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Optimizing Bioremediation of Mixed Contaminant Sites

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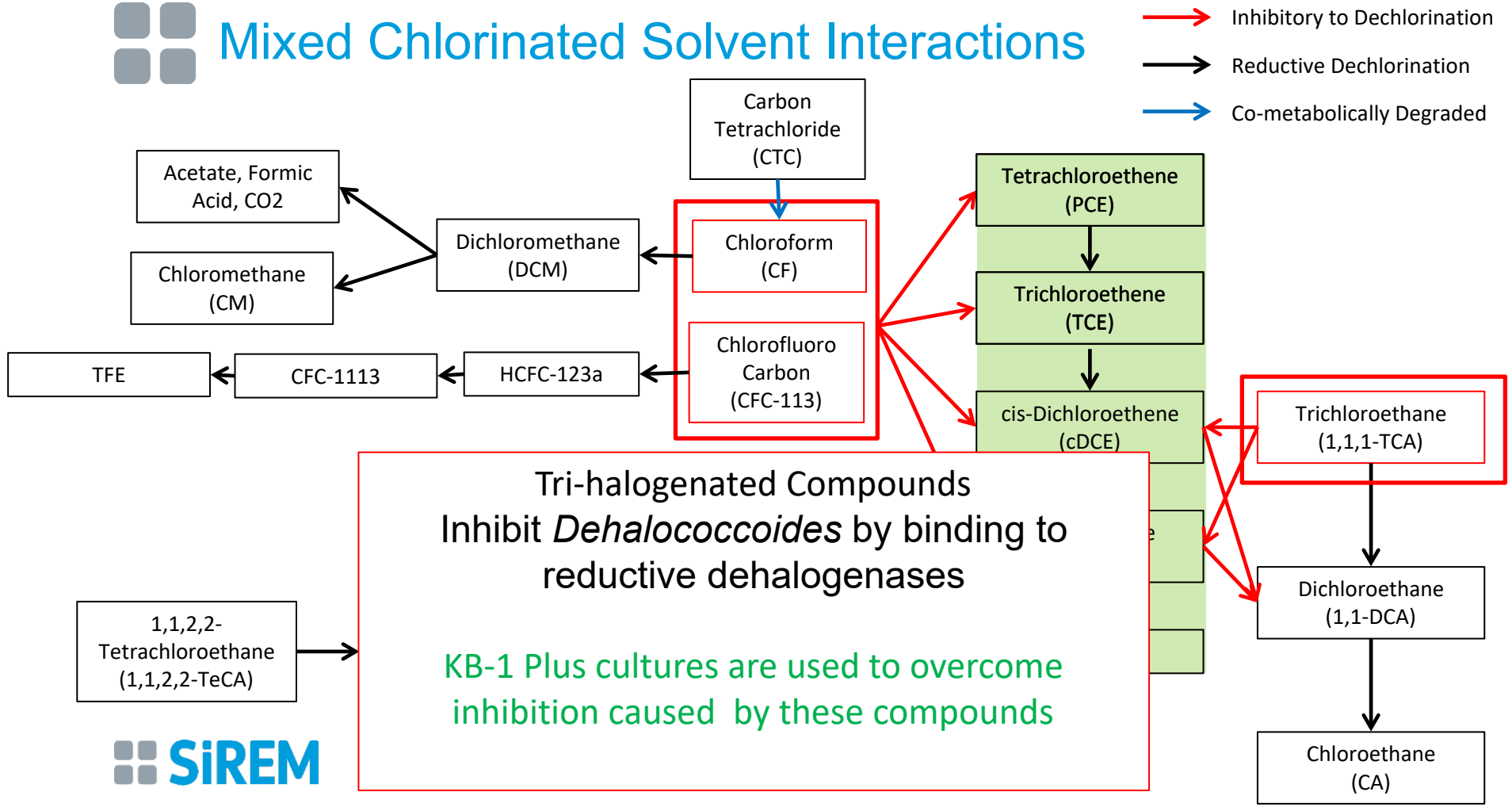
Let's Talk About…

1. Mixed Chlorinated Solvents
2. Sequential Anaerobic/Aerobic Bioremediation
3. Electron Acceptors/Electron Donors

Mixed Chlorinated Solvent Interactions



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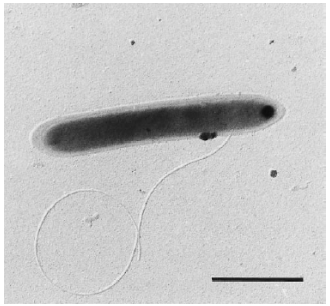
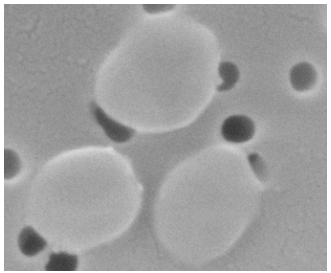
Dehalobacter (*Dhb*) & *Dehalogenimonas* (*Dhgm*)

- 1,1,1-TCA degradation to CA (*Dhb*)
  (Grostern and Edwards, 2006)
- Chloroform to Dichloromethane *(cfrA*)
  (Grostern, Edwards, Duhamel and Dworatzek, 2010)
- DCM to acetate
  (Justicia-Leon et al., 2011)
- 1,1,2,2-TeCA to ethene (*Dhgm*)
  (Manchester et al., 2012)



Dehalobacter



Dehalogenimonas

Abiotic & Biotic Degradation of Trihalogenated Compounds

- 1,1,1-TCA

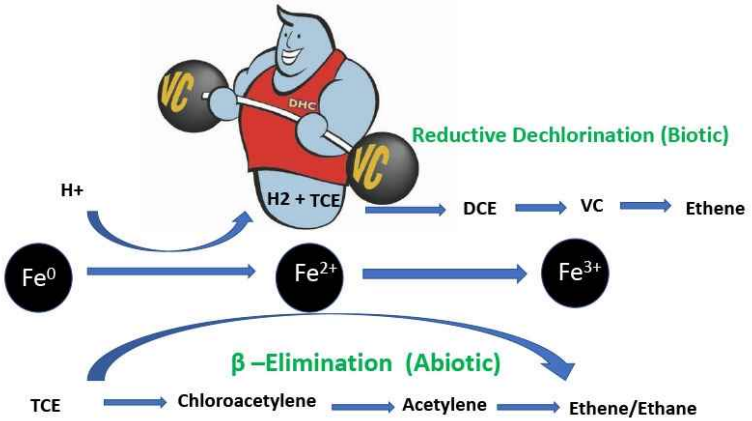
  Metal sulfides can degrade 1,1,1-TCA (Scheutz et al., 2011)

- CFC-113

  Abiotic dechlorination of CFC-113 and CFC-11 by ZVI (Philips et al, 2020)

- Chloroform

  CF degradation was 8X-14X faster when a *Dhb* culture was combined with ZVI compared with ZVI alone. (Lee et al., 2015)



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CASE STUDY 1: CHLORINATED METHANES AND ETHENES

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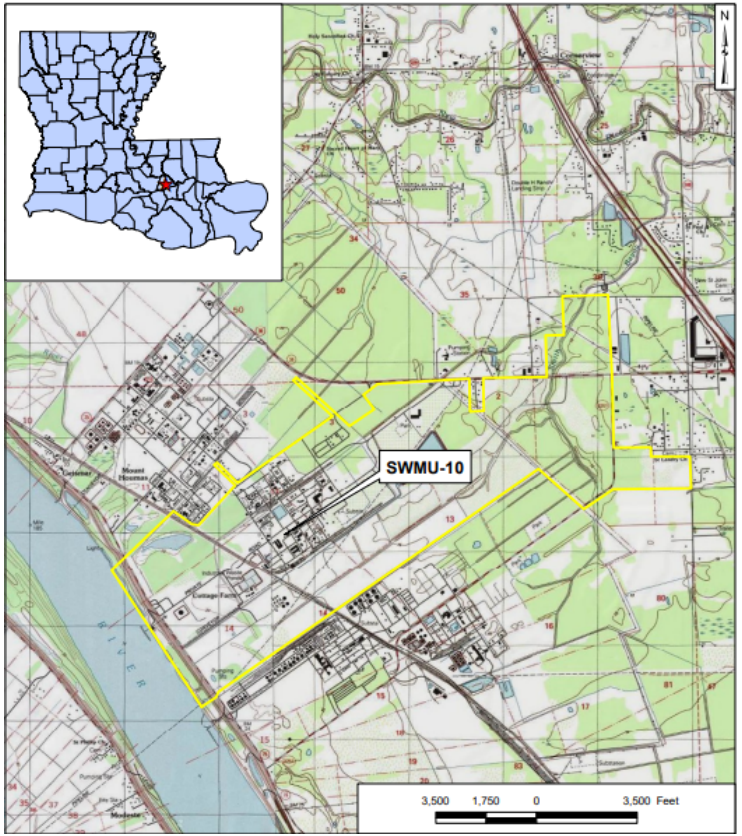
Site Overview

- Manufacturing facility located in Louisiana
- Contaminants include: PCE, TCE, CTC, CF

- Treatability Study in 2016
  - ➢ Is anaerobic biodegradation a viable remedial option?
  - ➢ Can ZVI optimize EISB?
  - ❖ Conclusion: The best treatment strategy was observed with the addition of ZVI combined with KB-1 Plus and electron donor addition.

- Pilot Test in 2018
  - ❖ ZVI was injected into the “60 foot zone” – consisting of silts, sandy silts, and silty clays
  - ❖ Two injection wells in SWMU-10 area – injected with ZVI,, KB-1 Plus, and electron donor targeted an ROI of 15’



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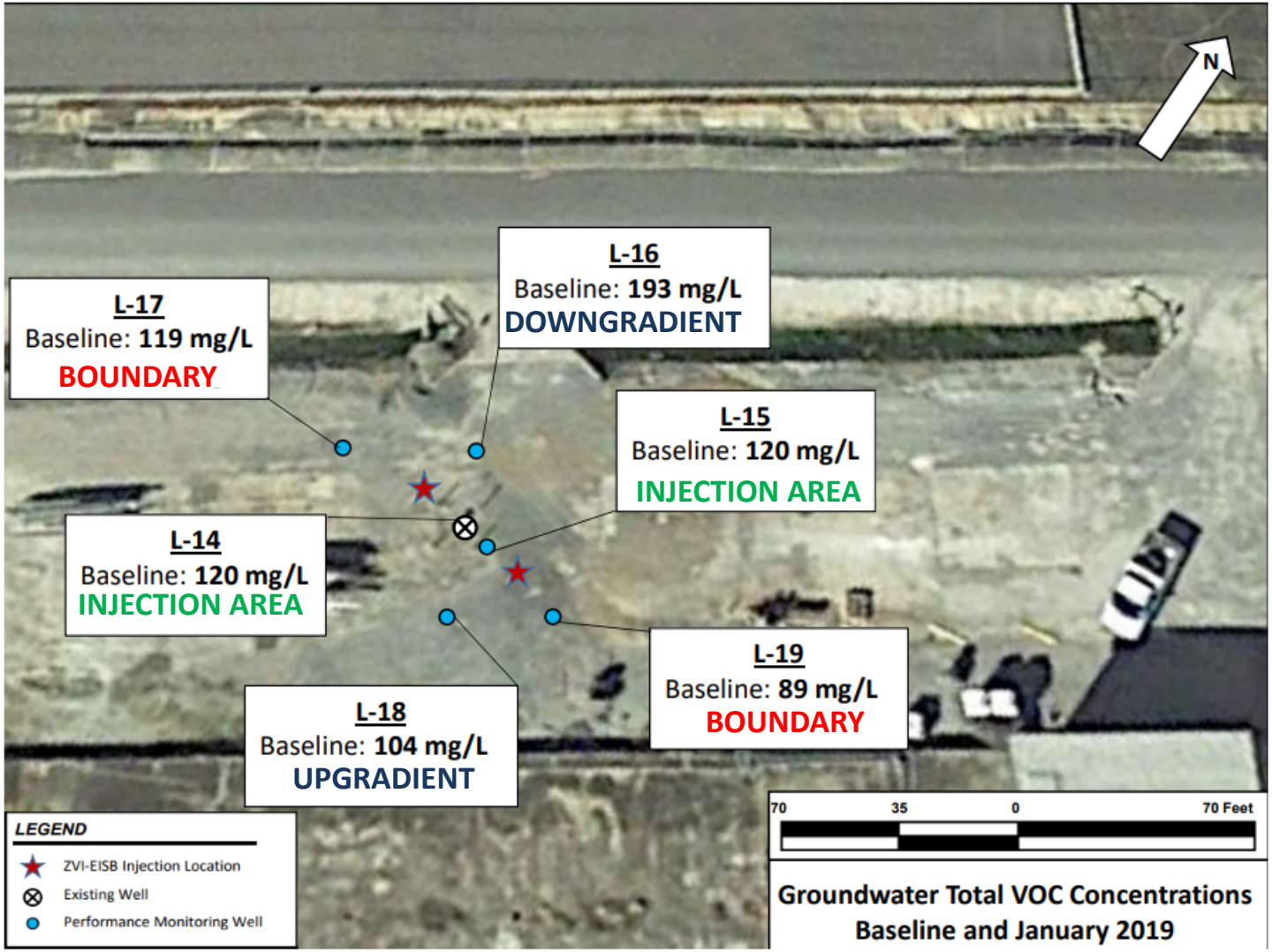
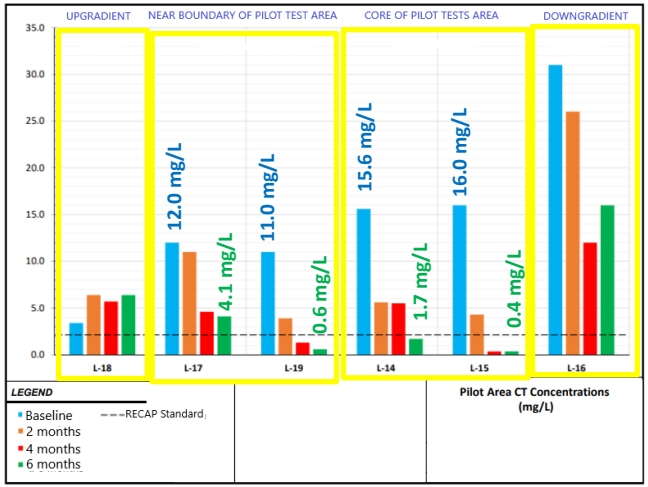
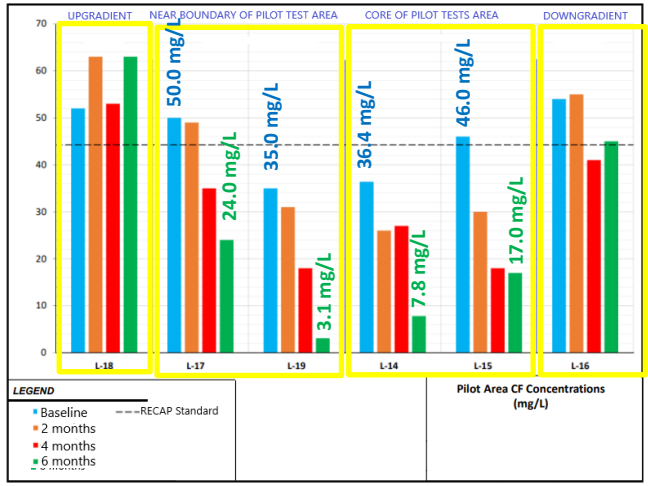

N
L-16
Baseline: 193 mg/L
DOWNGRADIENT
L-17
Baseline: 119 mg/L
BOUNDARY
L-15
Baseline: 120 mg/L
INJECTION AREA
L-14
Baseline: 120 mg/L
INJECTION AREA
L-19
Baseline: 89 mg/L
BOUNDARY
L-18
Baseline: 104 mg/L
UPGRADIENT
LEGEND
ZVI-EISB Injection Location
Existing Well
Performance Monitoring Well
70
35
0
70 Feet
Groundwater Total VOC Concentrations
Baseline and January 2019

CT Concentration (mg/L)

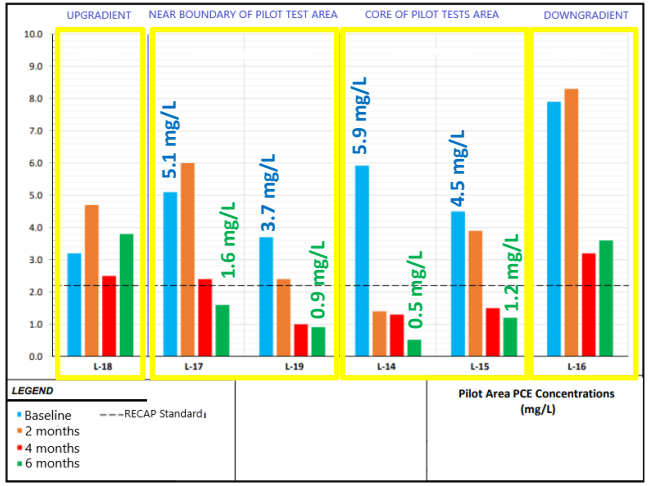


CF Concentration (mg/L)

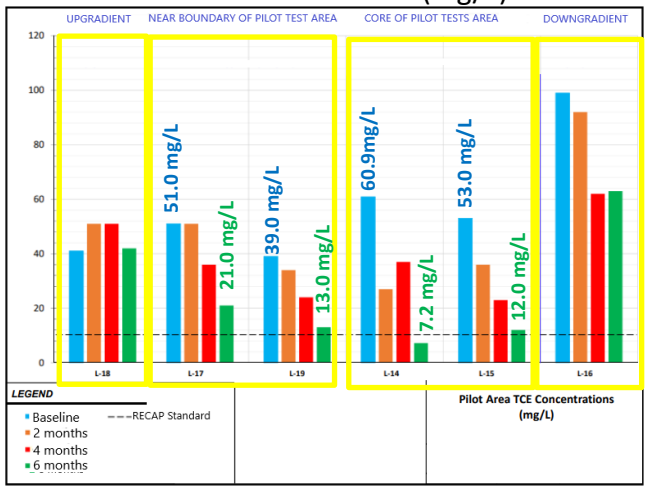


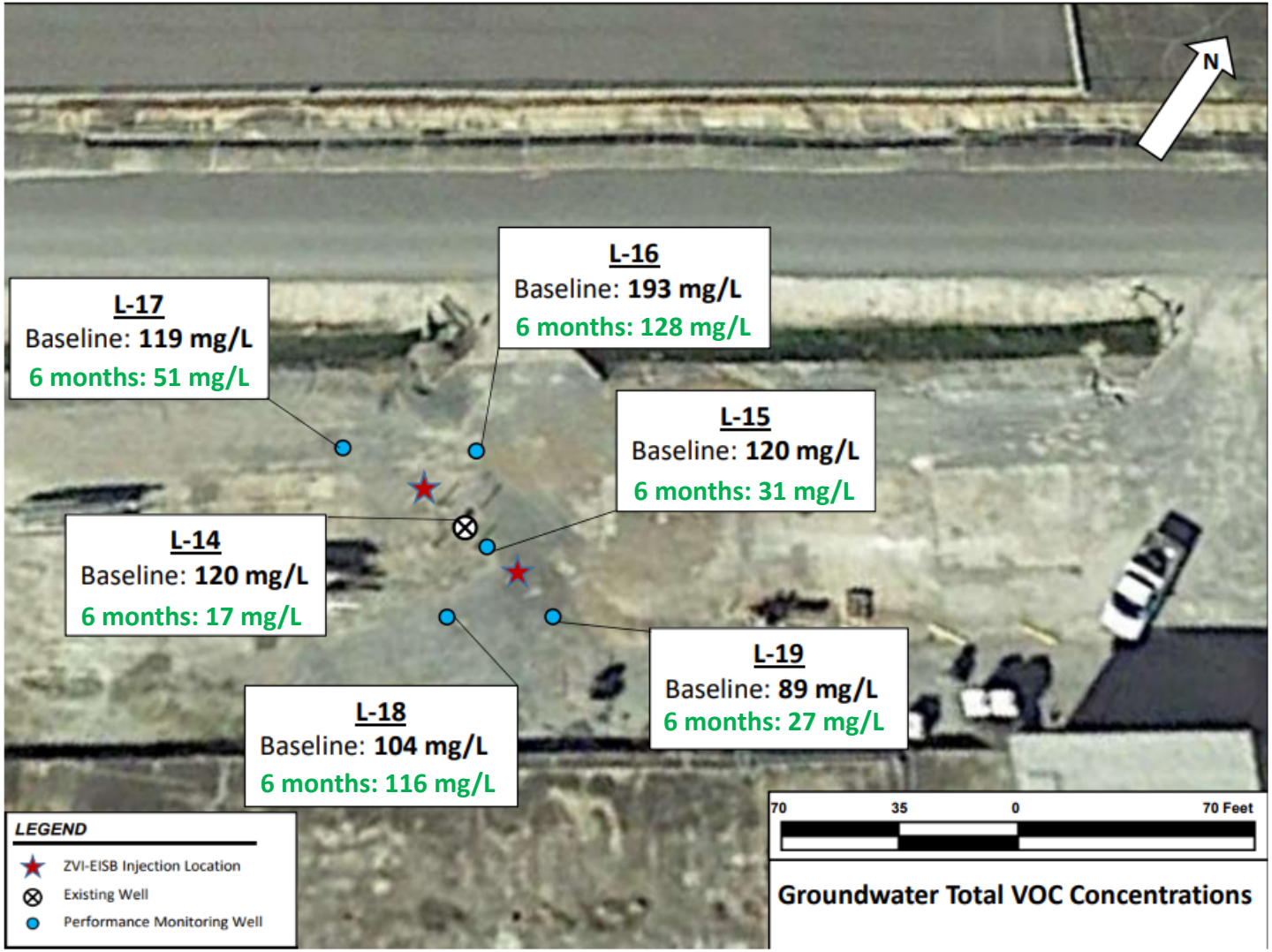
Baseline
2 Months
4 Months
6 Months
RECAP Standard (LA State Standard)

PCE Concentration (mg/L)



TCE Concentration (mg/L)




N
L-16
Baseline: 193 mg/L
6 months: 128 mg/L
L-17
Baseline: 119 mg/L
6 months: 51 mg/L
L-15
Baseline: 120 mg/L
6 months: 31 mg/L
L-14
Baseline: 120 mg/L
6 months: 17 mg/L
L-19
Baseline: 89 mg/L
6 months: 27 mg/L
L-18
Baseline: 104 mg/L
6 months: 116 mg/L
LEGEND
ZVI-EISB Injection Location
Existing Well
Performance Monitoring Well
70
35
0
70 Feet
Groundwater Total VOC Concentrations

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CASE STUDY 2: CHLORINATED METHANES AND 1,4-DIOXANE

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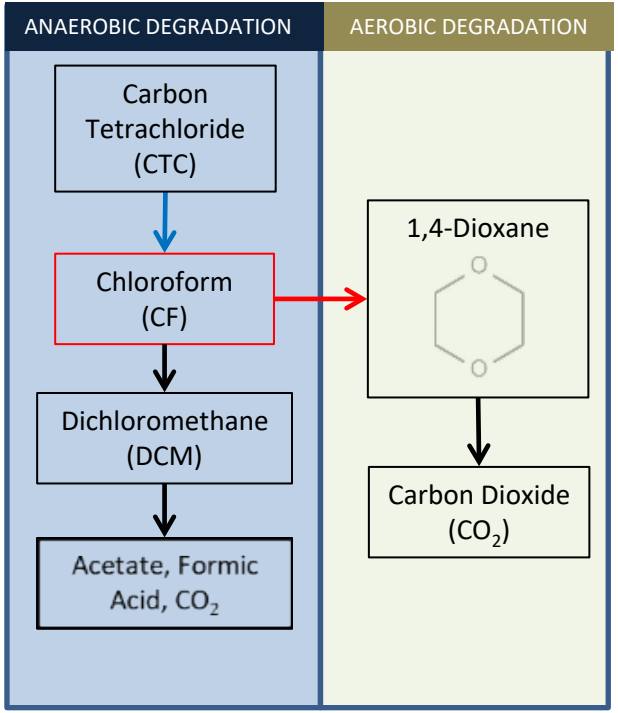
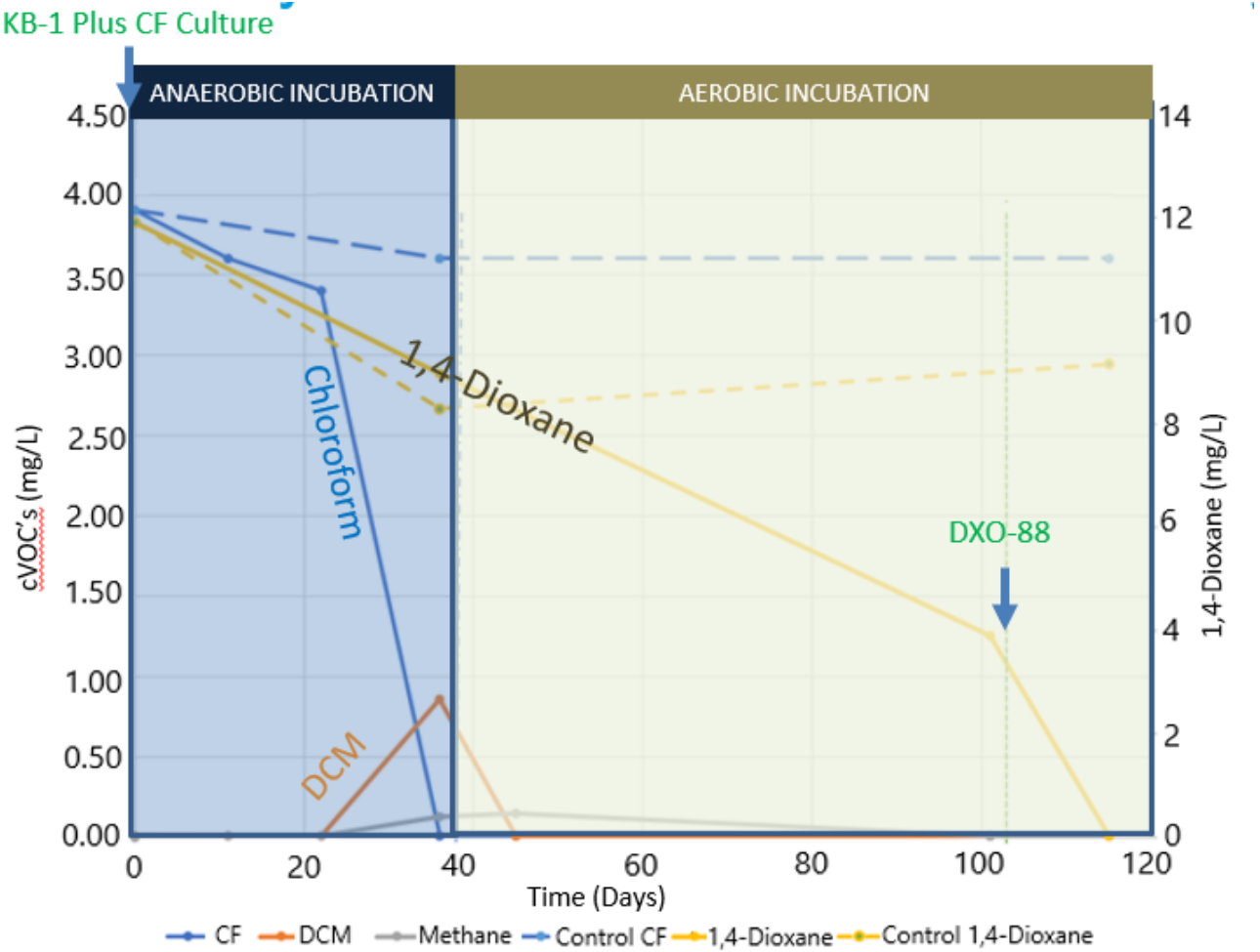
1,4-D and CF Treatability Study (Confidential Site)

- Problem: Chloroform more readily degrades under anaerobic reductive conditions and 1,4-D under aerobic conditions, CF inhibits aerobic 1,4-D degradation

Solution?: Phased anaerobic/aerobic bioaugmentation

- KB-1® Plus – CF Anaerobic Culture
- DXO-88™ – 1,4-Dioxane Aerobic Culture




KB-1 Plus CF Culture
ANAEROBIC INCUBATION
AEROBIC INCUBATION
cVOC's (mg/L)
1,4-Dioxane (mg/L)
Chloroform
1,4-Dioxane
DCM
DXO-88
Time (Days)
CF
DCM
Methane
Control CF
1,4-Dioxane
Control 1,4-Dioxane

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CHLORINATED SOLVENTS & PETROLEUM HYDROCARBONS

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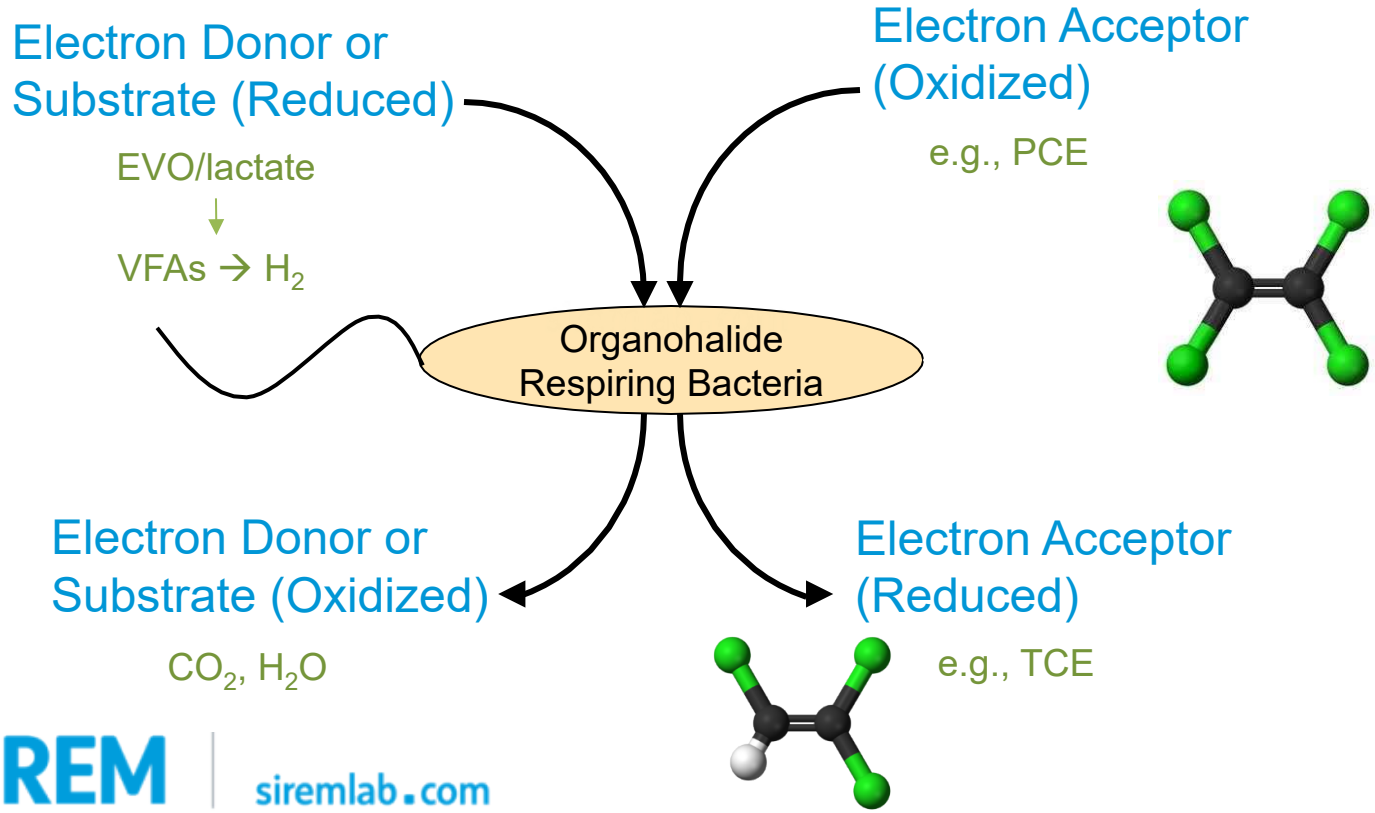
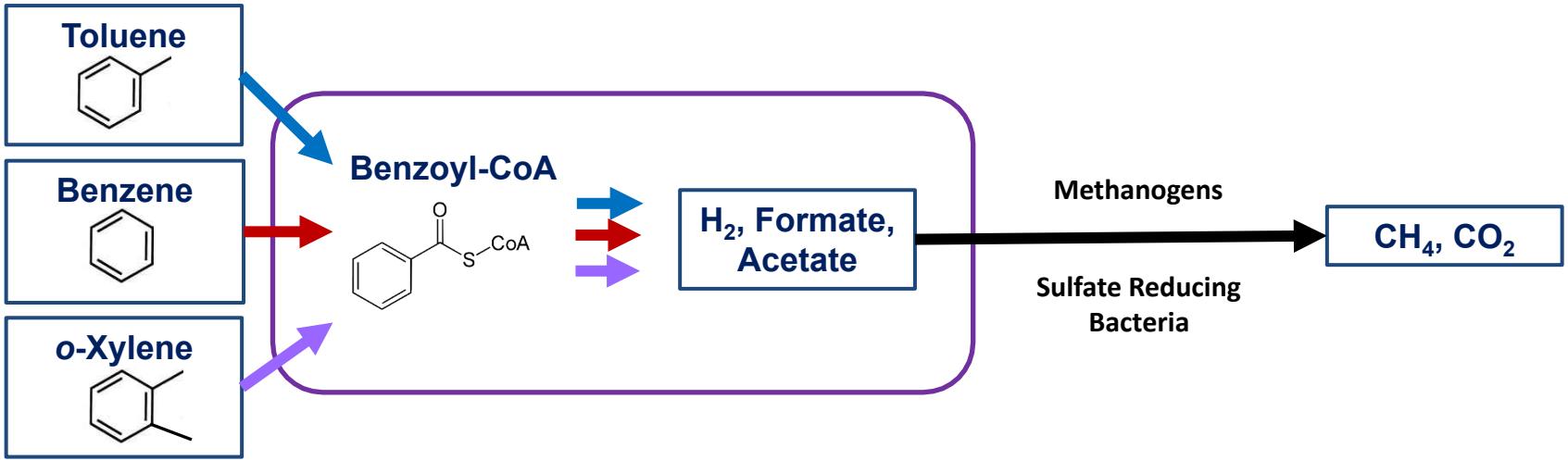
Chlorinated Solvents as Electron Acceptor



Key Difference Between Bioremediation of Chlorinated Solvents vs Hydrocarbons

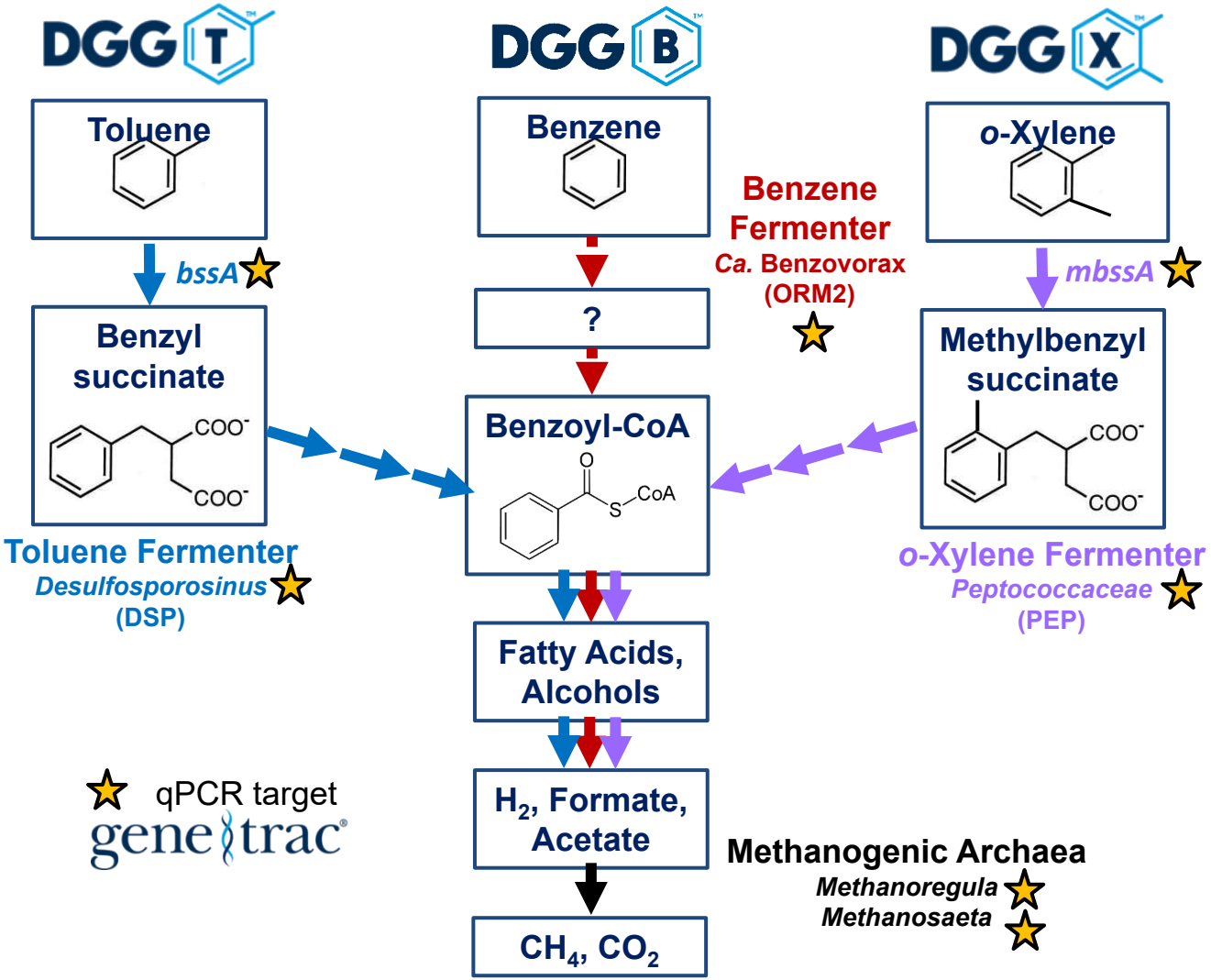
Hydrocarbons are *electron donors* rather than electron acceptors

- Adding carbon (sugars, VFAs, yeast extract) may not enhance bioremediation performance



DGG PLUS™

- Anaerobic culture for benzene, toluene and xylene
- The key microbes in each culture include **hydrocarbon fermenters** and **methanogens**
- Key microbes & functional genes can be monitored by **qPCR** and/or **NGS**



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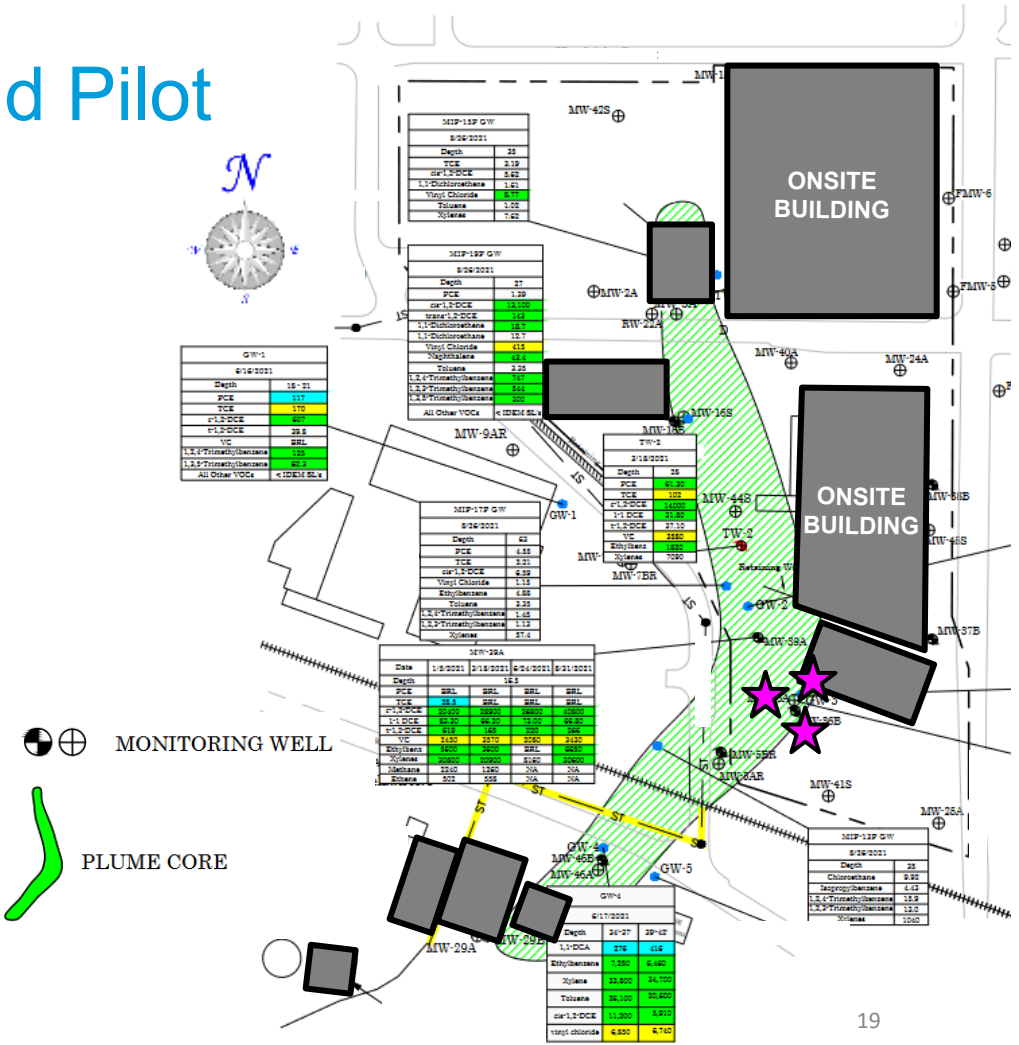
CASE STUDY 3: CHLORINATED ETHENES & CHLORINATED ETHANES, & PETROLEUM HYDROCARBONS (ANAEROBICALLY)

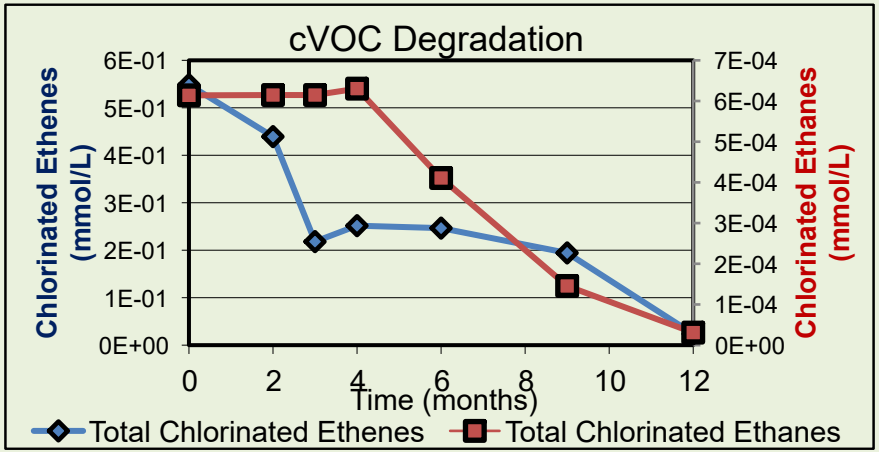
Results from a Field Pilot

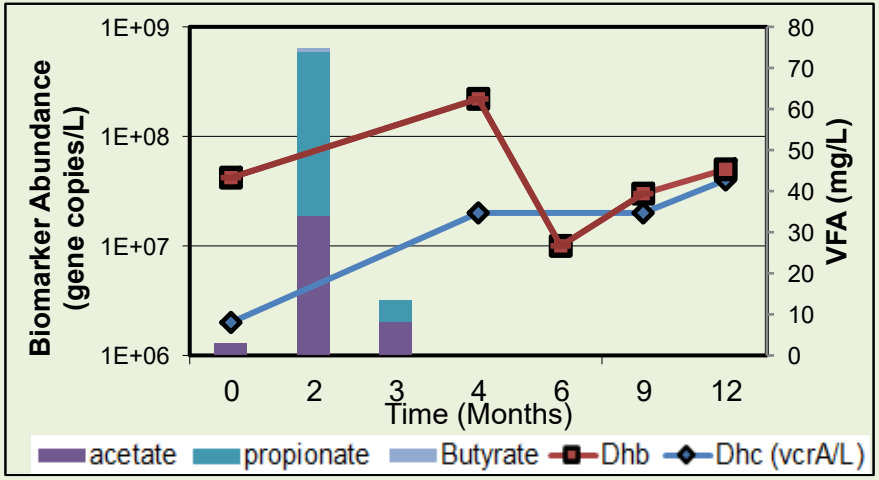
- US chemical manufacturing site, groundwater contaminated with chlorinated ethenes, chlorinated ethanes, and TEX
  - Green = exceeds drinking water limits
  - Blue = exceeds residential vapor limits
  - Yellow = exceeds industrial vapor limits

- In Sept 2020, a blend of KB-1® Plus and DGG Plus™ was injected at 3 points (★) near the center of the plume core

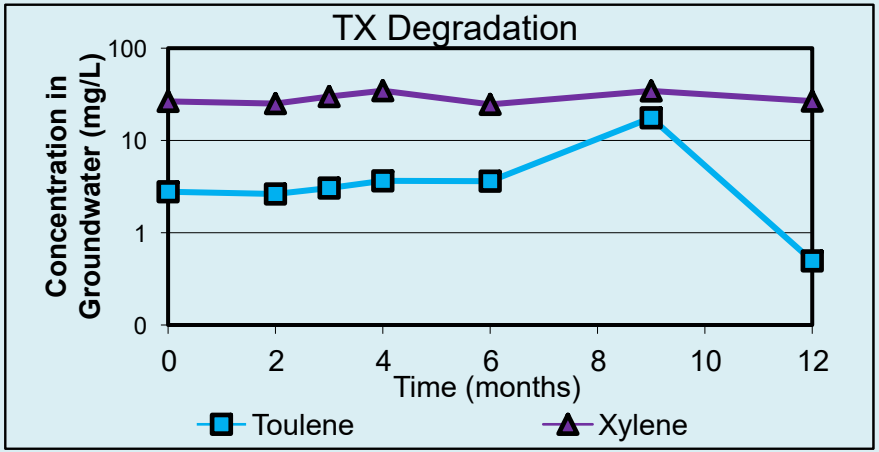


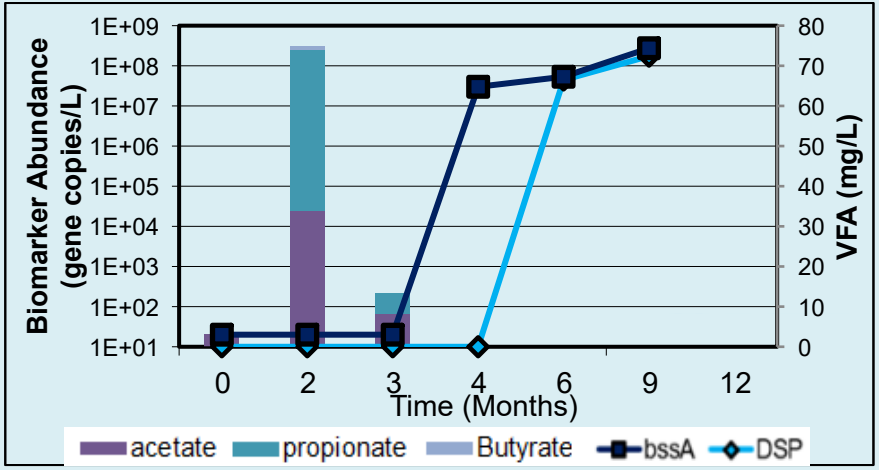
CHLORINATED ETHENES & ETHANES





TOLUENE & XYLENE





Conclusion – Mixed Contaminated Sites are Complex

- Treatability studies provide proof of concept and information to optimize the remedial strategy
- Molecular Gene-Trac testing can be used to determine if key degrading bacteria are present and at sufficient concentrations
- Bioaugment to introduce key degrading bacteria

Questions?

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