EVALUATION OF A SUSTAINABLE BIOBARRIER TO TREAT LARGE DILUTE CHLORINATED VOC GROUNDWATER PLUMES

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Battelle: Fifth International Symposium on Bioremediation and Sustainable Environmental Technologies. 2019. Baltimore, Maryland

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BACKGROUND

- ESTCP-funded project (ER-201629)
- Treatment/control of large dilute plumes remains a challenge
- Current approaches can have high capital and O&M costs
- Cometabolism shows promise:
  - Indigenous organisms grow aerobically on supplied substrate (propane, methane, etc.), rather than the trace contaminant
  - Good degradation kinetics
  - Ability to treat contaminants to parts-per-trillion levels

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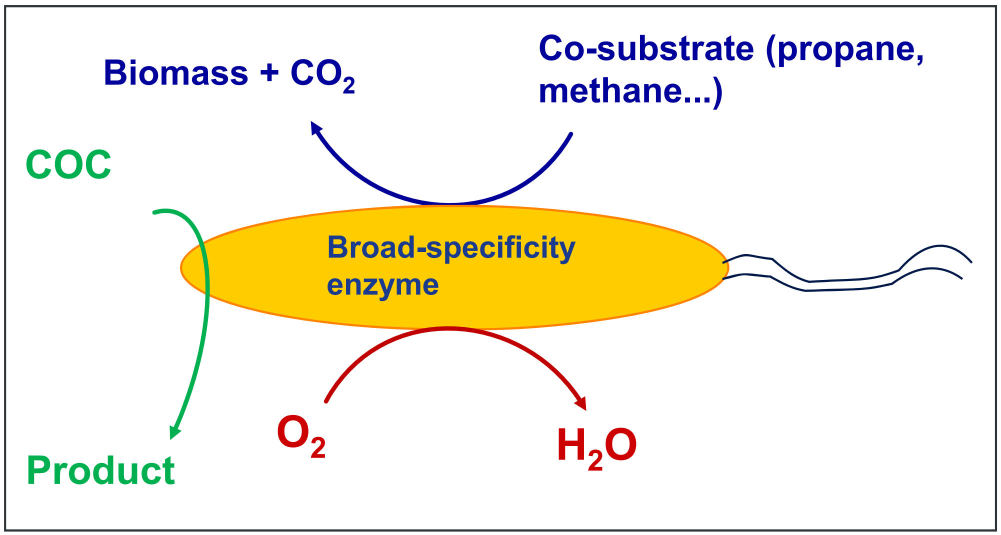
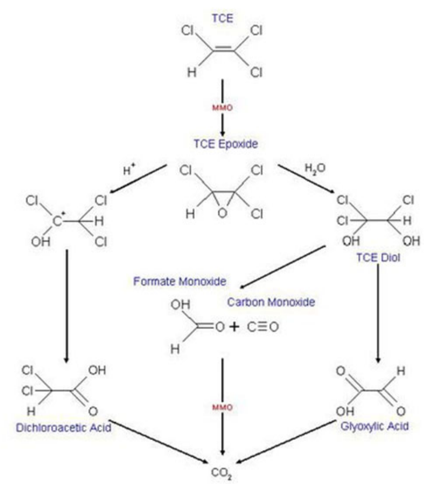
COMETABOLISM

Metabolism of an organic substrate by a microorganism that is unable to use that compound as a source of energy or an essential nutrient element (Alexander, 1967)



Cells gain energy and carbon from co-substrate

"fortuitous metabolism"



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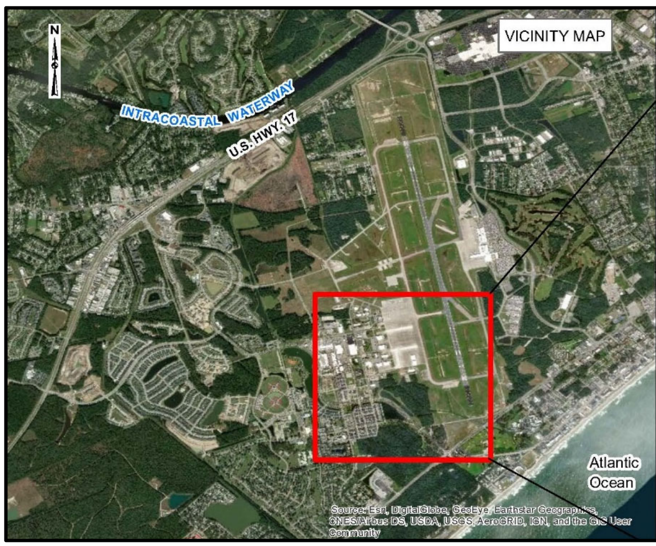
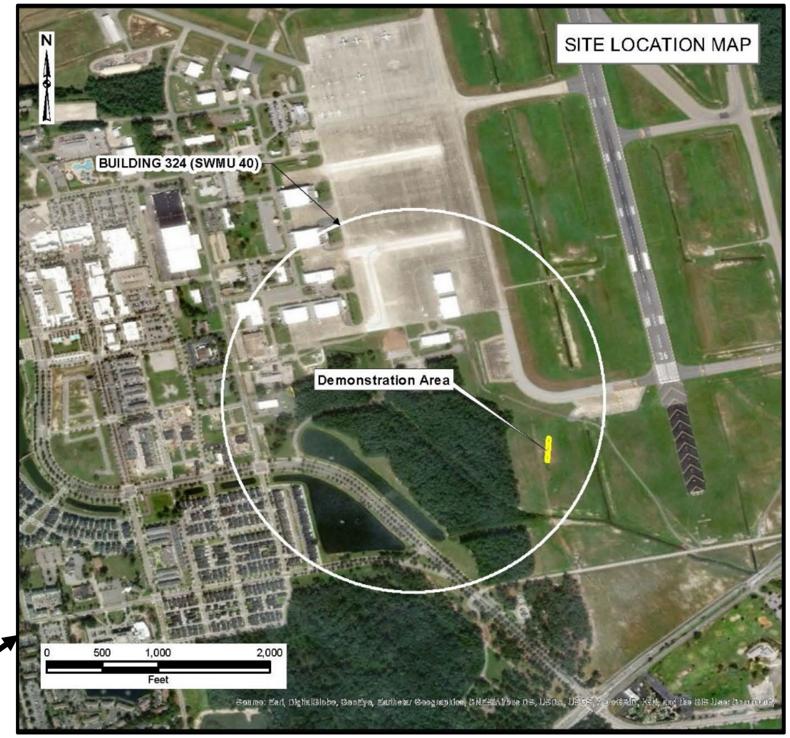
DEMONSTRATION SITE

- ► Former Myrtle Beach Air Force Base, SC
- ► Building 324 Plume (SWMU 40)





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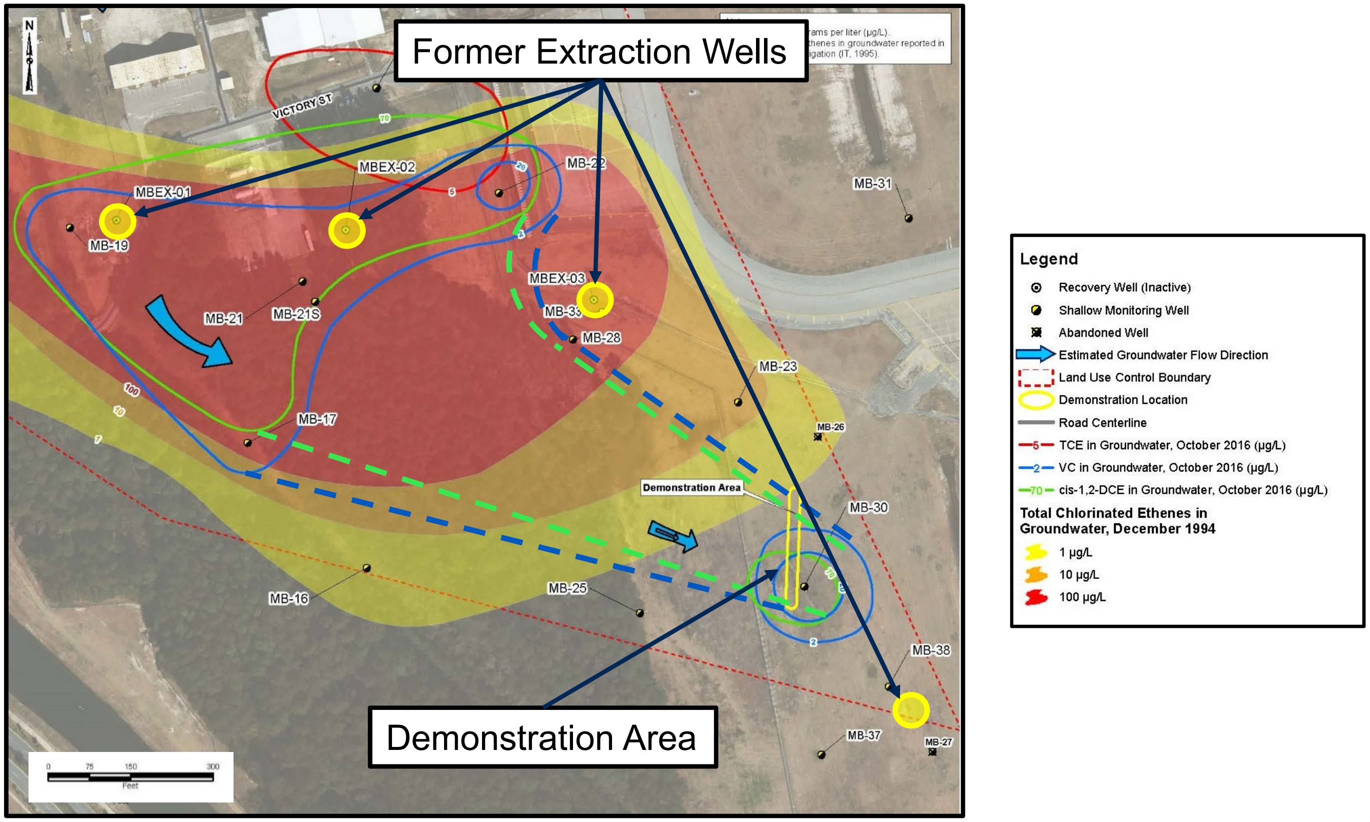
CHLORINATED ETHENE DISTRIBUTION

- 1994: Plume >2,000' long and up to 1,000' wide
- P&T from 1995 to 2006
  - Reached asymptotic levels
  - MNA current remedy
- Current plume dimensions less defined
- Demonstration area:
  - *cis*-DCE and vinyl chloride plume ~210' wide
  - No TCE above MCLs



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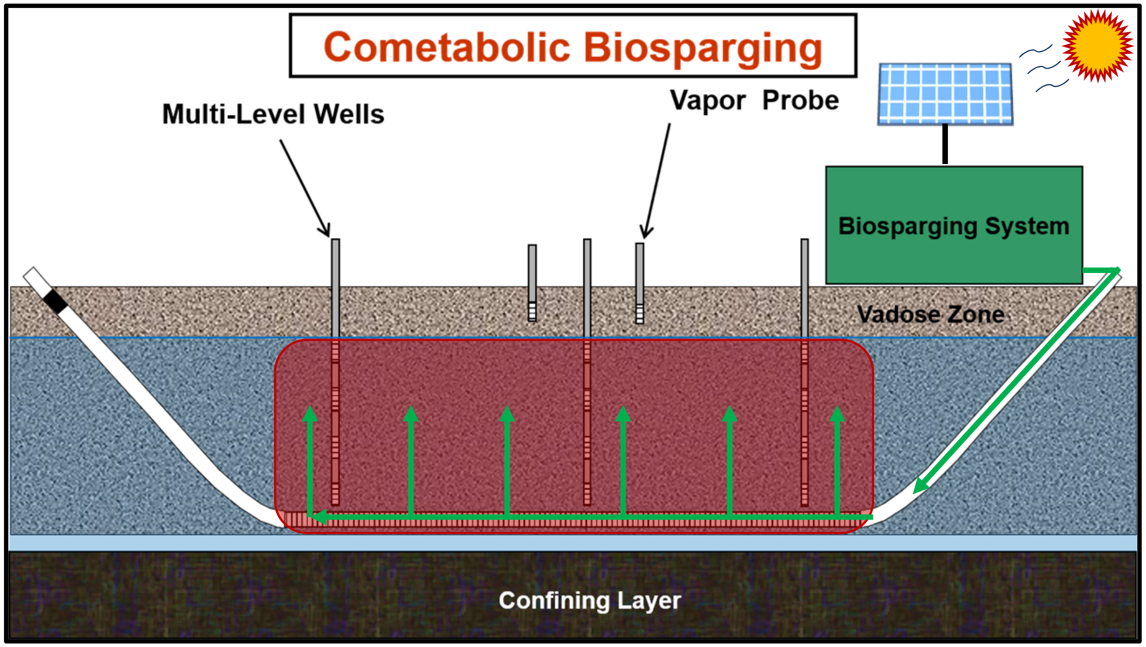
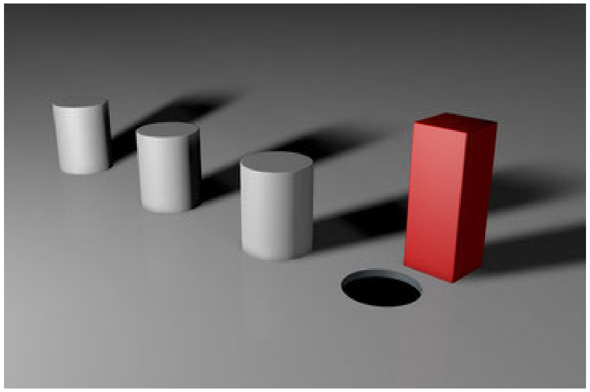
ORIGINAL CONCEPT



- ✓ Cometabolic biosparging
- ✓ Off-the-grid (solar + gas pressures)
- X Horizontal sparge wells



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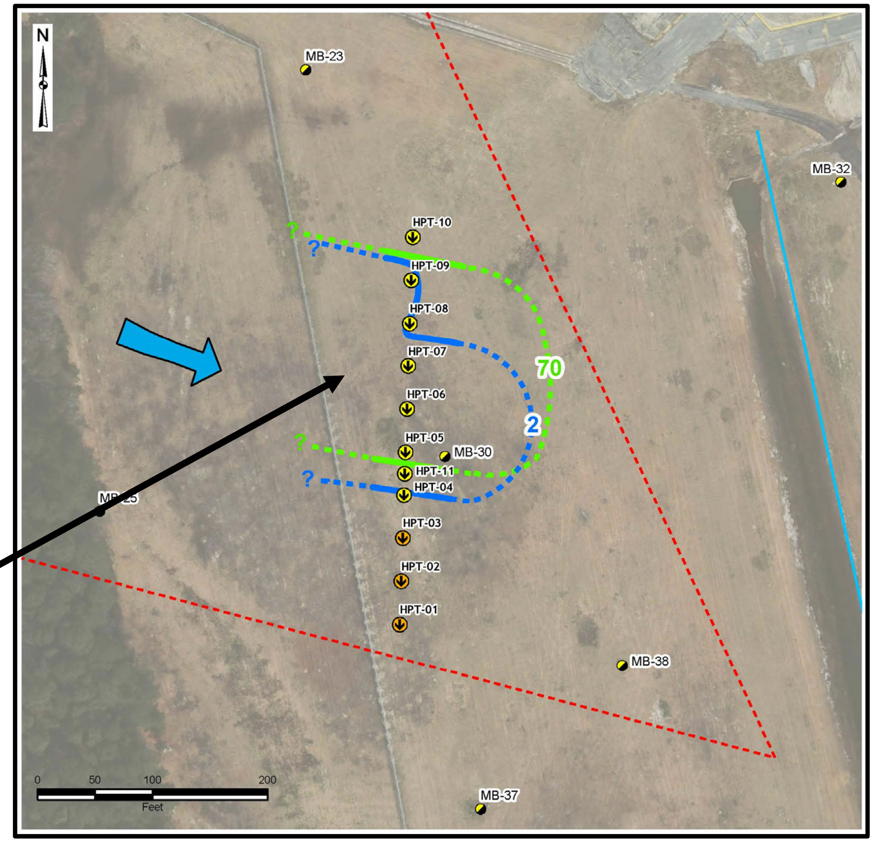
DIRECT-PUSH INVESTIGATION

- 8 HPT-GW borings
  - > Formation permeability/conductivity
- Discrete groundwater sampling
  - > 2-5 discrete samples per boring
  - > 28 total samples
- 2 continuous soil cores

Geoprobe HPT-Groundwater Sampler



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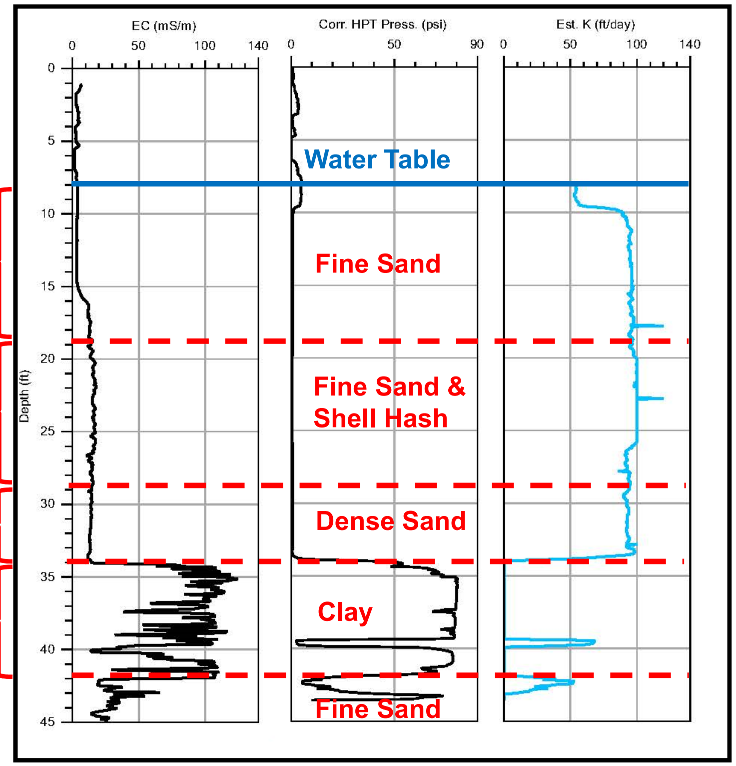
CORRELATION OF SOIL CORES TO HPT LOGS

- Water table ~8’ bgs
- Estimate K’s of 90-100 ft/day in upper 3 units
- 8’ thick clay underlying shallow aquifer
- EC and HPT logs correlate well

HPT-06



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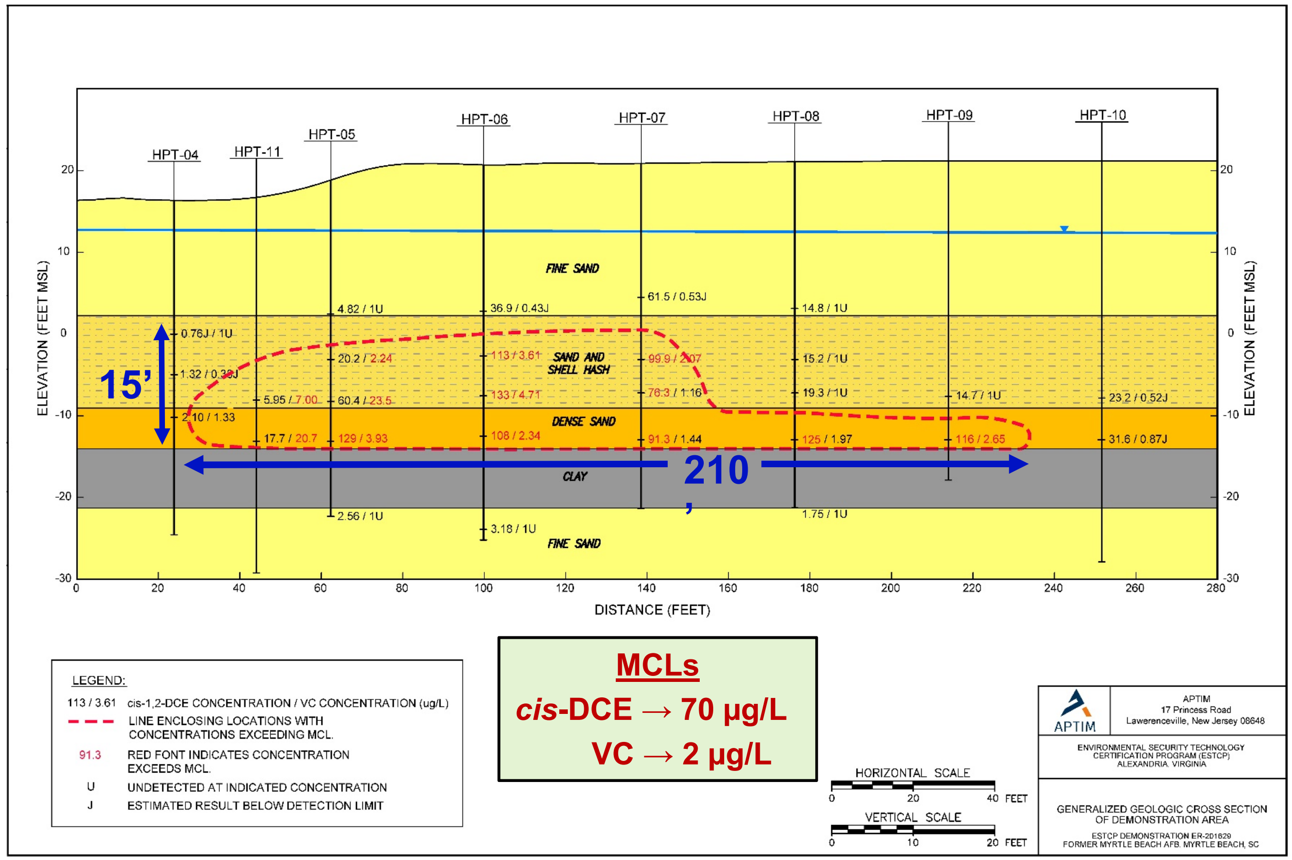
CONCEPTUAL SITE MODEL

- 5 hydrostratigraphic units
- *cis*-DCE and VC above MCLs
  - *cis*-DCE up to 133 µg/L
  - VC up to 23.5 µg/L
- Plume ~210' wide by 15' thick
  - Located within units 2 and 3
- Clay acts as a confining unit



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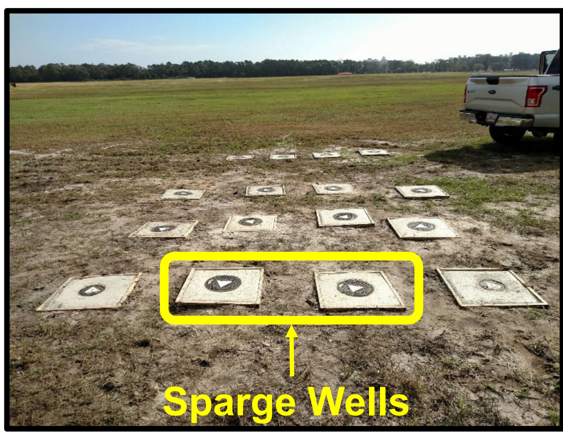
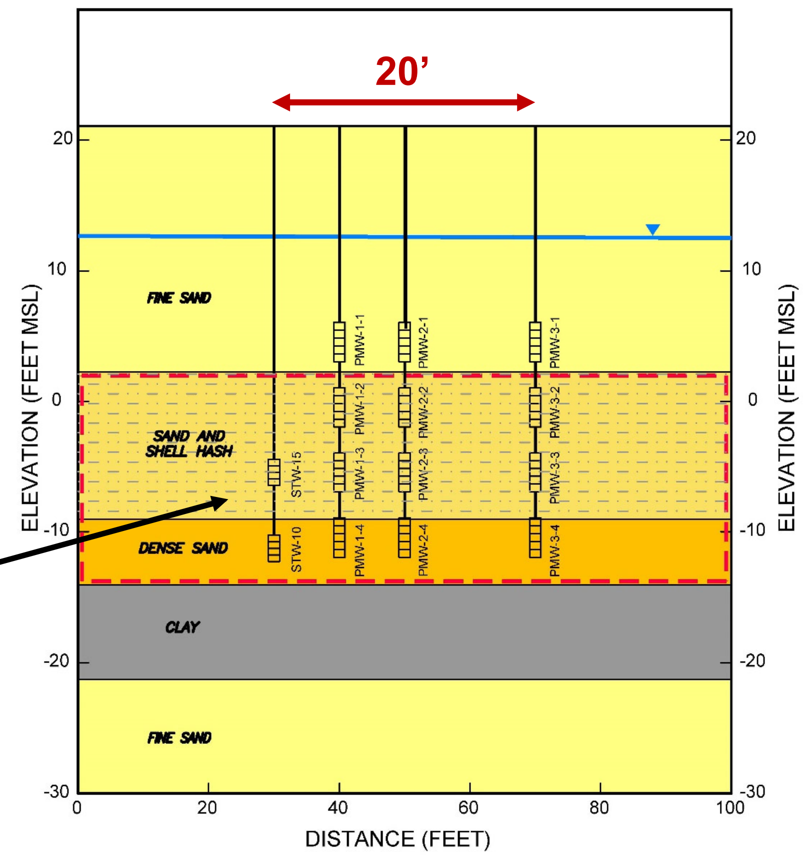
SPARGE TESTING WELL NETWORK

- 2 sparge wells
  - 2 foot screens
- 12 monitoring wells
  - 3 sets of 4 wells (4 intervals)
  - 3 foot screens
- 6 vapor probes → vadose zone





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SPARGE TESTING

- Oxygen and helium
- 8 sparge tests at 4 wells
- 10 minutes to > 1 hour
- Monitored DO and GW mounding
- Monitored vapor probes
  - Helium, oxygen, and other gases

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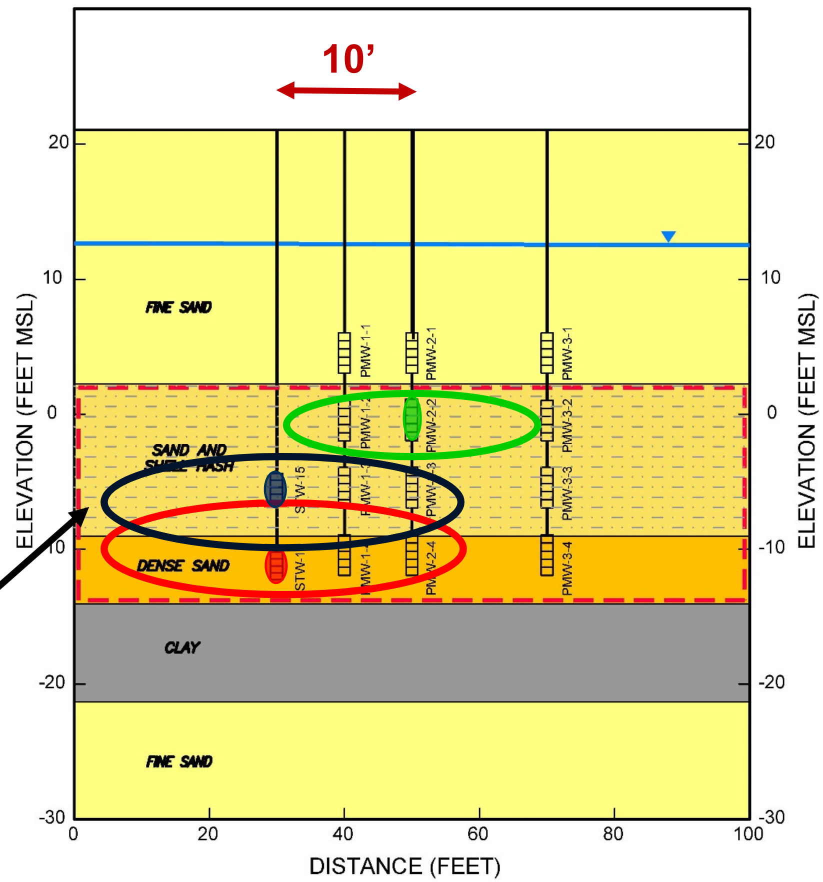
SPARGE TESTING RESULTS

- Low breakout & operating pressures (<12 psi)
- Shell Hash layer very anisotropic
- Preferential horizontal distribution of gases
- No observed impacts at vapor probes
- Not conducive to sparging with horizontal wells



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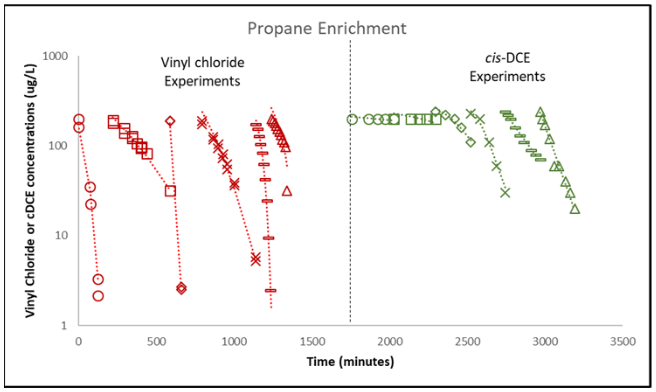
LABORATORY TREATABILITY TESTING

1) Can indigenous organisms be stimulated to degrade target cVOCs?
2) Are low levels (MCLs) achievable?
3) Nutrients required/beneficial?

4) Kinetics of biodegradation (alkane/alkene gases, cVOCs)?
5) What is the optimal level of co-substrate?
   - Competitive inhibition

Microcosms

Kinetic Testing



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MICROCOSM TESTING

Treatment Number	Treatment Description	Headspace	Alkane/Alkene Gas: Gas Purity (%)	Alkane/Alkene Gas: Headspace (%)	Alkane/Alkene Gas: Aqueous Concentration (ug/L)	Inorganic Nutrients Added
Triplicate Microcosms						
1	Killed Control + Methane*	Air	99.0	3.8	850	Yes
2	Live + TEP & N_20	Air	NA	NA	NA	Yes
3	Live + TEP & Methylamine	Air	NA	NA	NA	Yes
4	Propane	Air	99.0	1.5	1000	No
5	Propane + TEP & N_20	Air	99.0	1.5	1000	Yes
6	Propane + TEP & Methylamine	Air	99.0	1.5	1000	Yes
7	Methane	Air	99.5	3.8	850	No
8	Methane + TEP & N_20	Air	99.5	3.8	850	Yes
9	Methane + TEP & Methylamine	Air	99.5	3.8	850	Yes
10	Ethene	Air	99.5	1.1	1500	No
11	Ethene + TEP & N_20	Air	99.5	1.1	1500	Yes
12	Ethene + TEP & Methylamine	Air	99.5	1.1	1500	Yes
13	Natural Gas	Air	~95	3.8	850	No
14	Natural Gas + TEP & N_20	Air	~95	3.8	850	Yes
15	Natural Gas + TEP & Methylamine	Air	~95	3.8	850	Yes
Duplicate Microcosms						
16	Propane + DAP	Air	99.0	1.5	1000	Yes
17	Methane + DAP	Air	99.5	3.8	850	Yes
18	Ethene + DAP	Air	99.5	1.1	1500	Yes
19	Natural Gas + DAP	Air	~95	3.8	850	Yes

- 4 carbon gas substrates
- With and without nutrients
- 3 nutrient combinations
- Ammonia subsequently tested as nitrogen source

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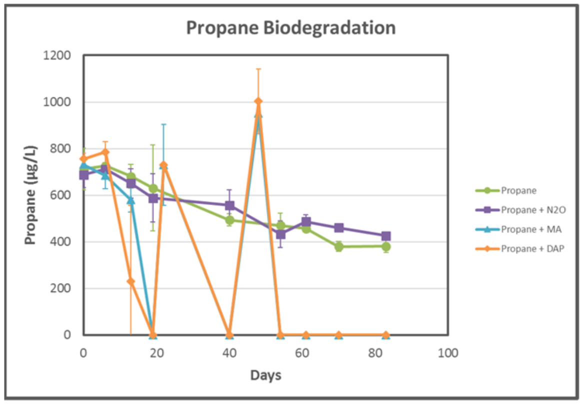
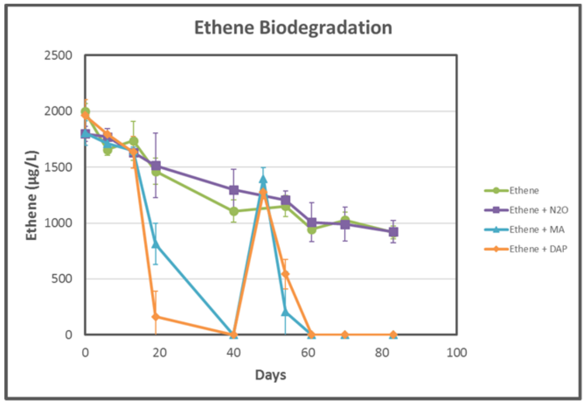
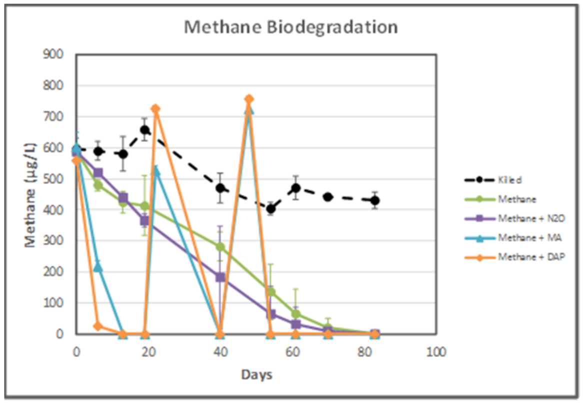
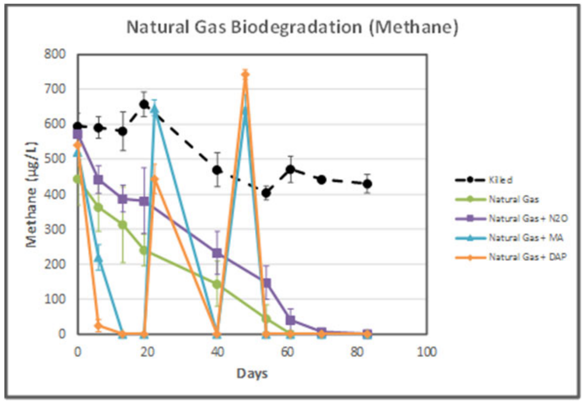
DEGRADATION OF PRIMARY GAS SUBSTRATES

- Methylamine and DAP are effective sources of N
- N_2O not effective
- Aquifer appears to be nutrient limited









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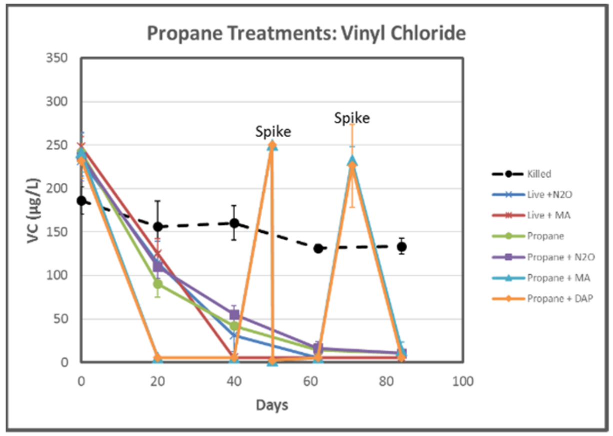
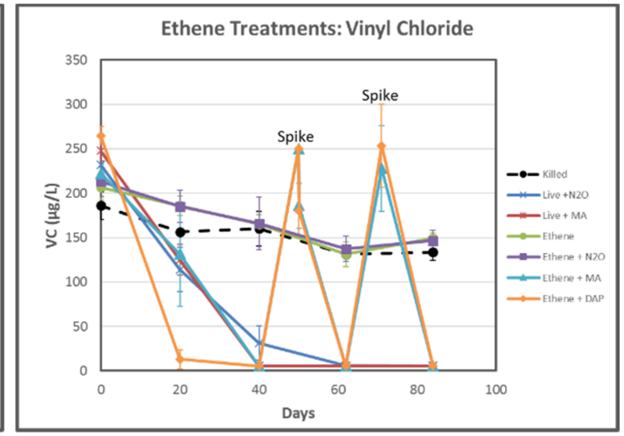
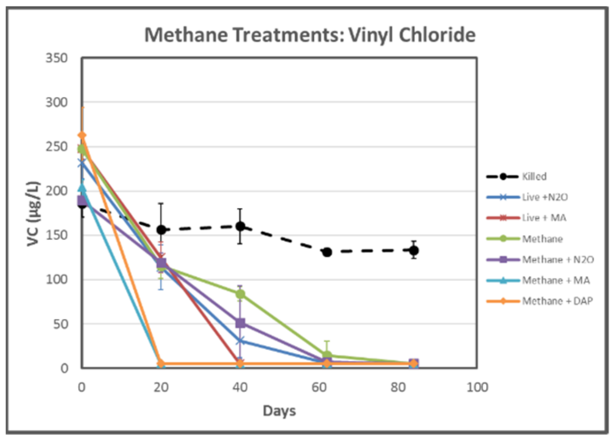
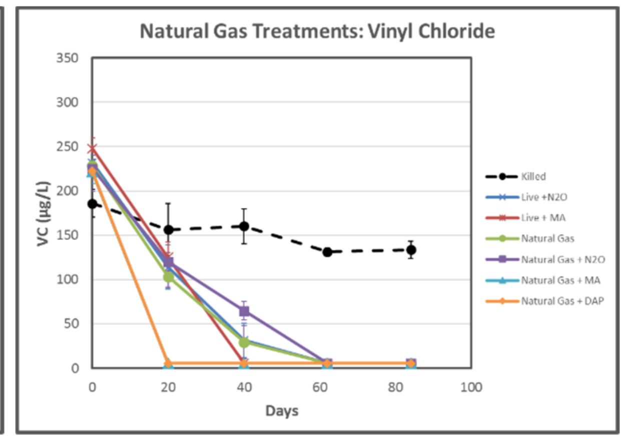
VINYL CHLORIDE DEGRADATION

- Degradation of VC observed in most treatments
- Degradation in “Live” controls
  - Indigenous aerobes capable of directly metabolizing VC, or
  - Organisms using another co-substrate present in soil or groundwater (methane, TOC)
- Rates faster in treatments amended with methylamine and DAP









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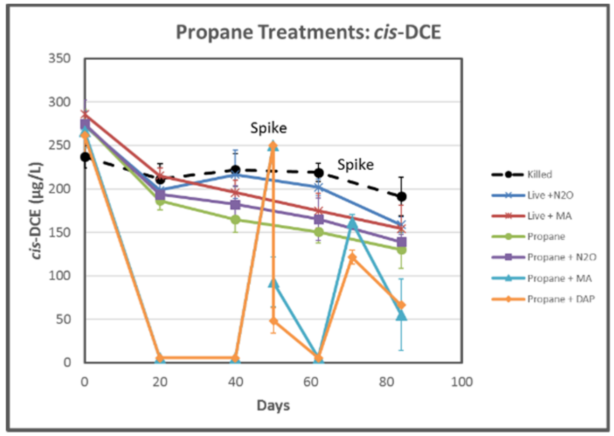
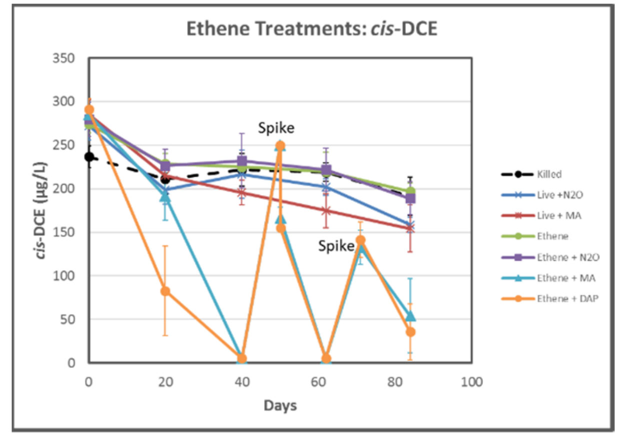
CIS-DCE DEGRADATION

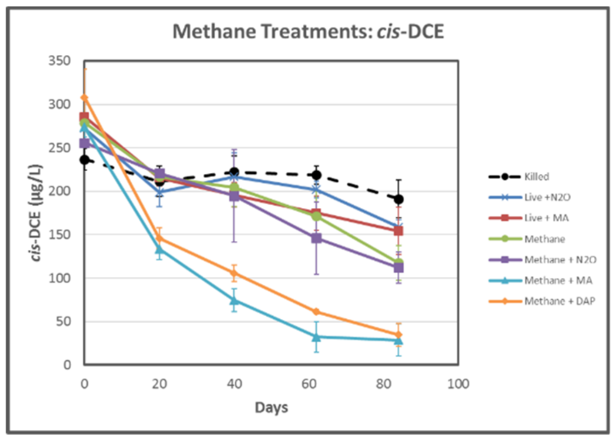
- *cis*-DCE degradation rates faster in propane and ethene treatments
- Degradation continued for >1 month in absence of amendment addition

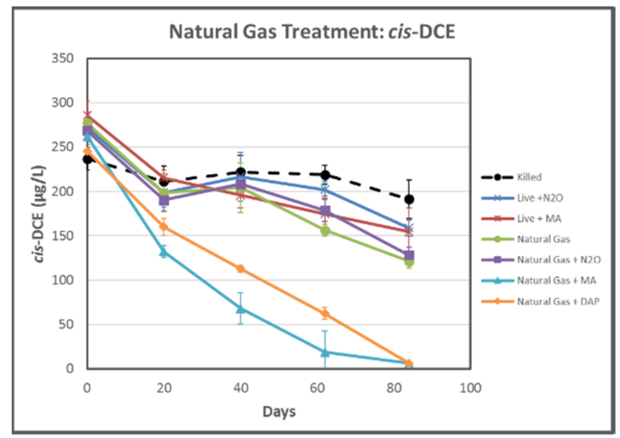




Additional Testing Showed:

- Nitrogen more limiting than phosphorous
- Methylamine and ammonia gases both effective sources of N





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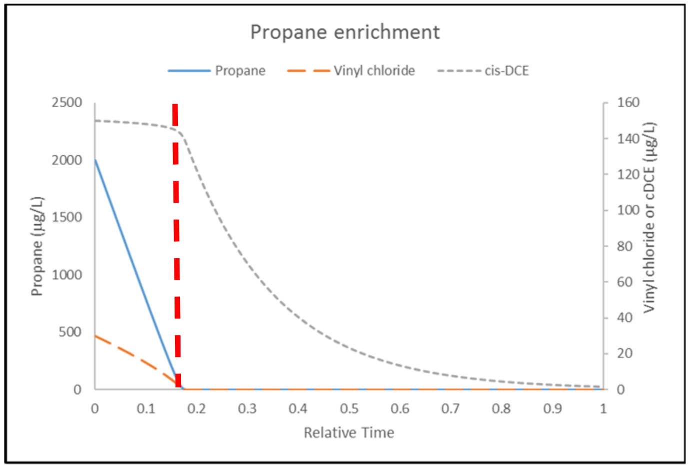
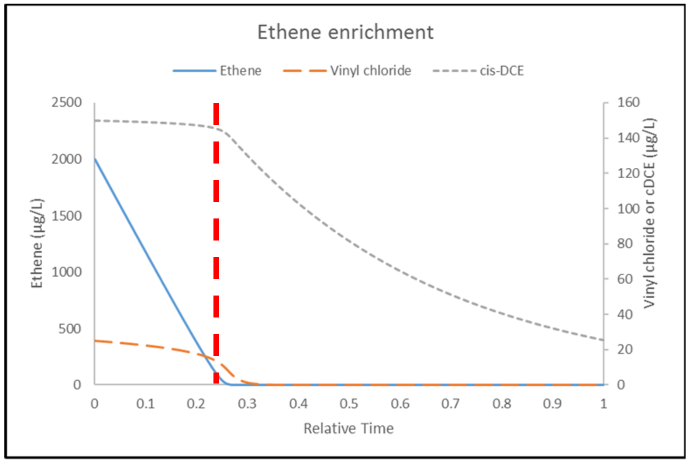
KINETIC TESTING

- Propane- and ethene-oxidizing cultures enriched from microcosms
- Propane-oxidizing culture grows much faster (enrichments)
- Degradation rates for *cis*-DCE and VC faster with propane culture
- Substrate inhibition of VC was less with Propane culture
- Propane determined to be the optimal gaseous substrate

Modeling Results





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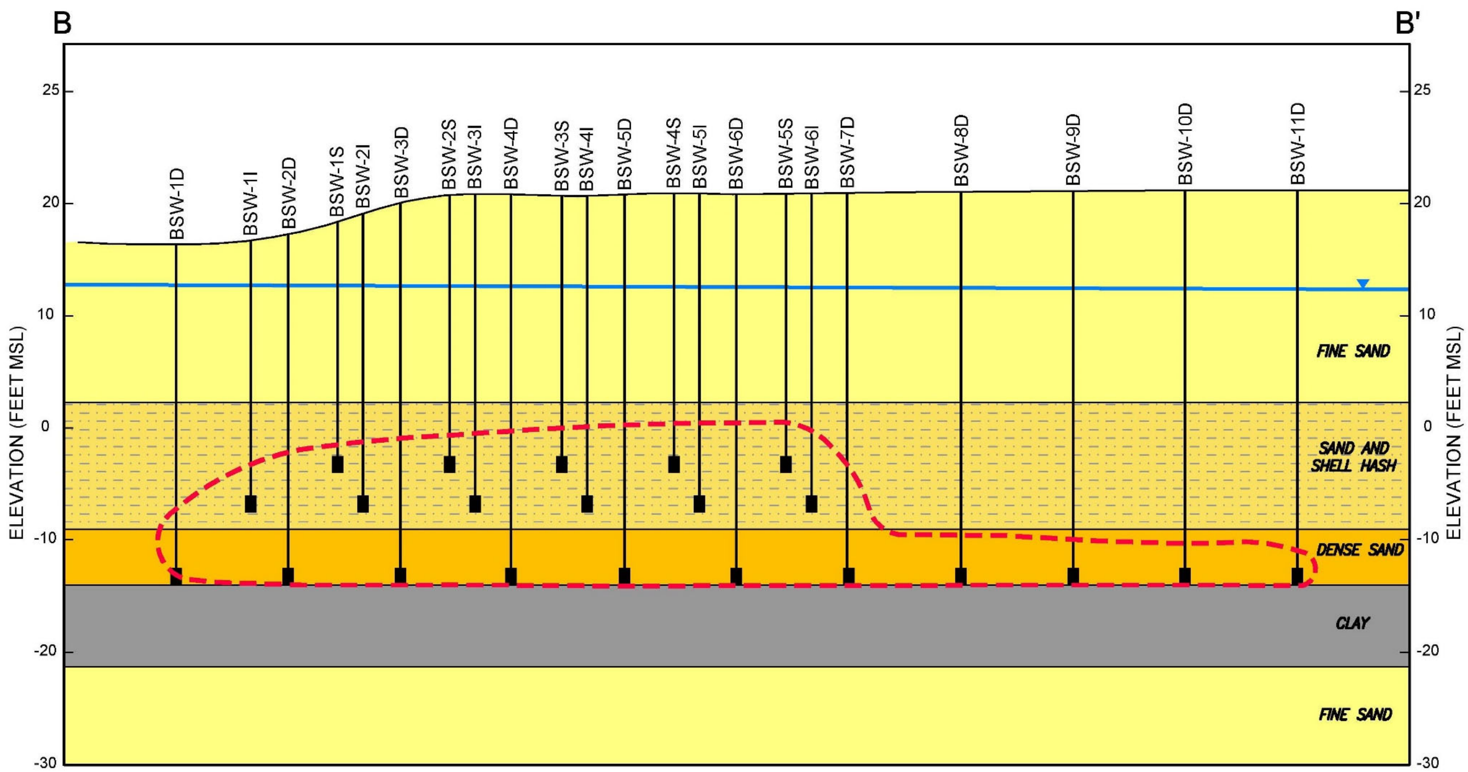
BIOSPARGING WELL LAYOUT



- 22 sparge wells
- 20' spacing
- 3 intervals

LEGEND:

- LINE ENCLOSING AQUIFER WITH CONCENTRATIONS EXCEEDING USEPA MCL's FOR *cis*-1,2-DCE AND VINYL CHLORIDE
- BIOSPARGING WELL SCREEN INTERVAL (18 INCHES LONG)

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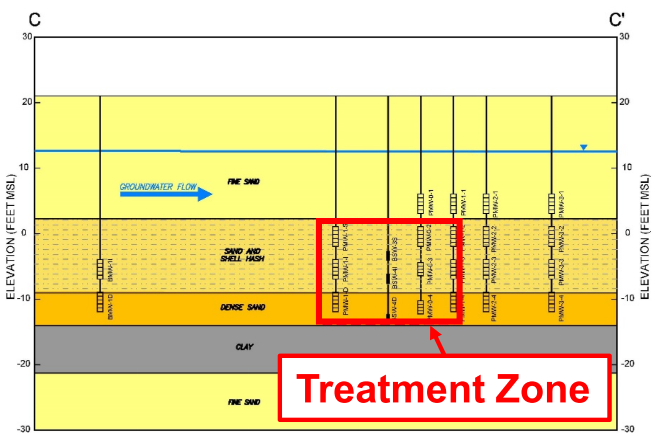
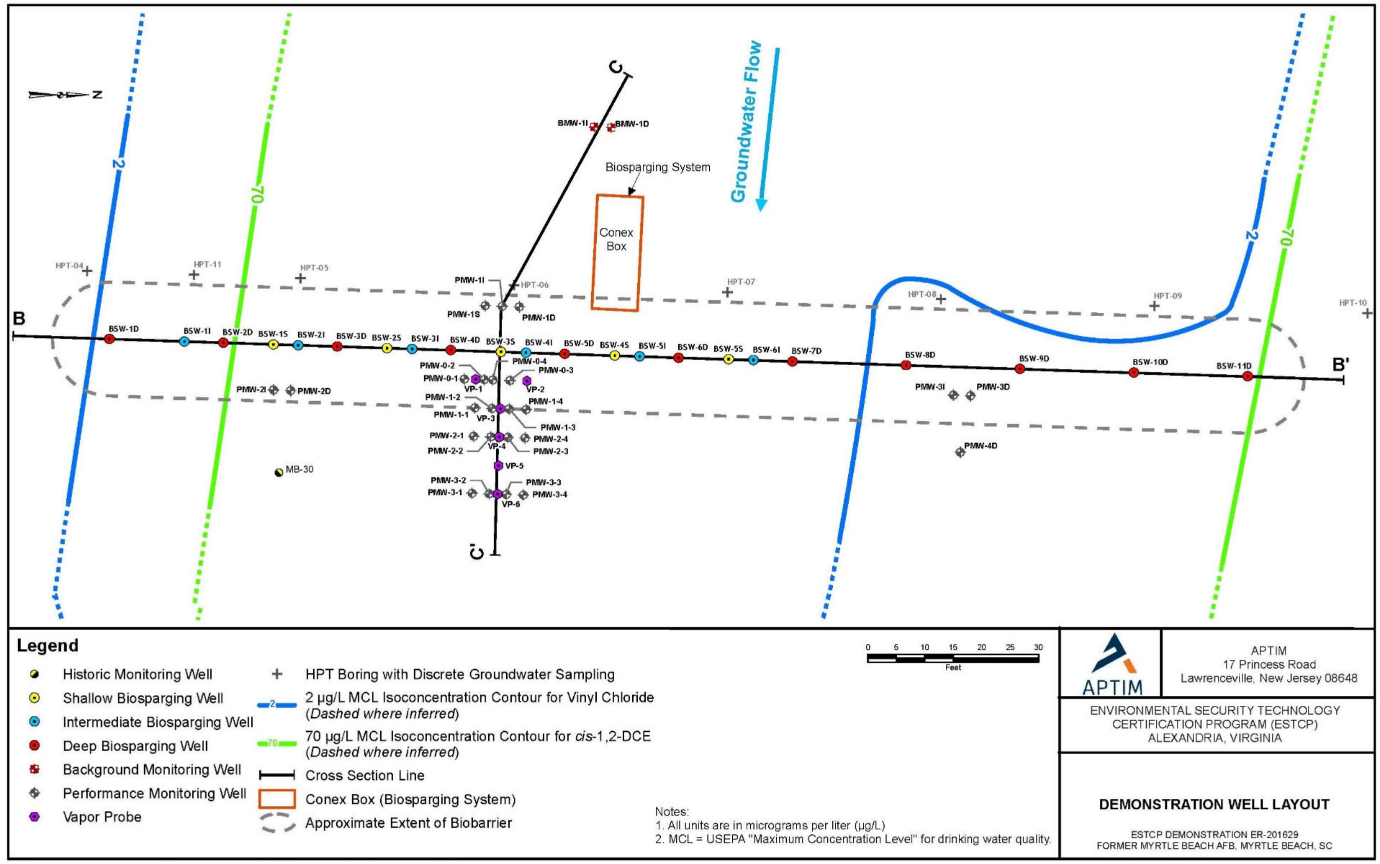
DEMONSTRATION LAYOUT

- Biobarrier 220’ x 20’
- 26 monitoring wells
  - 4 with permanent DO sensors
- 6 vapor probes





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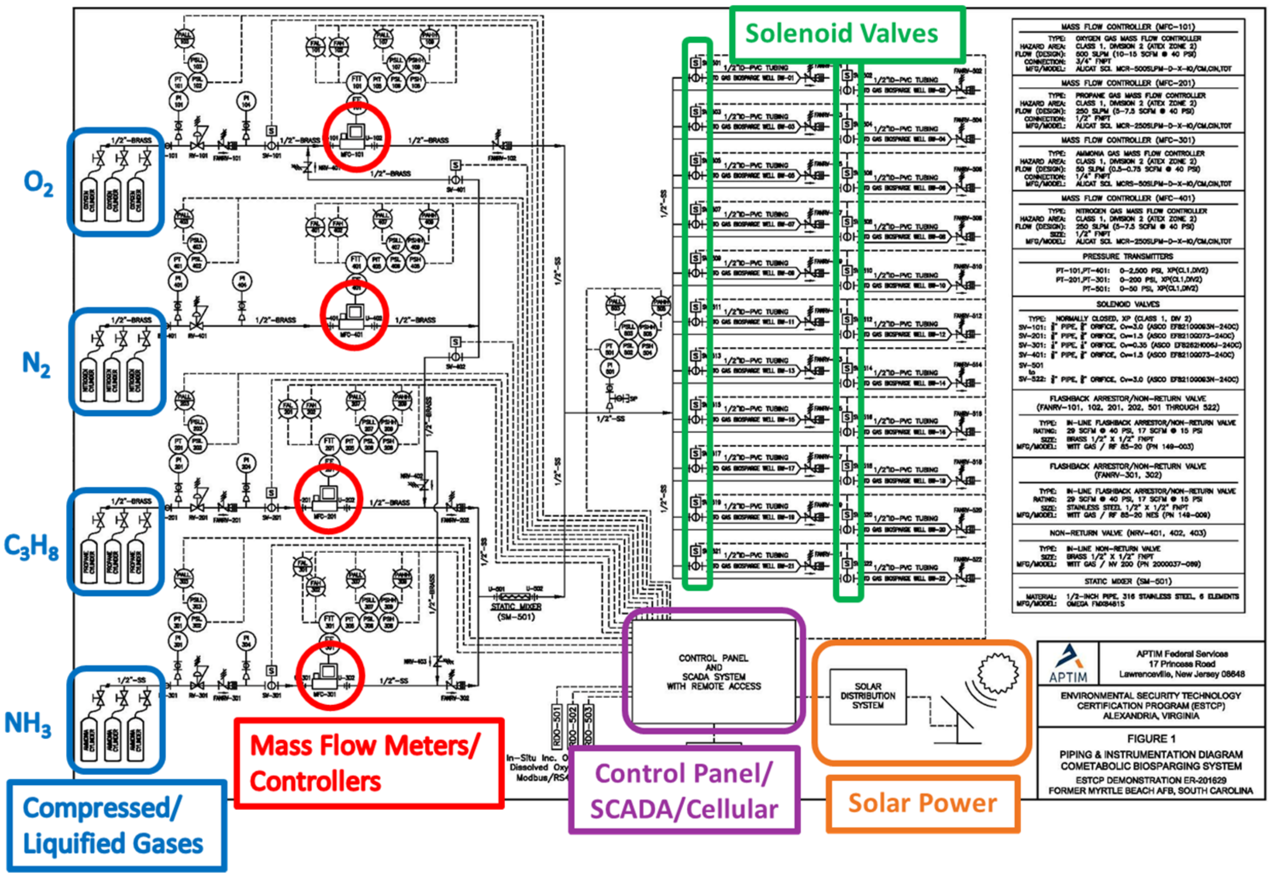
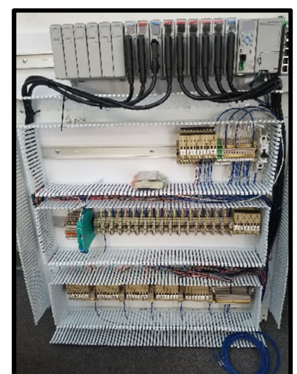
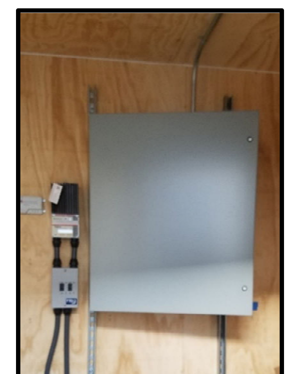
BIOSPARGING SYSTEM: PRIMARY COMPONENTS



- Compressed oxygen and nitrogen
- Liquified propane and anhydrous ammonia
- Solar power (off-grid)
- Control Panel/SCADA
- Cellular for remote monitoring/system changes





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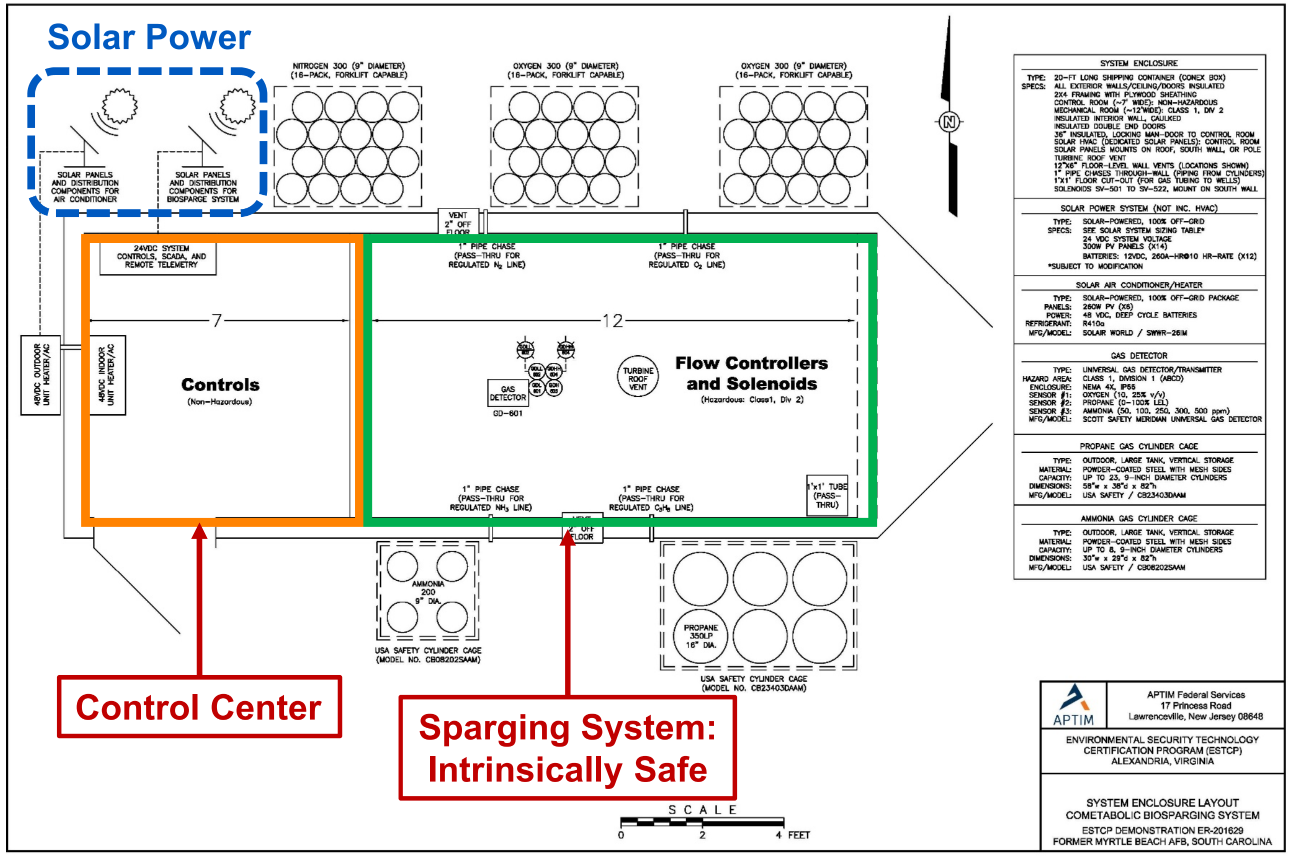
BIOSPARGING SYSTEM: GENERAL LAYOUT

- 20’ Conex box
- Control Center
- Intrinsically safe sparging system
- 16-packs of oxygen and nitrogen
- Propane/ammonia cylinders “ganged” together



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PLANNED SYSTEM OPERATION

- Oxygen-only phase (~5 weeks)
- Cometabolic treatment phase (14 months)
- Oxygen sparged as needed to maintain aerobic conditions (>3 mg/L)
- Propane/ammonia sparged every 4-8 weeks
  - "Batch" system
  - Minimize competitive inhibition
  - Nitrogen used as a carrier gas
- Nitrogen purge cycles between oxygen and flammable gases

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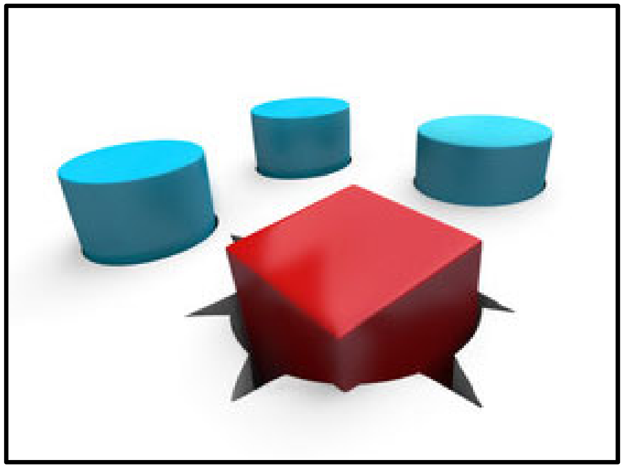
KEY POINTS

- Detailed site characterization & testing key to effective remedial design
- Indigenous bacteria capable of cometabolic degradation of target cVOCs are fairly ubiquitous
- Nutrient addition should be considered when evaluating & designing cometabolic bioremediation
- Sparging approach needs to be tailored to site hydrogeologic conditions



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ACKNOWLEDGEMENTS

- Research funding from ESTCP
- Graig Lavorgna, Rachael Rezes, and Paul Koster van Groos, APTIM
- James Begley, MT Environmental Restoration

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