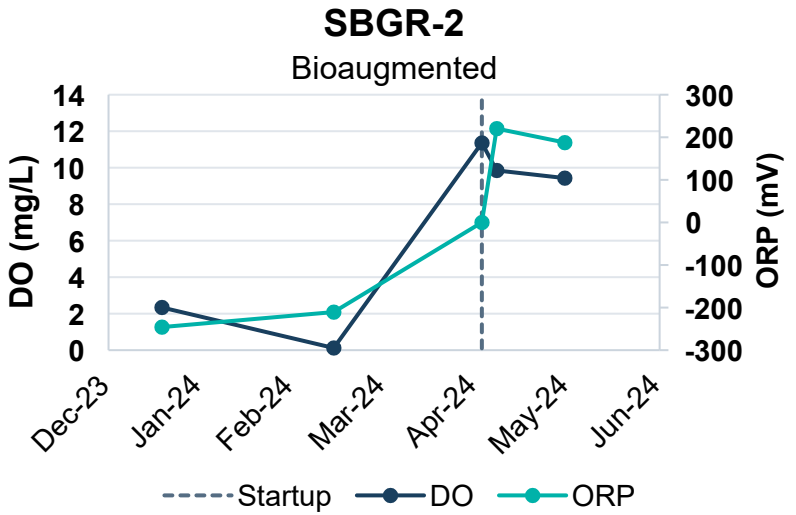
BIOAUGMENTATION



Preliminary Data – Field Parameters

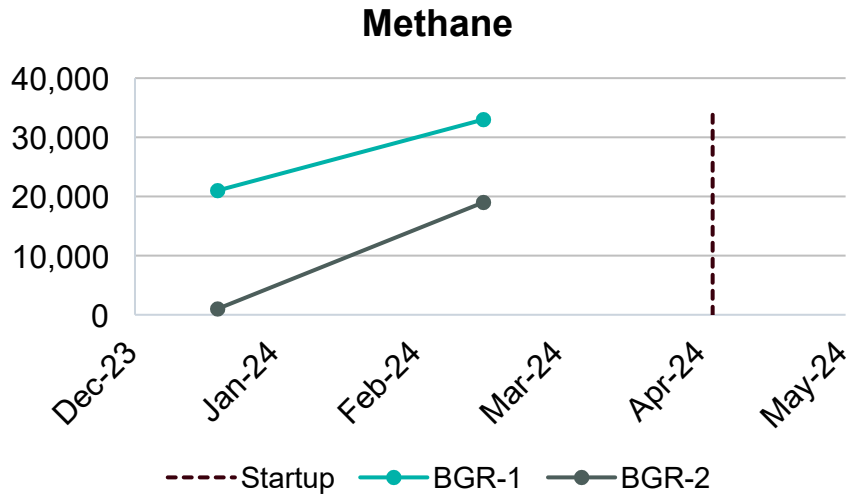
- System in operation since April 2024
- Preliminary data shows operating at desired 15-day HRT and maintaining aerobic conditions

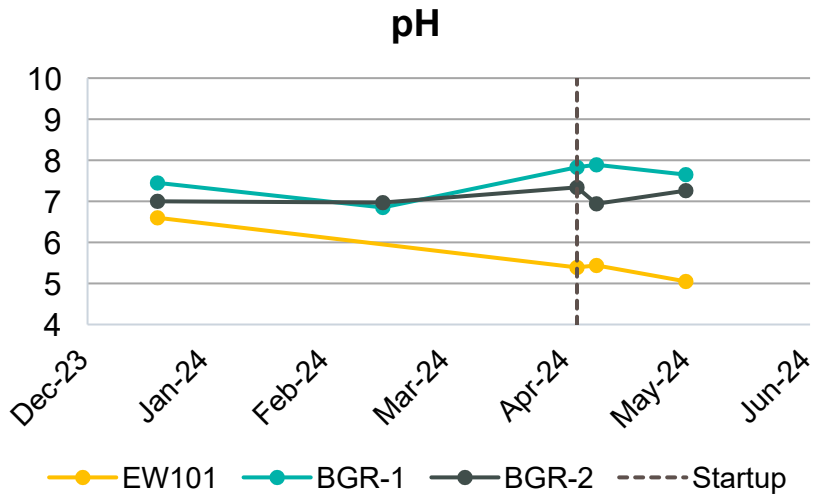




Preliminary Data – Geochemical Data

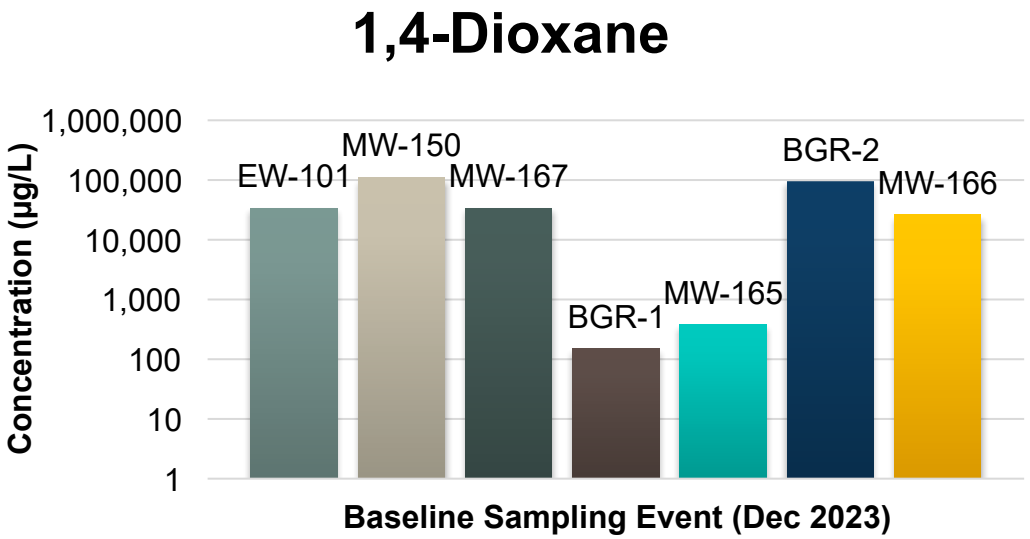
- Methane increased in SBGRs prior to startup of aeration, indicating reducing conditions were established
- Total organic carbon (TOC) > 50 mg/L in both SBGRs, showing plenty of carbon available to support microbial growth

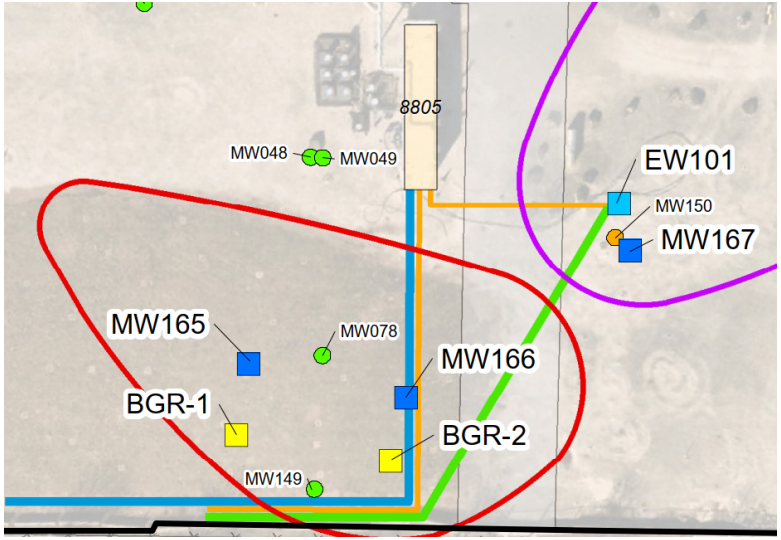




PRELIMINARY DATA - BASELINE 1,4-DIOXANE

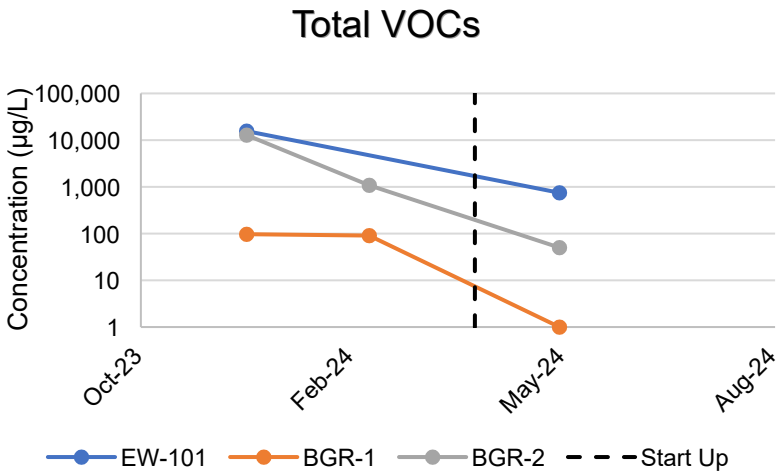
- Concentrations higher at BGR-2 (bioaugmented) than BGR-1 (biostimulated)
- Both BGRs located in source area

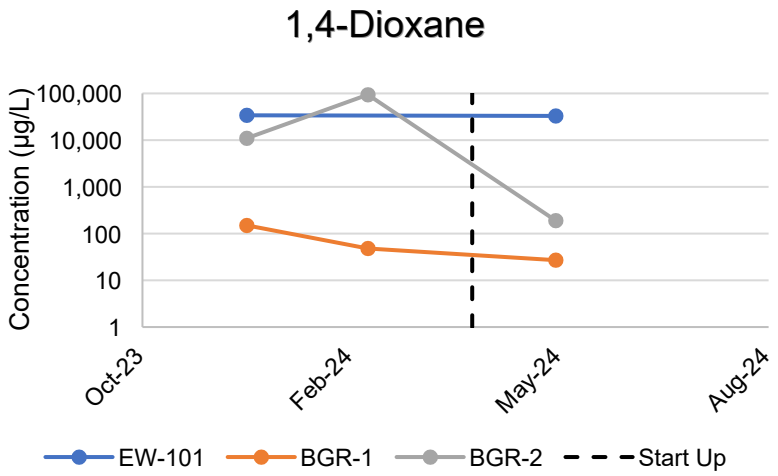




Preliminary Data

- Likely treatment of CVOCs in SBGR columns prior to startup
- Decreasing 1,4-dioxane concentrations in CB1190 Bioaugmented BGR-2





PRELIMINARY RESULTS

- Meeting project objectives
  - Sustainable
  - Nature/bio based solution
  - Lower capital and operational costs
  - Scalable and flexible
  - 1,4-dioxane removal and degradation
  - Mixed cultures supporting synergetic biodegradation functions

Next Steps

- In situ field pilot will be operated for at least one year with monthly microbial and analytical sampling
- After first 6 months of operation, optimization may include adjustment to HRT or biosparge rates
- Designed to be expanded into full scale system if results indicate acceptable treatment, similar to those observed in the drum scale
  - Pilot study may continue to be operated during full scale design/implementation to accelerate treatment

Thank you!

Claudia Walecka-Hutchison, PhD
CWaleckaHutchison@dow.com

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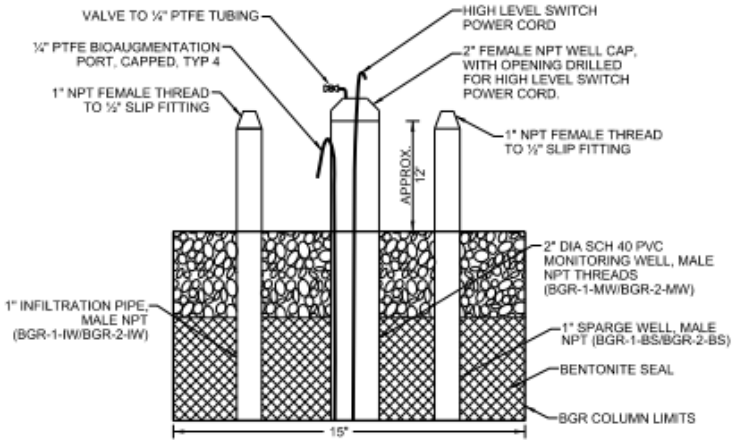

1 SUBGRADE BIOGEOCHEMICAL REACTOR WELLHEAD DETAIL

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NOTES:

1. PIPING COMPONENTS WILL BE SCHEDULE 40 PVC, UNLESS OTHERWISE NOTED.
2. OPENINGS WILL BE SEALED WITH TIGHTENING GLANDS, OR SIMILAR FITTINGS.