2013 remediation technologiesymposium

PROOF-OF-CONCEPT EVALUATION
PASSIVE IN-SITU BIOREMEDIATION OF CHLORINATED-BENZENE GROUNDWATER CONTAMINANTS USING GREEN TECHNOLOGY

Kent C. Armstrong – *BioStryke*® Remediation Products, LLC

Robert Chimchirian, P.E. ROUX Associates

I. Richard Schaffner, P.G. – GZA GeoEnvironmental, Inc.

Presentation Outline

- Site Description Evaluation I
- Summary of Pilot Study Process
- Evaluation Methods
  - Additive Release Process
  - Performance Monitoring & Testing
  - Conservative and Repeatable Process
- Description of *BioStryke*® TPH ENHANCED™
- Summary of Results Evaluation I
- Site Description Evaluation II
- Summary of Results Evaluation II
- Questions and Answers

Site Description
Former Landfill Closure Program

- Since 1980 Operated as Solid Waste Disposal Facility
  - Demolition Debris
  - Commercial Solid Wastes
  - Sanitary Wastes
- State of Rhode Island Closure Program
- Dissolved Phase Plume, Smear Zone and Saturated Solid Contaminants
- Elevated Naturally Occurring Organic Mass Present
- Acts as Electron Acceptor Sink
- Contaminant Source Mass within Saturated Mixed Soil and Waste Materials

Site History

- Previous Remediation Strategy Included
- In-Situ Air Sparge /Vapor Extraction System (AS/VES)
- Previous Remediation Goals Included
  - Removal of Soil Vapors
  - Removal of Dissolve Phase Contaminants
  - Increase Groundwater Oxygen Levels to Support Aerobic Bioremediation
- Difficulties and Costs Associated with Cost-Effective Delivery of Oxygen into Landfill Subsurface
- New Goals to Include
  - Evaluate Alternative Biodegradation Pathway
  - Achieve Cost-Effective Source Destruction
  - Eliminate Above-Ground Equipment Needs
  - Lower O&M Project Costs
- Best Approach Determined to be Non-Assimilatory Reduction Technology

Technical Approach

- Proof-of-Concept Evaluation
- Designed to Demonstrate Feasibility of Anaerobic Biodegradation Pathway for Chlorinated-Benzene Contaminants
- Enhanced Non-Assimilatory Reduction
  - Proposes Use of CB Contaminant as Electron Donor
  - Utilizes Additive Blend of Electron Acceptors
  - Providing Metabolic Analog to Oxygen
- Proof-of-Concept Evaluation Permitted in 2009
- Evaluated Process Using Different Deployment
  - Gravity Feed into 8-inch Injection Well
  - Passive Release Sock (PRS) into 2-inch MW
  - Compared Results
  - Same Sampling/Testing Procedures

Proof-of-Concept Evaluation

- Additive Superior to Oxygen
- Additive Contains Preferred Electron Acceptors for Enhancing In-Situ Biodegradation of VOCs
- Order-of-Magnitude Greater Maximum Solubilities vs. Oxygen
  - Approximately 400x greater solubility
- Increases Likelihood of Overcoming Competition from Landfill-derived Organic Carbon
- Treatment Zone
  - Smear Zone Source Mass
  - Dissolved Phase Contaminants
  - Within & Beneath Suspected Source Zone
- Contaminants of Concern include:
  - 1,2-dichlorobenzene
  - 1,4-dichlorobenzene
  - Chlorobenzene, and
  - Benzene

Additive Description

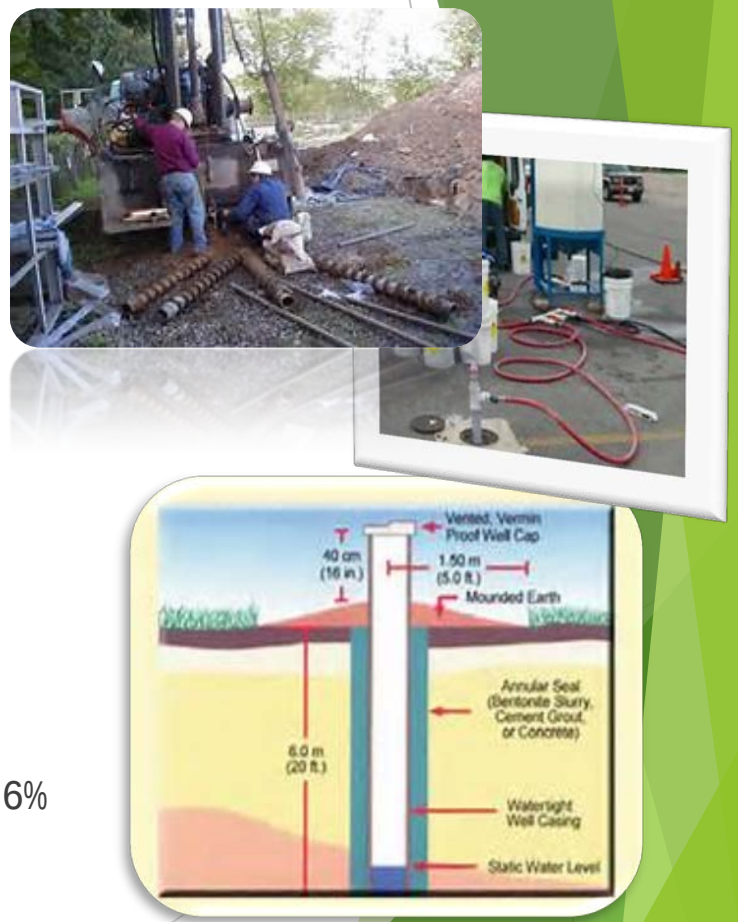
- BioStryke® TPHenhanced™
  - Biostimulates Native Microbial Populations
  - Eliminates Energy Costs; Nuisance Odors, Emissions, and Vapors
- Facilitates Source Mass Transfer
  - Microbial Populations Increase
  - Production of Volatile Fatty Acids Increase
  - VFAs Lower Sorption Coefficients
  - Enhances Desorption of Residual Source Mass
  - Increased Contaminant Bioavailability
- Capable of Sustaining Smaller Microbial Densities than Aerobic Respiration
  - Eliminates Oxidation of Ferrous Iron Concerns
  - Ferric Iron Relatively Insoluble, PPTs, Fouls
  - Minimizes Long-Term Maintenance Issues
- Carbon converted to biomass and sequestered into formation matrix

PRS Deployment Units

- **Pilot Study**
  - Additive Filled PRS Deployment Units
  - Selectively Permeable Wicking Fabric
  - Passive Additive Release Over-Time
  - No Long-Term Impact to Site Geochemistry
- **PRS Deployment Units**
  - PRS Unit is 5-feet long, 1-5/8th inch Circumference
  - Fits within Existing 2-inch Monitoring Well
  - Each unit contains ≤2 pounds of Additive
  - Creates Minimal AOI of 1 meter or less
  - Suspended within Screened Interval of Test Well
- **Additive Distribution**
  - Passively Releases into Water Column
  - Slowed by PRS unit
  - Additive Typically Depleted with 7-12 days
  - Deployment Units replaced 11-times during Evaluation

Deployment Injection Methodologies

- **Gravity Fed Injection-Deployments**
  - Into Two (2) Existing 8-inch Injection Wells
- **Extent of Impact**
  - Area-of-Influence approached 6-meters (18-ft)
  - Monitoring wells located within AOI - Downgradient
  - Passive-Aggressively Amends GW Column
- **Additive Deployment Rates**
  - Additive Solution Concentration 525 mg/L
  - Blended with water to attain 8% Slurry
  - Deployed 3,400 and 5,700 gallons slurry per well
  - Estimated Pore Space to Volume Displacement of 10.6%
  - Model Full-Scale Impacts to Site Geochemistry
- **Deployment performed November 2011**



Performance Monitoring

- **Sample Collection Low-Flow Purge Protocols**
  - *Performance Sampling began December 2011*
  - *Ended July 25, 2012*
  - *Total of seven (7) Sample Rounds Competed*
- **Purging of GW Monitoring Well Adversely Skews Study Results**
  - *Removes Amended Groundwater*
  - *Removes Biostimulated Microbial Population*
- **Monitoring Data and Samples Collected from:**
  - *Casing volume of test Well itself (PRS)*
  - *Downgradient wells (Injection locations)*
- **PRS Deployment Units are removed and Replaced After Completion of Each Monitoring/Sampling Event**
- **Performance Evaluation Compared Baseline to End of Evaluation**

Anticipated Observations - Geochemical

- Increased Oxygen Reduction Potential (ORP)
- Reduced Production of Methanogenic Gasses and Conditions
- Rapid Utilization of Additive Components
- Increased Native Populations of Heterotrophic Petrophylic Microbials
- Enhanced Volatile Fatty Acid (VFA) Production
- Increased Contaminant Bioavailability
- Increased Rates of PHC Degradation in Direct Response to Additive Availability

BioStryke Remediation

Pilot Study Process Confirms Biostimulation as a Source Control Strategy

Anticipated Observations - Contaminants

- Rapid Biodegradation of Dissolved Phase Petroleum Hydrocarbon Contaminants
- Increased Microbial Population Growth
- Increased Production of Volatile Fatty Acids (VFA's)
- Enhanced Flux (desorption) of PHC Residual Source Mass
- Increased Contaminant Bioavailability
- Enhanced Anaerobic Biodegradation
- No Fuel Consumption, Generation of Nuisance Emissions, Vapors, Noise
- Cost-Effective Remedial Performance with Less Environmental Impact = ***GREEN***

PRS Location Results

PRS Locations Demonstrated Significantly Lower Performance
Minimal Reductions in Contaminant-of-Concerns (COC)

Significant Increase in Contaminant Bioavailability

4x Increase in [Dissolved Phase] Contaminant Levels

Quickly Followed by Dramatic Decreases (59%)
and
Decreases in COD Levels and Increased pH levels

While gross %decreases for CB, 1,2-DCB, and 1,4-DCB were ostensibly the same; not likely due to dilution alone, rather data appears consistent with non-assimilatory reduction pathway.

Injection Location Results

Significant Contaminant Reductions Observed in monitoring wells immediately downgradient from injection locations.

- **Order of Magnitude Reduction in [Benzene] to < 5 µg/L**
- **Average Gross %Reduction in Chlorobenzene of e 90%**
- **Average Gross %Reduction in 1,2-Dichlorobenzene of e 93%**
- **Average Gross %Reduction in 1,4-Dichlorobenzene e 96%**

Secondary Supportive Evidence of Additive Induced Anaerobic Biodegradation Included

Increased Concentrations in Additive Followed by Dramatic Depletion of Additive Availability

Decreases in COD and Increased pH levels

Similar reductions in site contaminants within the treatment zone not subject to non-assimilatory reduction were not observed

BioStryke Remediation

Summary of Results

Demonstrated feasibility of low-cost methodology
Anaerobic In-Situ Bioremediation

- **Reduce Overall Impact of Remediation**
  - **Lower Carbon Footprint**
- **Eliminate Above Ground Equipment Support Needs**
- **Eliminate Energy Use/Cost; and Nuisance Emissions, Vapors, and Fumes**

Requires Diligence with Regards to Groundwater Monitoring Process requires, and Additive Contains Nitrates and Other Electron Acceptors

Cannot be used in proximity of on-going pump-and—treat system
Cannot be used in proximity of sensitive receptors and/or potable drinking water supply wells

Reduce risks of biofouling as compared to aerobic remedial processes
Leverage aqueous solubility orders-of-magnitude greater than Oxygen

New Jersey Evaluation Site II

Active Manufacturer of cleaning, sanitizing, pest control, maintenance and repair products

Former Proctor & Gamble Site

- **Dissolved Phase Contaminant Plume Migrating Off-Site**
- **Wanted to Lower Carbon Footprint**
- **Eliminate Above Ground Equipment Support Needs**
- **Eliminate Energy Use/Cost, Nuisance Emissions, Vapors, and Fumes**

New Jersey Evaluation Site Geochemical Impacts

METRIC	Nov 12 2012	April 15 2013	May 8 2103	July 10 2013	Aug 6 2013
Additive	NA	440 mg/L	130mg/L	2,730 mg/L	99 mg/L
ORP	NA	76.7 mV	142.0 mV	225.0 mV	204.5 mV
DO	NA	5.0 mg/L	0.3 mg/L	2.2 mg/L	2.3 mg/L

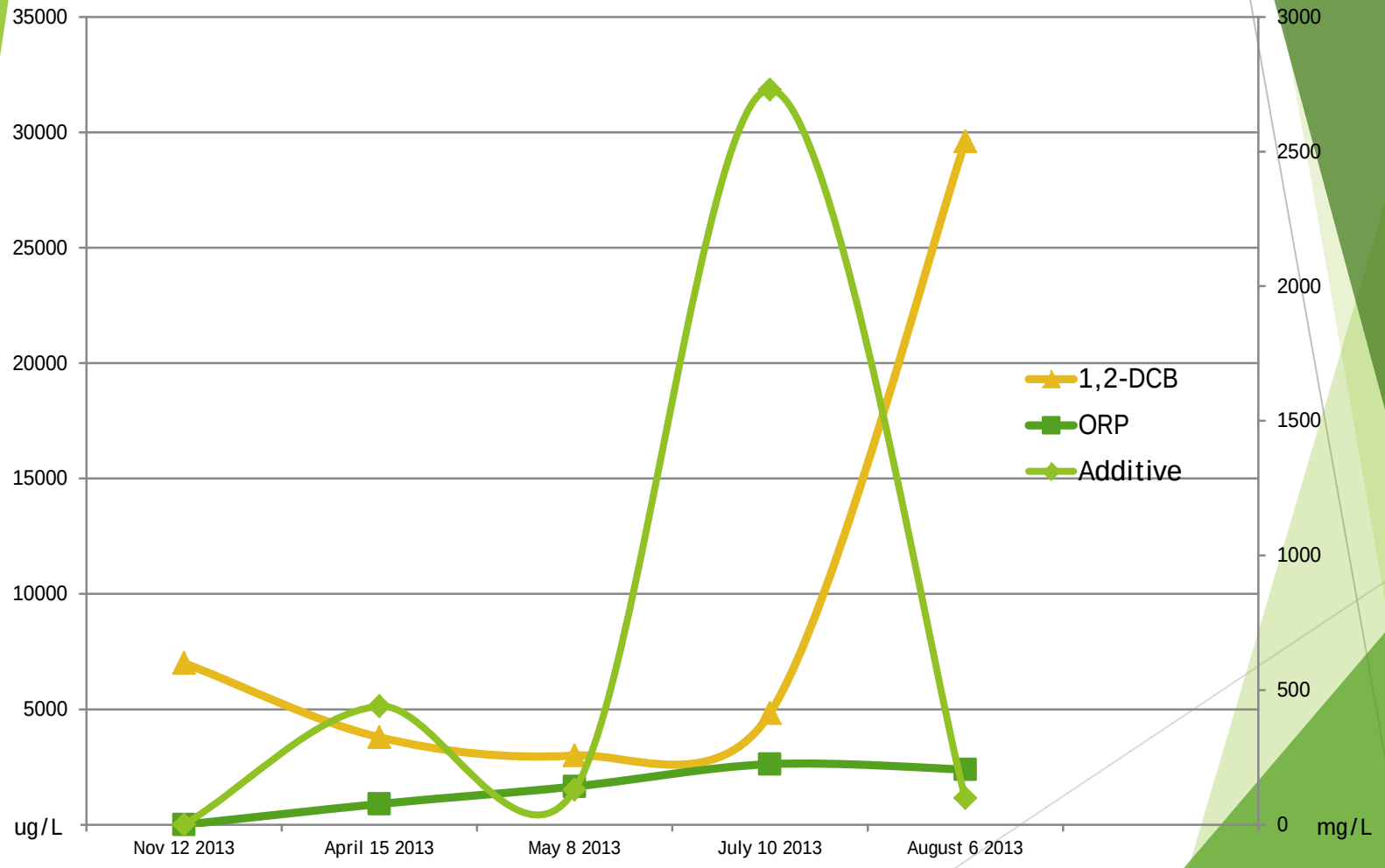
- As additive availability increased
- ORP and DO characteristics within treatment zone responded, providing 'enhanced' anaerobic-reducing conditions
- If chlorobenzene contaminant can act as electron donor
- Periods of anaerobic contaminant degradation should occur
- Deployment via DPT; 10-ft centers, injecting 56 gallons additive slurry per node with centrally located monitoring well within 10 x 10 treatment zone

New Jersey Evaluation Site Contaminant Degradation

METRIC	Nov 12 2012	April 15 2013	May 8 2103	July 10 2013	Aug 6 2013
Additive	NA	440 mg/L	130mg/L	2,730 mg/L	99 mg/L
1,2-Dichlorobenzene	7,000 µg/L	3,709 µg/L	3,000 µg/L	4,830 µg/L	29,600 µg/L
1,3-Dichlorobenzene	84.0 µg/L	34.3 µg/L	40.0 µg/L	74.5 µg/L	323.0 µg/L
1,4-Dichlorobenzene	660.0 µg/L	324.0 µg/L	310.0 µg/L	662.0 µg/L	3,770 µg/L
Chlorobenzene	770.0 µg/L	45.4 µg/L	42.0 µg/L	61.4 µg/L	435.0 µg/L

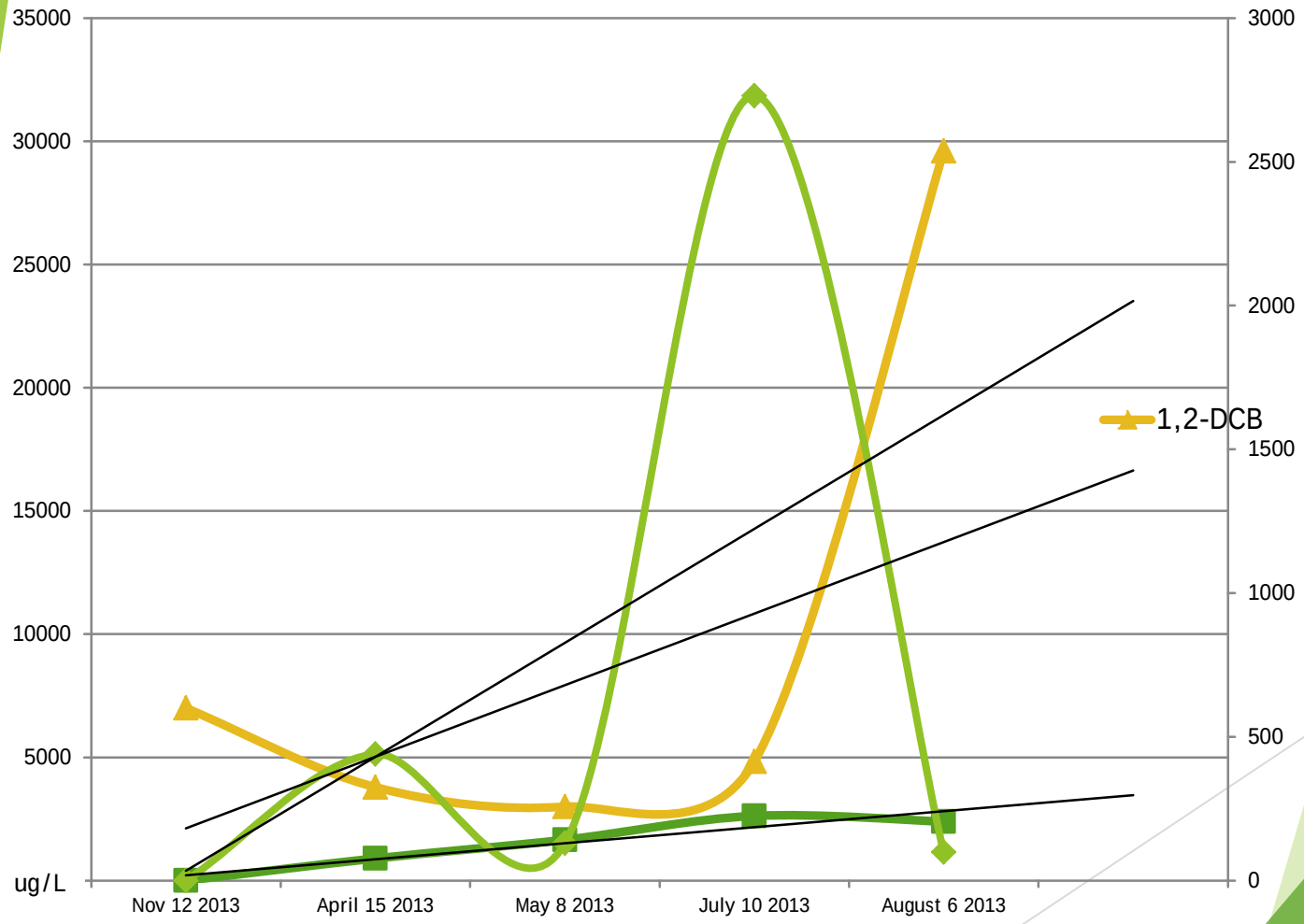
- With additive availability comes increased heterotrophic microbial activity
- Corresponding decreases in dissolved phase contaminant concentrations
- March 2013 deployment resulted in 60% decrease total VOCs in < 60 days
  - With additive availability comes increased microbial population growth
- Increased production of volatile fatty acids resulting in enhanced desorption of residual source mass contaminants

BioStryke™ TPHenhanced® New Jersey Proof-of-Concept Evaluation



BioStryke Remediation

BioStryke™ TPHenhanced® New Jersey Proof-of-Concept Evaluation



BioStryke Remediation

Summary of New Jersey Evaluation

Confirmed In-Situ Biodegradation Pathway Plausible using Chlorinated Benzene as electron donor under Anaerobic Conditions

- **PRS Evaluation Low-Impact, Low-Risk w/ Minimal to *NO* Long-Term Impact to Site BioGeochemistry**
- **Performed on-Site Under Actual Site Geochemical Conditions Providing "*Go-no-Go*" Evaluation Process that is Conservative-Representative**
- **Provides Owners/Generators, Practitioners, & Regulators Added Confidence Prior to Commitment to any Additive Based Remedial Strategy**
- **Requires Scheduled, Consistent and Accurate Field Monitoring, Groundwater Sampling and Laboratory Analytical Testing**
- **Assists in Establishment of Full-Scale Amendment Demand , Rate of Assimilation, Treatment Timelines, and Full-Scale Additive Cost Estimates**
- **Approved by Ministry of Ontario Environment, USAF, NASA, Numerous United State Environmental Regulatory Agencies, International**

Thank You ?? Questions ??

Particular Thanks to:

ROUX Environmental, Inc.

Mr. I. Richard Schaffner

RemTech 2013; and,

ESAA Symposium Staff

Thank You

BioStryke Remediation Products, LLC
P.O. Box 254, Andover NH
www.biostryke.com