# Enhanced Bioremediation of Contaminated Soils using Sustainable Soil Amendments

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# Field-Proven Portfolio of Remediation Technologies

## Chemical Oxidation

- Klozur® Persulfate Portfolio
  - Klozur® SP
  - Klozur® KP
  - Klozur® One
  - Klozur® CR
- Hydrogen Peroxide

## Aerobic Bioremediation

- Terramend® Reagent
- PermeOx® Ultra
- PermeOx® Ultra Granular

## Metals Remediation

- MetaFix® Reagents

## Chemical Reduction

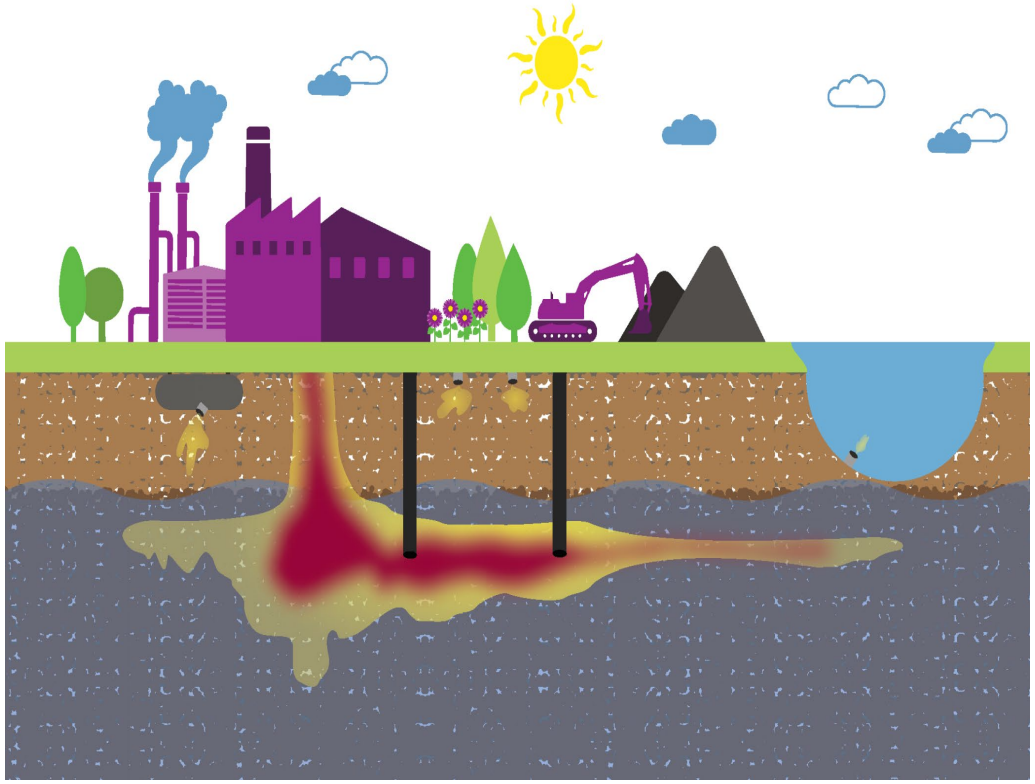
- EHC® ISCR Portfolio
  - EHC® Reagent
  - EHC® Liquid
  - EHC® Plus
- Daramend® Reagent

## Enhanced Reductive Dechlorination

- ELS® Microemulsion
- ELS® Liquid Concentrate
- ELS® Dry Concentrate

## BioGeoChemical

- GeoForm® Reagents



# Agenda

1. The Problem and The Opportunity
2. Sustainable Reagents for Aerobic and Anaerobic Bioremediation
   - ✓ Composition of Terramend® Carbon & Terramend® Inorganic reagents
   - ✓ Composition of Daramend® and Daramend® Plus Reagents
   - ✓ Compare and Contrast with traditional fertilizer-based approach
   - ✓ Microbiology & Biochemistry during soil treatment
3. Bench-scale treatability approach and results

# The Problem

- Traditional approach relies on supplying nitrogen and phosphorus at an “optimized” C:N:P ratio to support biodegradation of targeted hydrocarbons (PAHs, TPH, CP)
- Typical amendments used include commercial and agricultural fertilizers
- This approach fails frequently as inorganic nutrients are used rapidly when bioavailable, and are lost through wasteful processes including luxury consumption, denitrification, and precipitation
- The fertilizer approach also fails to address the issues of acute microbial toxicity and inadequate bioavailable water
- Soil volume increases post-treatment due to the addition of bulking agents

# The Opportunity

Overcome inefficiencies in the traditional approach by using specialized soil amendments that provide nutrients, increase bioavailable water, and protect soil microorganisms from high acute toxicity.

- Sustainable amendments capable of creating the optimal conditions for degradation
- Capable of treating high concentrations of contaminants while overcoming acute toxicity to indigenous microbes
- Allows balance between soil water content (bioavailable water) and the ability to maintain aerobic conditions
- Lower overall remediation costs

# Terramend® Carbon and Terramend® Inorganic Reagents

| Attribute | Terramend® Carbon | Terramend® Inorganic |
|---|---|---|
| **High Surface Area Hydrophilic Plant Fiber** | ✓ | ✓ |
| **Slow-release Organic Carbon & Nutrients (N, P, S)** | ✓ | ✓ |
| **Inorganic Nitrogen & Phosphorus** | - | ✓ |
| **Emulsifying Agent** | ✓ | ✓ |
| **pH Balanced** | ✓ | ✓ |

- Both formulations are designed to stimulate the growth of aerobic microorganisms in soil by providing an effective blend of organic carbon, amino acids, and organic nitrogen and phosphorus.
- Terramend Carbon treats PAHs, phthalates, and chlorophenols (including PCP).
- Terramend Inorganic treats BTEX, GRO, DRO, and TPH.

# Daramend® and Daramend® Plus Reagents

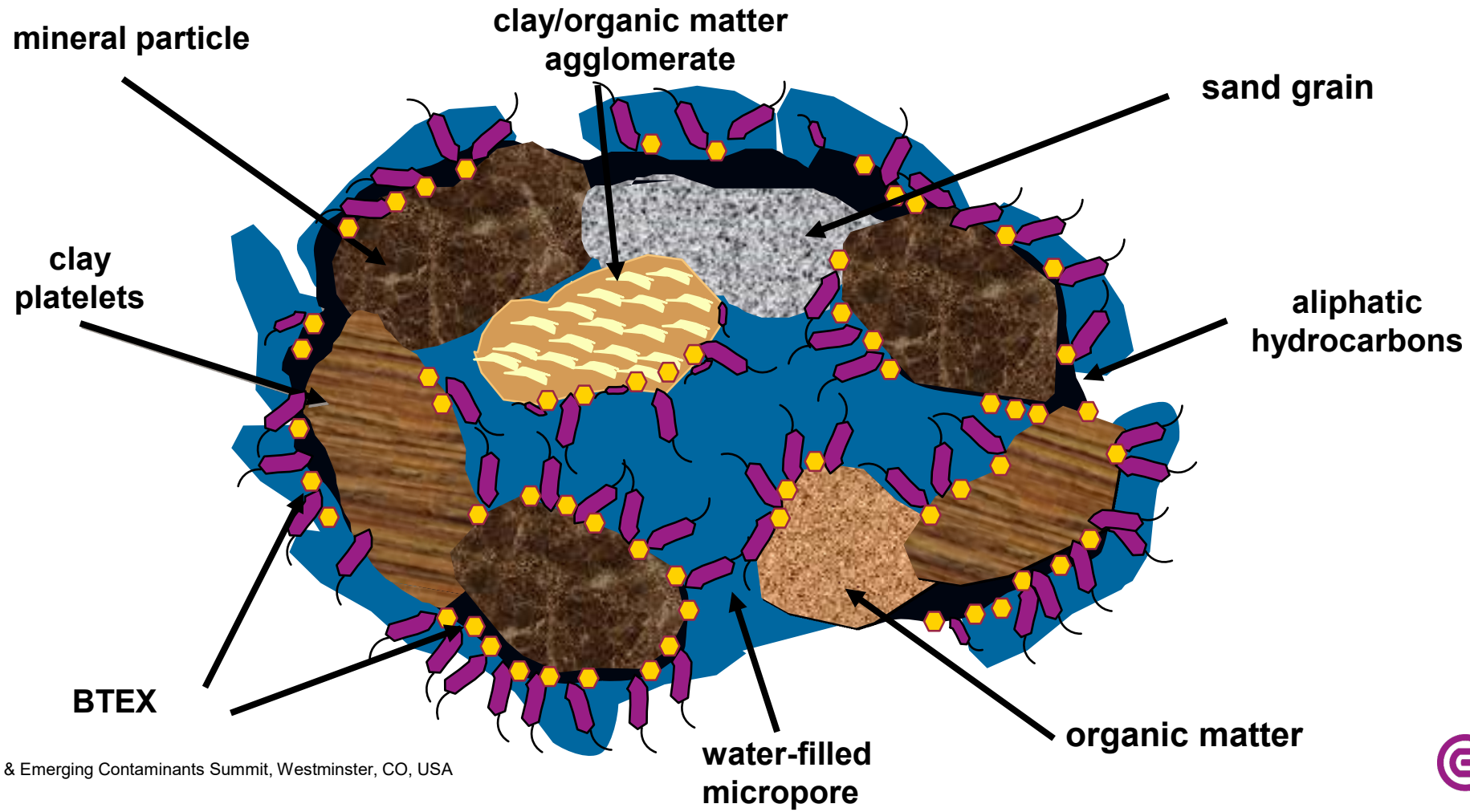
| Attribute | Daramend® | Daramend® Plus |
|---|---|---|
| High Surface Area Hydrophilic Plant Fiber | ✓ | ✓ |
| Rapid-release Organic Carbon & Nutrients (N, P, S) | ✓ | ✓ |
| Emulsifying Agent | ✓ | ✓ |
| pH Balanced | ✓ | ✓ |
| Microscale ZVI | ✓ | ✓ |
| Activated Carbon | - | ✓ |

- For the treatment of chlorinated pesticides, herbicides, organic explosives, chlorinated solvents and heavy metals.
- Creates anaerobic and reducing conditions

# Distinguishing Features of the Terramend® Reagents

- Prevents formation of large, dense aggregates, with anoxic centers, as often seen with other soil bioremediation technologies
- Small particle size and hydrophilic nature
  - Requires a relatively small dosage to achieve a large increase in soil water holding capacity (WHC) and bioavailable water
  - Makes the soil easier to handle
  - Reduces the need to collect and treat free water
- Processed from plant materials rich in cellulose and hemicellulose, with very little lignin (unlike wood chips/saw dust that are high in lignin content)
  - Readily biodegradable
  - Does not bind contaminants in a manner that shields them from biodegradation
- Works effectively at lower dosages
  - 1% to 5% by wt. of soil as opposed to 10% to 20% by wt. of saw dust, wood chips, or other common bulking agents

# How does Terramend® Work?



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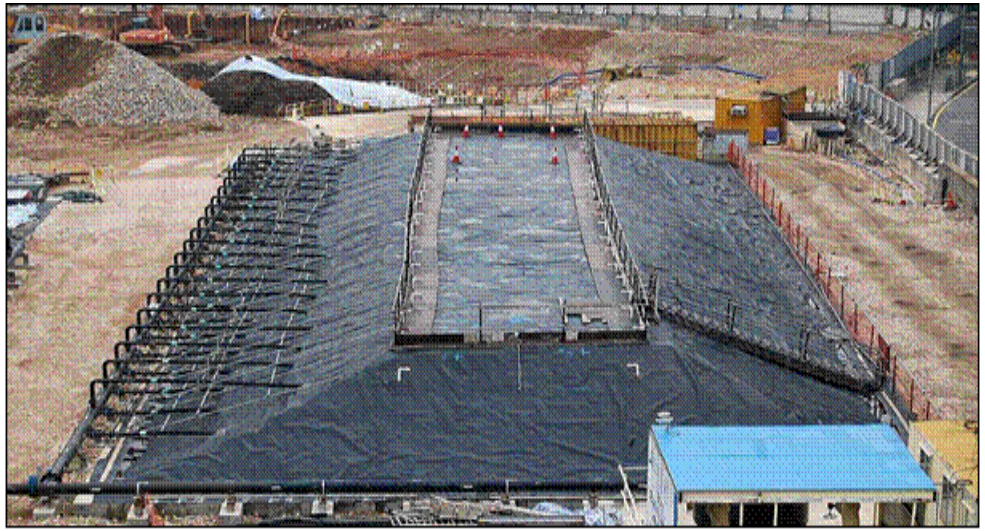
# How do I use Terramend® Reagents?

In-situ treatment of surface soil (0 – 24” bgs)

On-site treatment of excavated soil in HDPE-lined biocell

On-site treatment of excavated soil in mixed biopiles


On-site treatment of excavated soil in aerated biopiles





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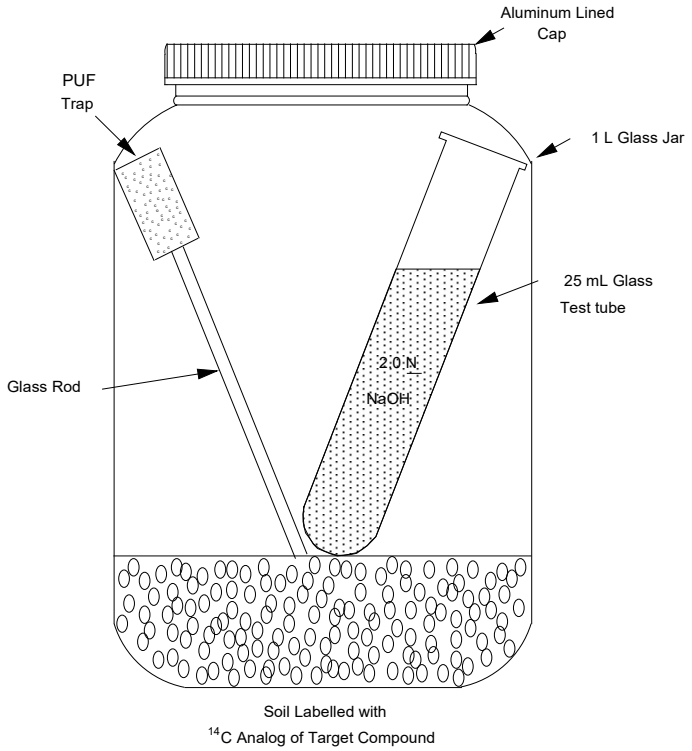
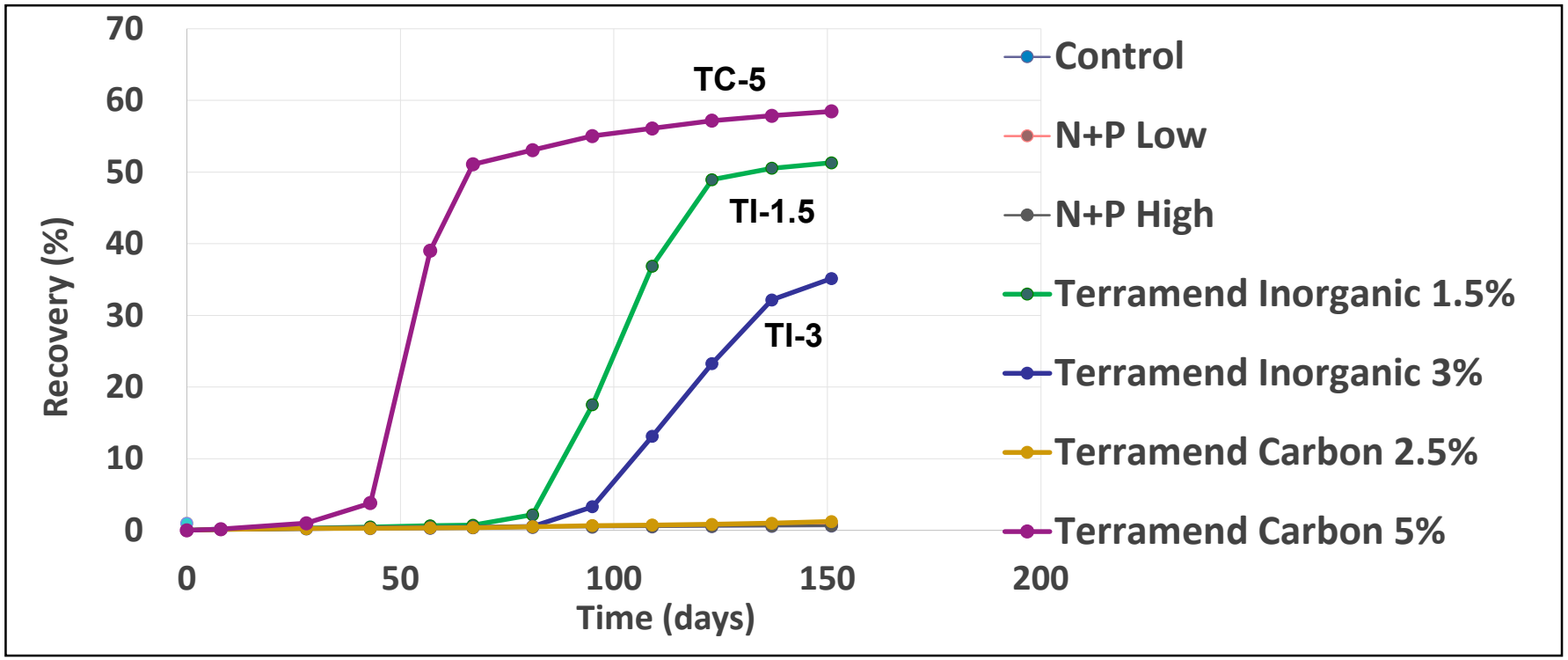
# Bench-scale Treatability Testing

- ✓ Objectives
- ✓ Methodology
- ✓ Results for PCP, and Petroleum Hydrocarbons

# Bench-scale Treatability Testing for PCP in Soil

## Mineralization of $^{14}C$-PCP to $^{14}C$-$CO_2$




- Documents complete biodegradation of PCP
- Compares performance of reagents and dosages

- Hydrophobic soil with acutely toxic COI
- Terramend® Carbon at 5% w/w performed best
- Poor response to both N+P nutrient treatments



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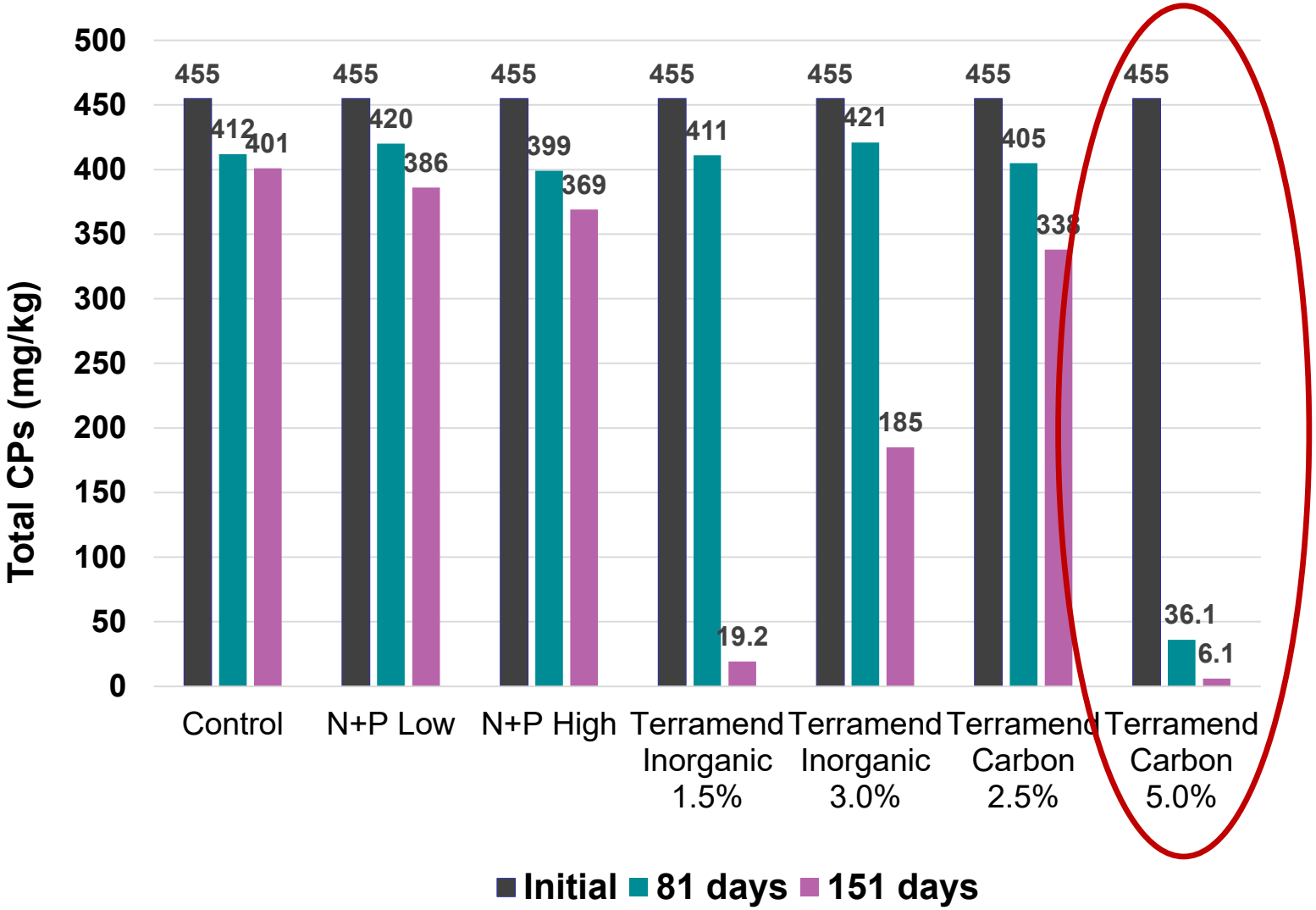
# Bench-scale Treatability Testing for PCP in Soil

## Total Extractable Chlorinated Phenols




- Strong correlation between mineralization of $^{14}$C-PCP and reduction in total soil PCP
- Treatment that supported greatest conversion of PCP to $CO_2$ also achieved lowest residual PCP concentrations
- Higher dose of slowly-released Terramend Carbon provided optimal moisture without turning soil anaerobic
- Inorganic N+P was ineffective regardless of dosage



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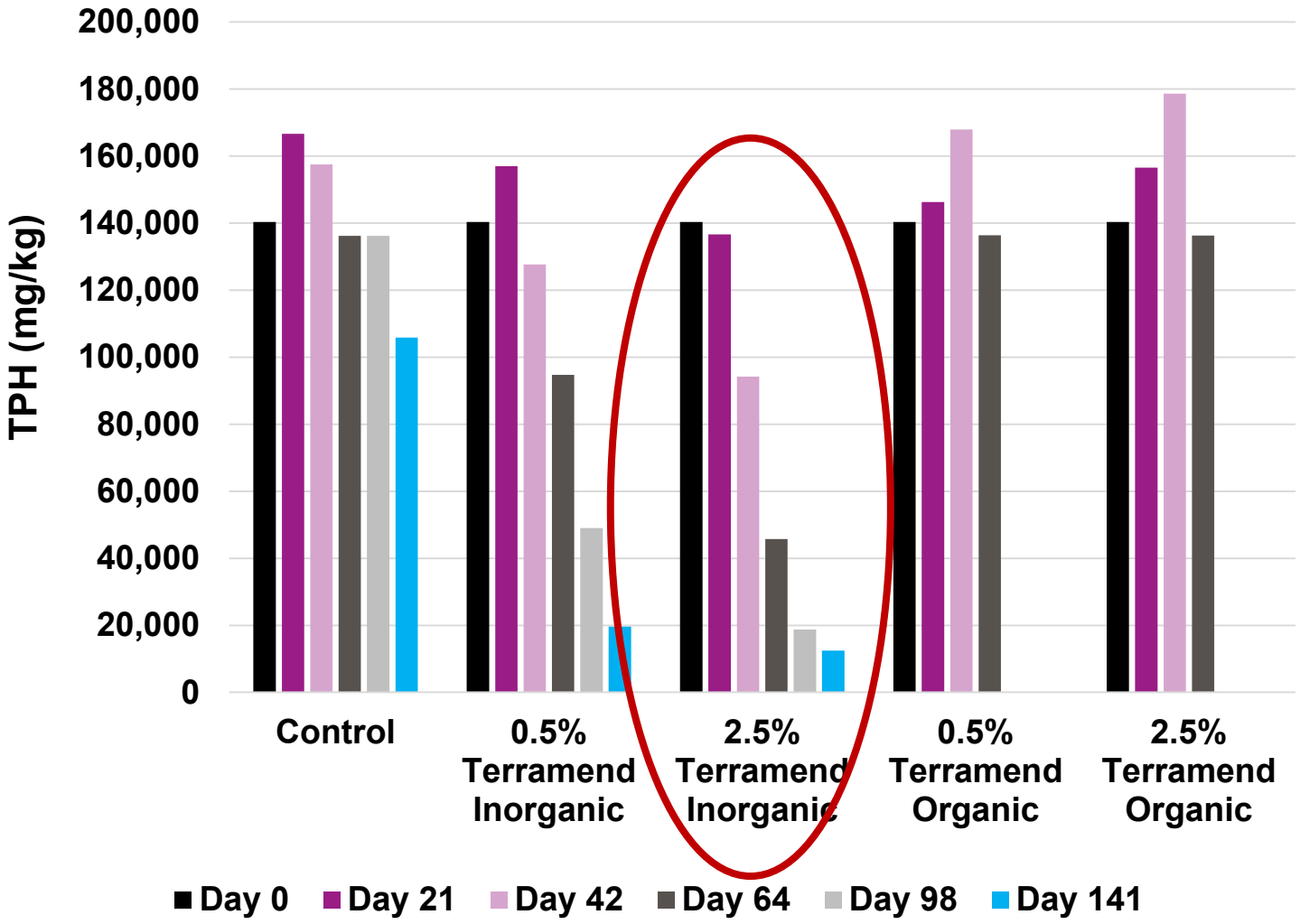
# Bench-scale Treatability Testing

## Terramend® Treatment of Stabilized Drill Cuttings




- Very high TPH drill cuttings from oil extraction
- Initial treatment with wood mulch (10% w/w) did not achieve the desired TPH reduction
- The as-received soil (pre-treated with mulch) were subjected to 141 days of Terramend® treatment with weekly aeration by mixing
- There was a sharp difference in response to Terramend Inorganic vs Terramend® Carbon.
- Most effective treatment was the higher dosage of Terramend® Inorganic
- TPH was reduced by 91% in response to this treatment



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# Project Snapshots

1. Terramend® Inorganic Treatment of Aged Hydraulic Oil and Diesel Fuel
2. Terramend Carbon Treatment of Bis(2-ethylhexyl) Phthalate
3. Terramend Carbon Treatment of PAHs, PCP, and Mineral Oil TPH
4. Terramend® Carbon Treatment of MGP PAHs

# Project Snapshot #1

## Terramend® Inorganic

## Ex-Situ Treatment of Hydraulic Oil

## & Diesel Fuel

- Midwest Industrial site
- Former agricultural equipment repair facility
- Approximately 4,400 tons of soil treated on-site
- Terramend® reagent cost was about $39 /ton of treated soil.




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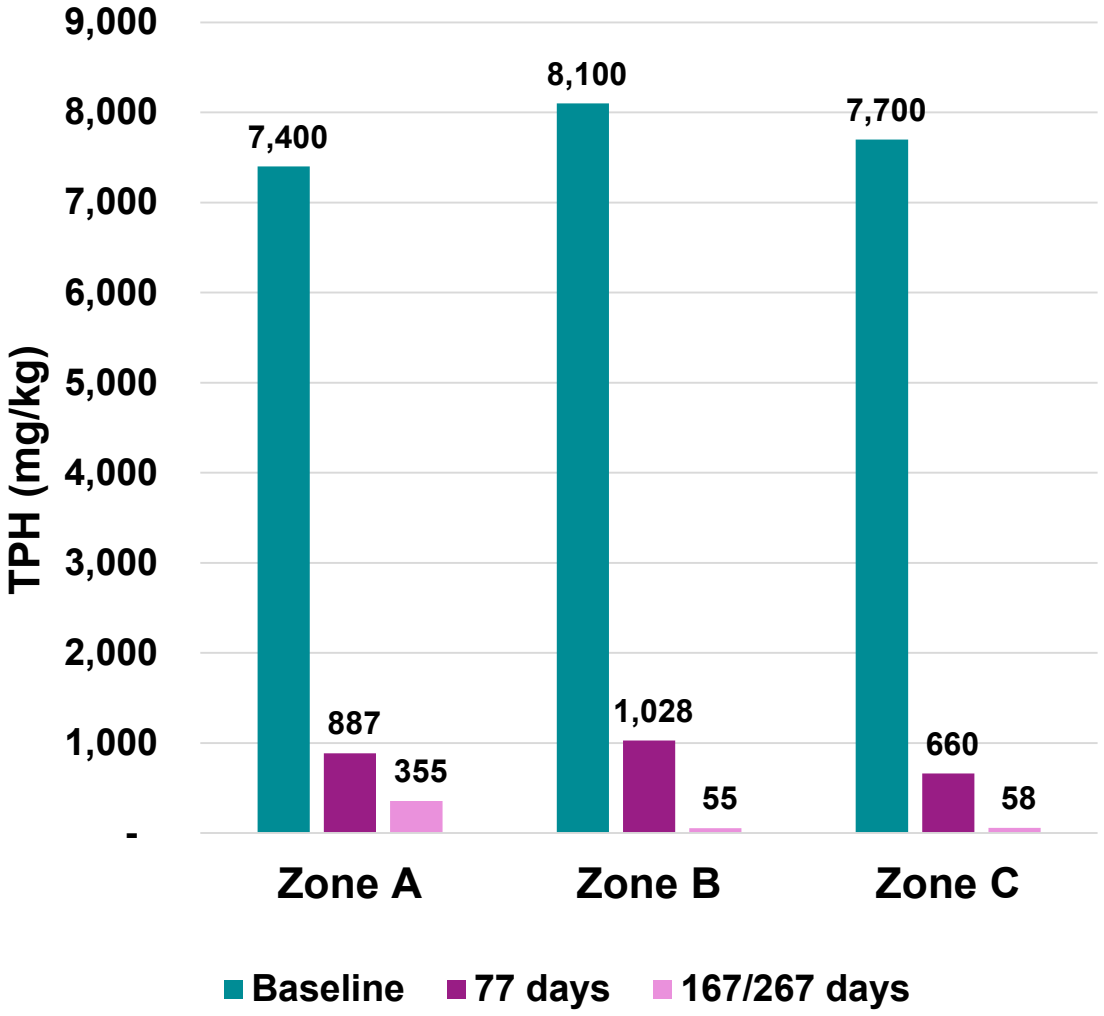
# Bioremediation of Hydraulic Oil + Diesel Fuel Contaminated Soil with Terramend® Inorganic Reagent




## On-Site Treatment of Industrial Soil

- 4,400 tons treated in HDPE-lined biocell with soil in a 24” (60 cm) layer
- Hydraulic oil and diesel fuel ($C_{16}$ – $C_{35}$)
- Calcareous sandy loam, neutral pH, low organic matter
- Terramend® Inorganic dosage of 3.0% w/w in split application (2.0% at start and 1.0% on day 90)
- Soil water content maintained near 60% WHC
- Aeration by tillage twice weekly for the first month, with tillage reduced to weekly thereafter
- Each data point represents the mean of 5 composite samples with each composite created by blending 10 grab samples from full depth of treatment



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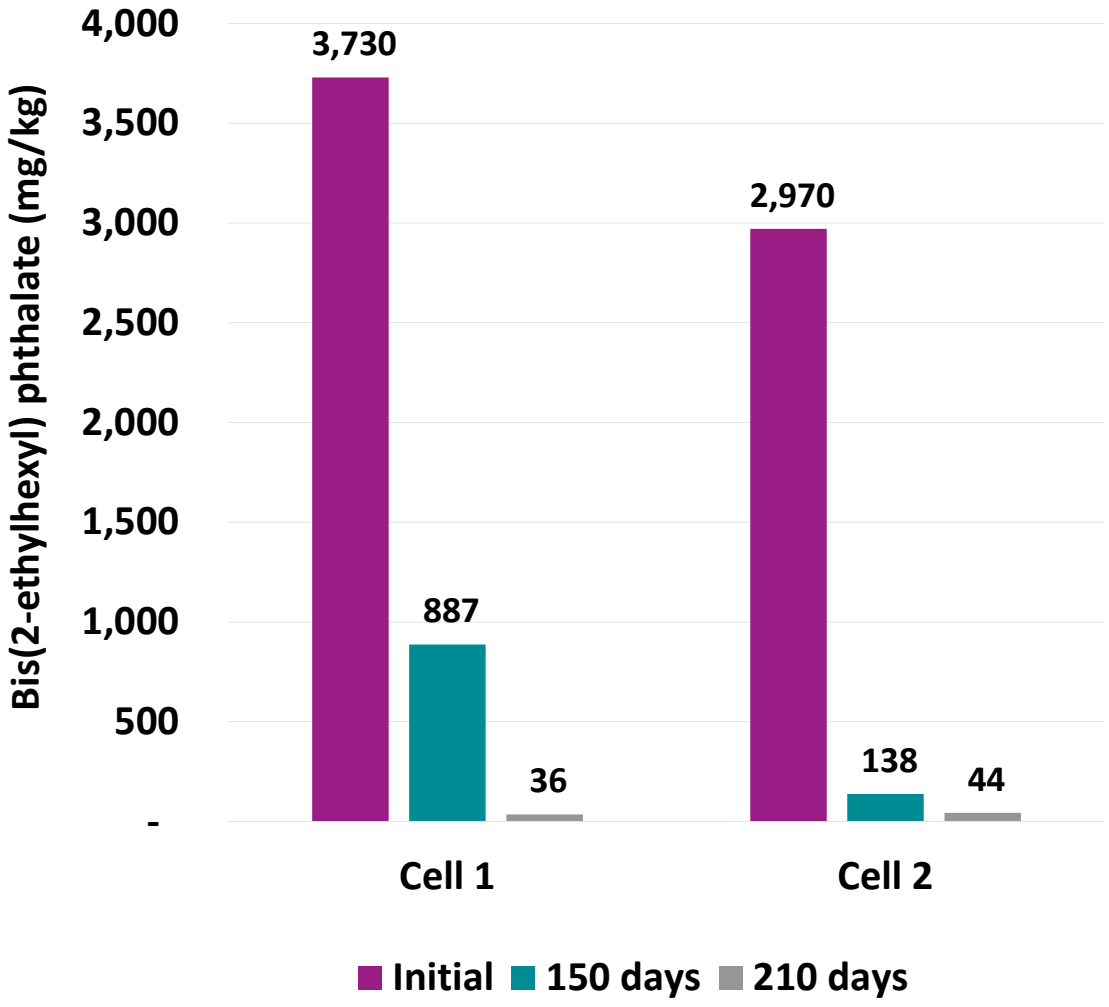
# Project Snapshot #2

## Terramend® Carbon
## On-Site Treatment of Phthalates in Excavated Soil

- Industrial site in eastern New Jersey
- Former chemical industry facility
- Approximately 600 tons of soil treated on-site
- Two 300-ton batches in biocell
- Terramend® reagent cost was about $36 /ton of treated soil.

# Terramend® Organic Treatment of Bis(2-ethylhexyl) Phthalate

## (Ex-situ On-Site Treatment in New Jersey)




- Due to its low solubility, phthalate degrades slowly
- Terramend® formulation and dosage was established during bench-scale testing
- Reagent dosage of 3.0% w/w
- Soil moisture set to 60% WHC by spray irrigation system
- Slowly released carbon and nutrients was proven to be very effective
- Visible fungal growth on soil treated with Terramend® Carbon reagent



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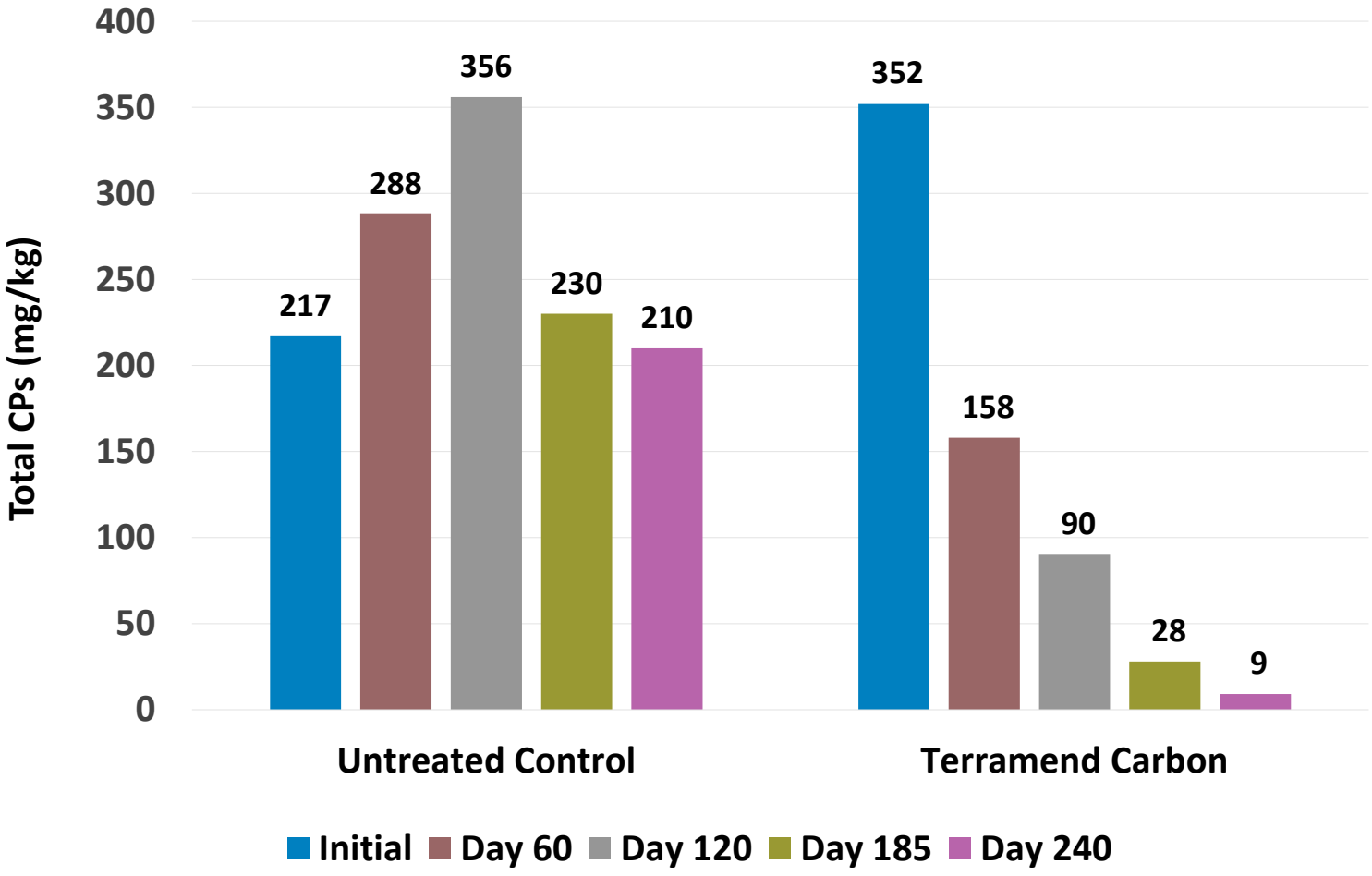
# Project Snapshot #3

## Terramend® Carbon

## Ex-Situ Treatment of PAHs, PCP, and Petroleum Hydrocarbons

- Industrial Wood Preserving Site in operation since 1950
- Pressure treatment using creosote, PCP and mineral oil
- On-site treatment of excavated soil in HDPE-lined cell
- 1,200 tons/year in batch system over three years
- Terramend® reagent cost was about $24 /ton of treated soil for the lightly impacted soil and about $48/ton of treated soil for the heavily impacted soil.

# Ex-Situ Bioremediation of PCP-impacted Wood Treatment Soil with Terramend® Carbon




- Treatment cell was covered to extend treatment season in a cool climate area
- First batch included monitoring of untreated control soil simultaneous with Terramend® Carbon treated soil
- Also treated 4,800 tons of lightly impacted soil in-situ (0 – 60 cm bgs)



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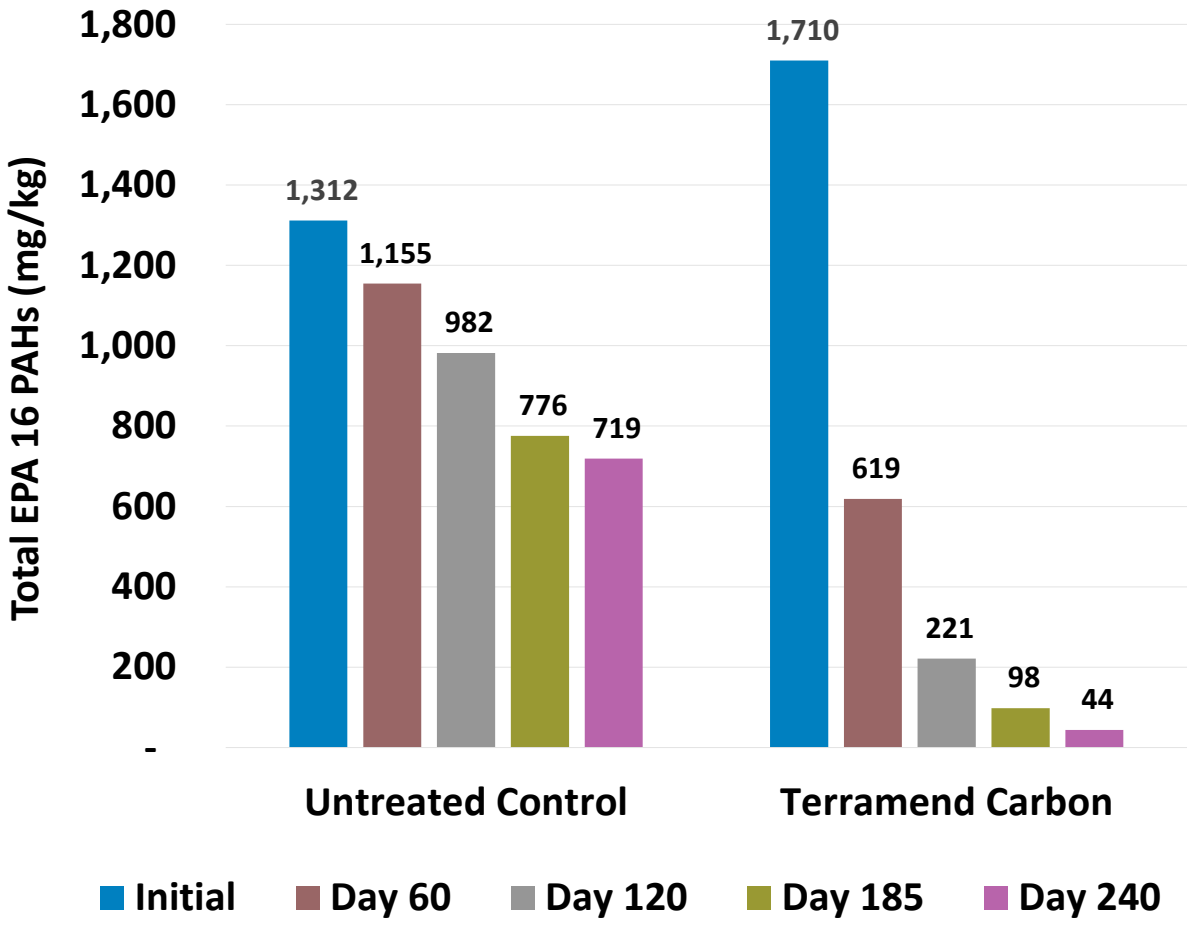
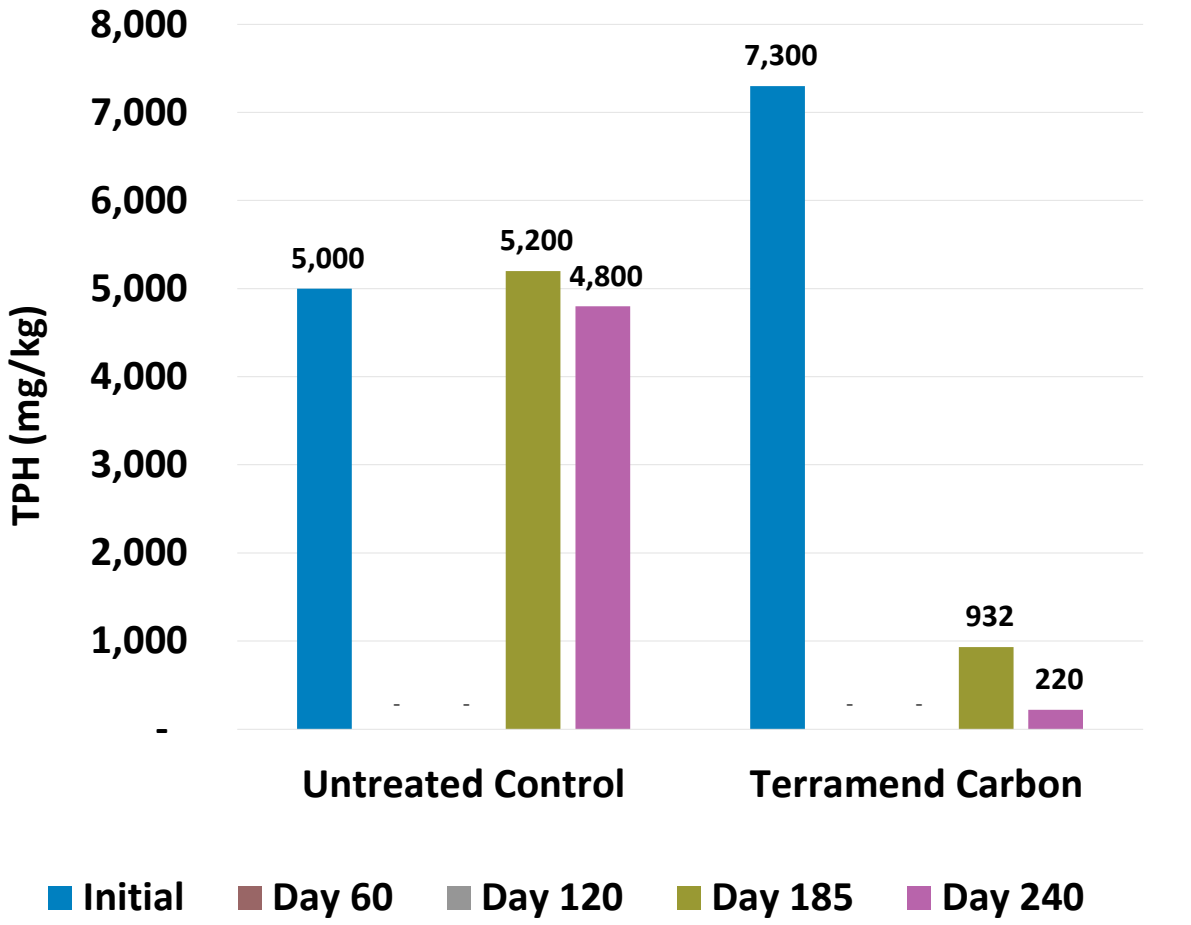
# Treatment of PAHs and Petroleum Hydrocarbons



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# Project Snapshot #4

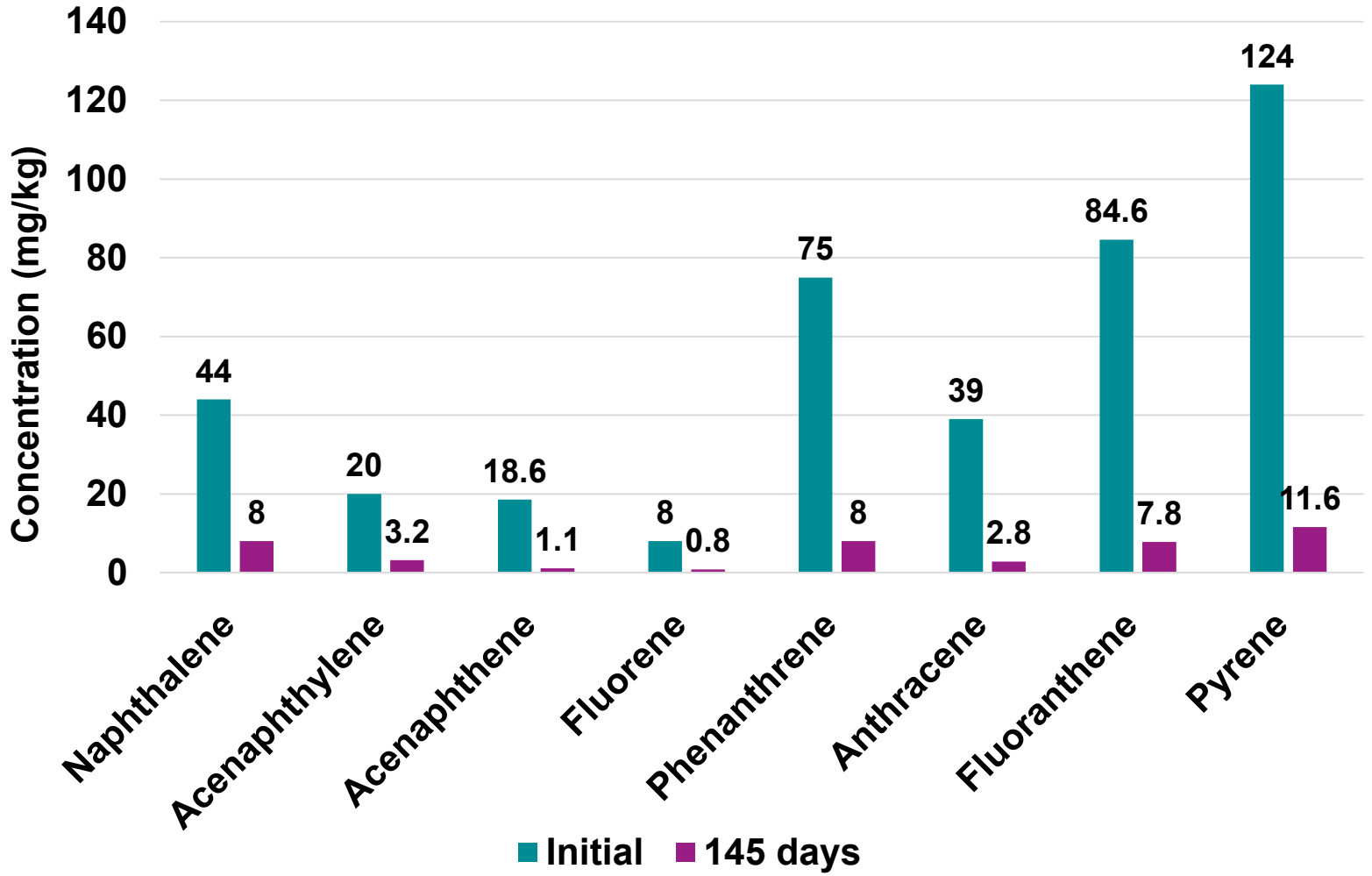
## Terramend® Carbon

## Ex-Situ Treatment of PAHs at MGP Site

- Pacific Northwest Manufactured Gas Plant Site
- On-site treatment of excavated soil in a bio-cell
- Terramend® reagent cost was about $72/ton of treated soil.

# Ex-situ Terramend® Treatment of PAHs

## Pacific Northwest MGP Site




### Lower MW PAHs

- Terramend Carbon application at 4.0% w/w
- Weekly tillage for aeration
- Removal efficiencies of 90% or more for most of the lower molecular weight PAHs



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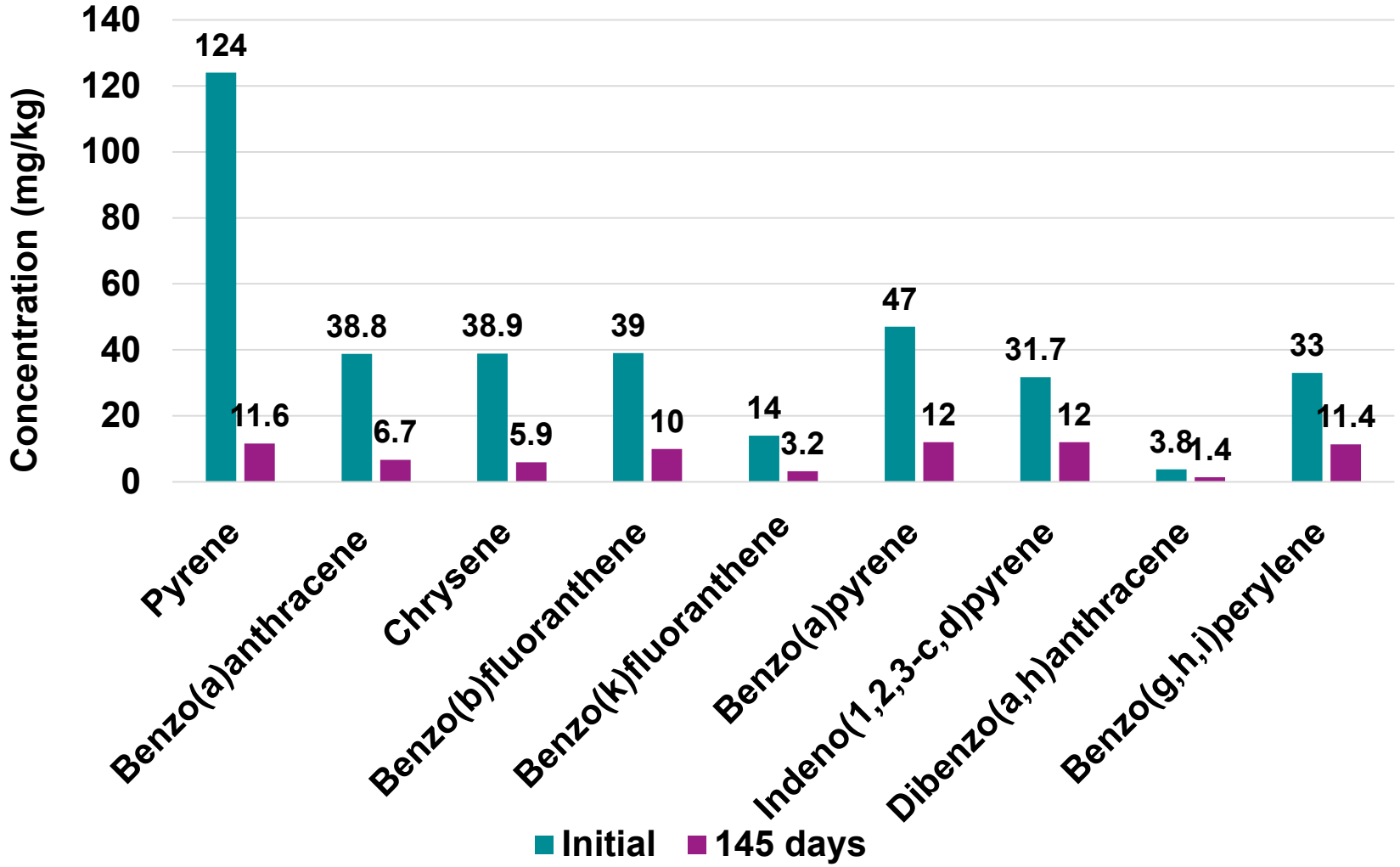
# Ex-situ Terramend® Treatment of PAHs

## Pacific Northwest MGP Site




### Higher MW PAHs

- Good treatment efficiency on even high molecular weight PAHs
- Removal efficiencies between 60% and 85% for most of the higher MW PAHs
- Somewhat lower removal efficiency than for creosote soils
- Possibly related to acute soil toxicity



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# Why should I use Terramend® Reagents?

- **Allows In-situ or On-site Treatment of Soils Contaminated with TPH, PAH, PCP, phthalates, and certain pesticides:** Ideal for both in-situ treatment of surface soil and on-site treatment of excavated soils by tilling or in mechanically-aerated biopiles.

- **Substantial Cost Savings:** Eliminates excavation where applicable, transportation, and off-site disposal resulting in remediation costs that are less than half of the next best alternative treatment.

- **Preserve, Protect & Reuse Soil**: In-situ and on-site treatment allows soil to remain on-site for revegetation or used in construction.

- **Sustainable Remediation**: Terramend® reagents provide a sustainable form of remediation from the perspectives of carbon footprint and recycling of agricultural and industrial process byproducts.

- **Excellent 25-year track record in many field-scale applications**

**Alternative to Landfill Disposal**


**Beneficial On-Site Reuse of Soil**



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# Terramend® Case Studies

- ✓ PAHs
- ✓ PCP
- ✓ Bunker Oil
- ✓ Diesel Fuel
- ✓ Phthalates
- ✓ Wood Preserving Sites
- ✓ MGP Sites

# Daramend® Case Studies

- ✓ Lindane & other BHCs
- ✓ Chlordane
- ✓ Dieldrin
- ✓ Toxaphene
- ✓ 2,4-D & 2,4,5-T
- ✓ TNT & DNT
- ✓ RDX
- ✓ HMX
- ✓ Tetryl
- ✓ TCE & PCE
- ✓ PCE
- ✓ 1,2-DCA
- ✓ CT & CF

# Questions are Welcome!

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**“Sustainability is at the core of futurizing our business”**



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