# *Enhanced Bioremediation of Contaminated Soils using Sustainable Soil Amendments*

**Remtech Technology Symposium**

**October 2022**

**Presented by**
**Jean Paré, P. ENG.**

# Presentation Agenda

- ✓ *About us*
- ✓ *Bioremediation Key Parameters Review*
- ✓ *Troubleshooting Difficult soils/contaminants via bioaugmentation*
- ✓ *Bench scale treatability approach and results*
- ✓ *Project Snapshots case studies*
- ✓ *Conclusions*

# About us

**Canadian Company founded in 1988**

**Production and warehouses throughout Canada**

- Quebec
- Ontario
- Alberta
- British Columbia

**Sectors of activity:**

- Industrial and Municipal Potable & Waste Water
- Contaminated Soil and Groundwater
- Air, Odours and Atmospheric Emissions (Activated Carbon, filtering medias)
- Process Water & Thermal Exchange Fluids (Glycols)
- Drilling Fluids (Oil and Gas & Diamond exploration)
- Aircraft De-icing Fluids

# Our Services

CANADIAN LEADER IN ENVIRONMENTAL SOLUTIONS

Training & Education

Technical and Design Support

Field-Proven Technologies

Expert Technical Team

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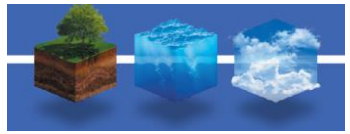

R&D and Treatability Laboratories

Field Support & Logistic

Mixing and Handling Equipment

## Specialized Products

- Chemical Oxidation
- Chemical Reduction
- Co solvent-Surfactant soil Washing
- Enhanced Bioremediation
- Permeable Reactive Barrier Amendments
- Metals Stabilization
- Activated Carbon Technologies

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# Excellence & Science through proud Suppliers & Partners

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## ADVANCED OXIDATION TECHNOLOGY (AOT) *Since 2005*

EVONIK Leading Beyond Chemistry *Since 2005*

CARBONE CANADA INC *Since 2014*

BIOCONSERVACION *Since 2014*

CARUS® *Since 2014*

EthicalChem An Ethical Solutions, LLC Division *Since 2016*

EOS Remediation, LLC *Since 2016*

ChemBio Formulation *Since 2017*

SiREM *Since 2017*

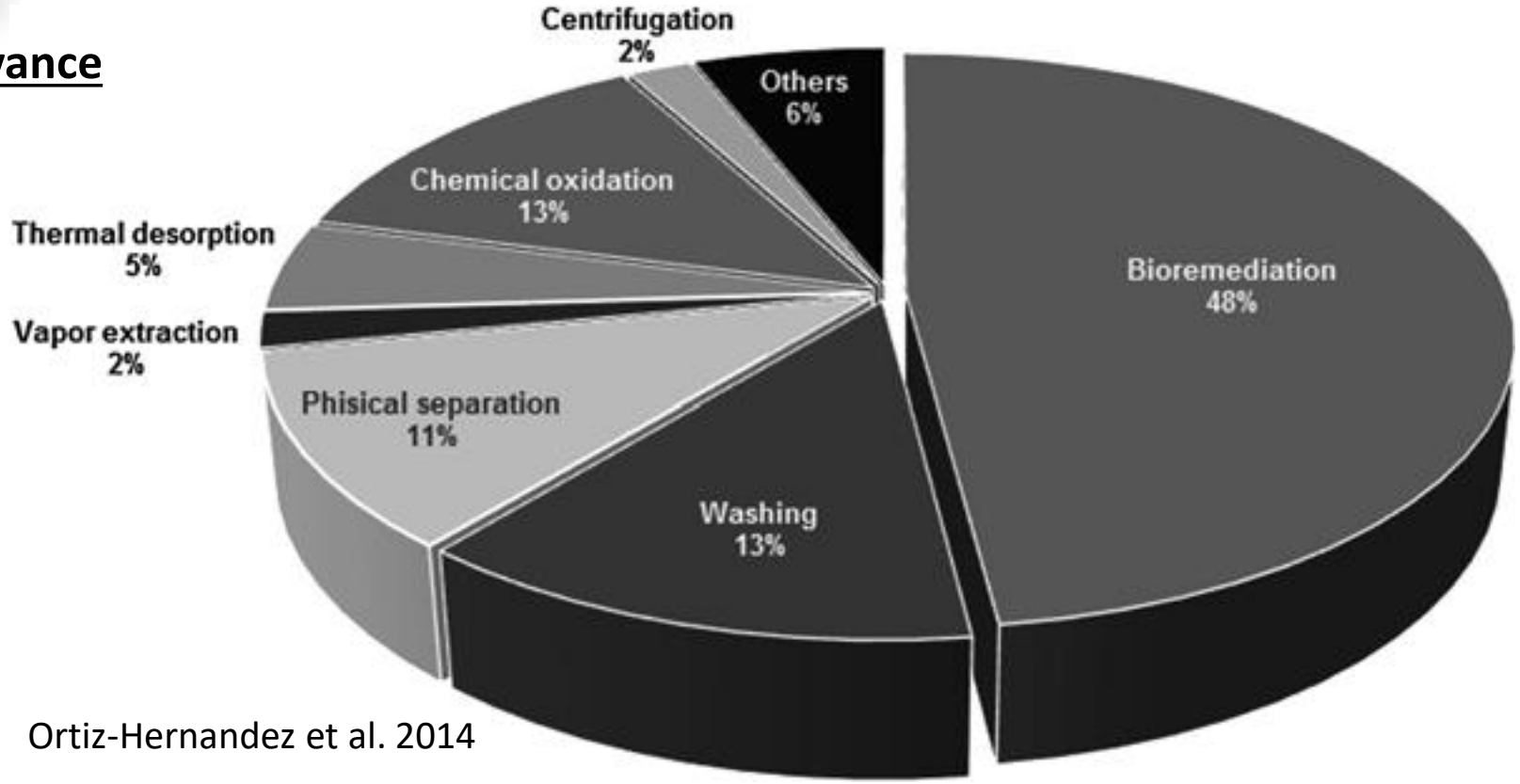
Höganäs *Since 2018*

# Typical site remediation technique

- ✓ Dig & Haul
- ✓ Pump & Treat
- ✓ Soil Vapour Extraction under vacuum with or without air/steam injection
- ✓ Chemical Oxidation In Situ/Ex Situ
- ✓ Chemical Reduction In Situ/Ex Situ
- ✓ Monitored Natural Attenuation
- ✓ Activated Carbon Sorption & Treatment Technology
- ✓ Enhanced Bioremediation
- ✓ Risk Analysis
- ✓ Stabilization/Solidification
- ✓ Soil Washing
- ✓ Phytoremediation
- ✓ Reactive Barriers
- ✓ Sorption Technologies (activated carbon based)
- ✓ Thermal degradation/desorption

# Bio-Remediation – Introduction

## Relevance




Ortiz-Hernandez et al. 2014

# Bio-Remediation – Introduction

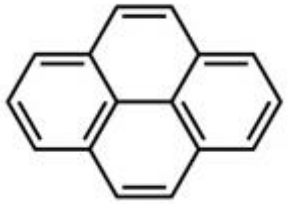
- Traditional focus has been on **supplying adequate inorganic nitrogen and phosphorus to support biodegradation** of target hydrocarbons, adjusting soil water content, and soil mixing for aeration.
- Generally supplied in the form of commercial/agricultural fertilizer
  **Target an "optimized" C:N:P ratio** based on an estimate of bioavailable carbon including target compoundsand native organic matter
- Commonly target C:N:P at 100:10:1 molar ratio
- **Failure can be observed due to quick inorganic nutrients usage when bioavailable and lost through wasteful processes including luxury consumption, denitrification, and precipitation.**
- **Agricultural fertilizer don't address low bioavailability of water in hydrophobic soils and the acute microbial toxicity created by some contaminants (e.g., PCP, Lindane)**
- Alternative approaches could be based on supplying nutrients, increasing bioavailable water and overcoming acute microbial toxicity with a sustainable organic soil amendments and/or external organism .

# Bio-Remediation – Key Parameters

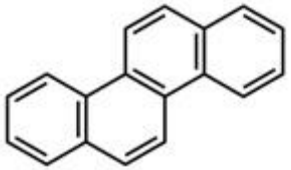
**Optimizing Bio-degradation process:**

## 1-Favoring the competent organisms:

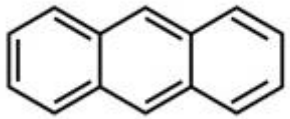
PAHs



Pyrene



Chrysene



Anthracene



Lignin

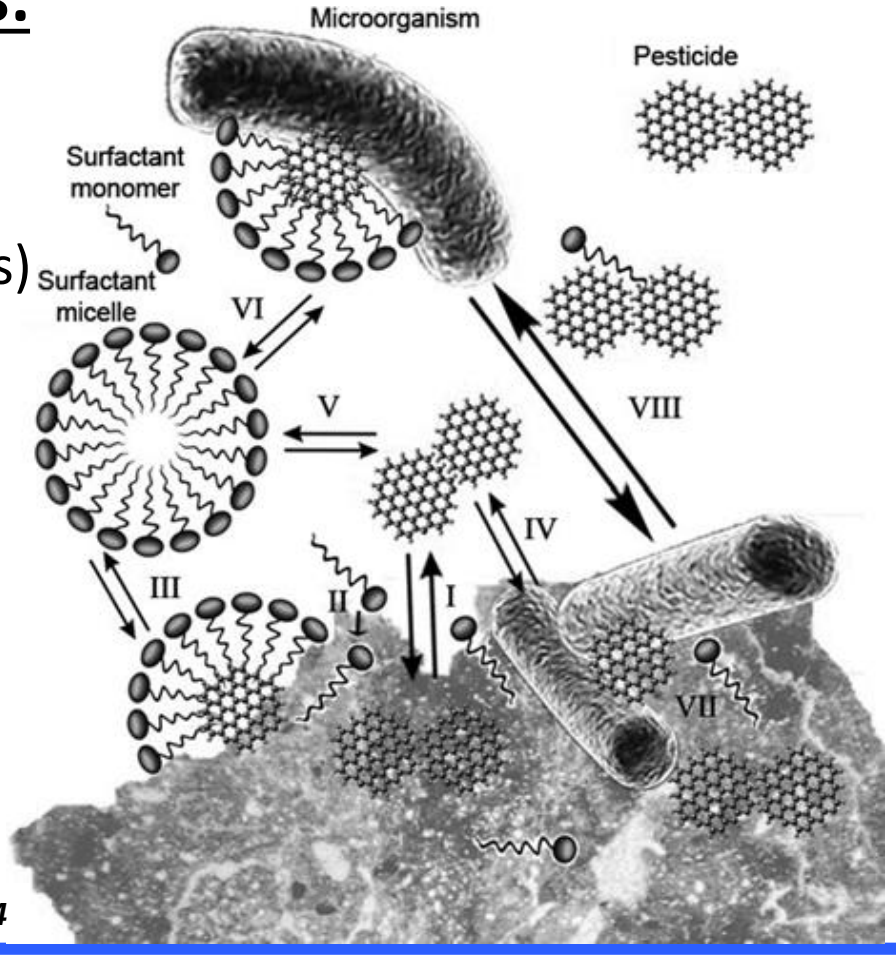
*Review:*
***Mushroom as a product and their role in mycoremediation,*** *S. Kulsheshtha et all, 2014.*

# Bio-Remediation – Introduction

## Optimizing Bio-degradation process:

### 2-Enhancing Bio-availability:

- Adding tension-active compounds (surfactants)
- Favoring the production of Bio-surfactants
- Increasing and maintaining proper temperatures range (35-55° C)




*Ortiz-Hernandez et al. 2014*

# Bio-Remediation – Key Parameters

**Optimizing Bio-degradation process:**

1-Favoring the competent organisms:

2-Enhancing Bio-availability

**3-Controling the temperature, pH & ORP**

**4-Provide sufficient oxygenation:**

-Bio-degradation efficiency of THP: a [$O_2$ ] in soils and waters.

-Air movement allows for the elimination of gaseous and toxic by-products.

**5-Targeting the right water content:**

- ↑ (Too much water): Air movement is impaired, anaerobic conditions take place, process slow down.

- ↓ (Not enough water): Molecules stop to move and process stall

# Bio-Remediation – Key parameters

## 6- Competent organism presence:

- ✓ **Bio-Augmentation:** Addition of exogenous microorganisms.

  Issues:

  -Environmental concerns and regulations around the introduction of these organisms in an aquifer or soil matrix

  -Adaptability, competition

- ✓ **Bio-Stimulation:** Stimulation of endogenous microorganisms.

  Issues:

  -Targeting the specific organisms that are competent in the degradation of the contaminants

# Enhanced Bio-Remediation - Tools, testing and trick

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## Adjusting the formulation before you get to the field

### *Bench Scale Study – Indigenous Organism Presence*

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# *ChemBio-Formulation*

Changing formulation = Changing the nature of the predominant microorganisms

Bacteria driven Remediation →

Fungi driven Remediation →

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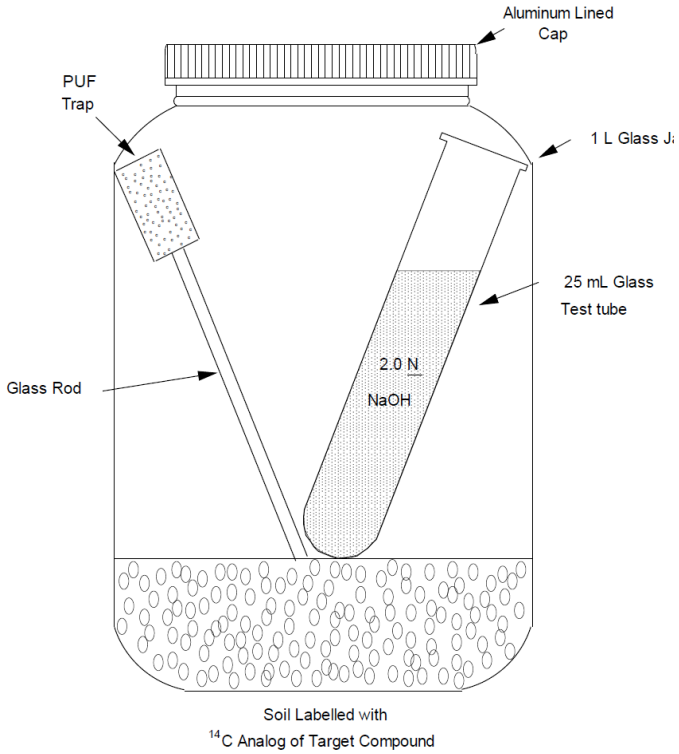
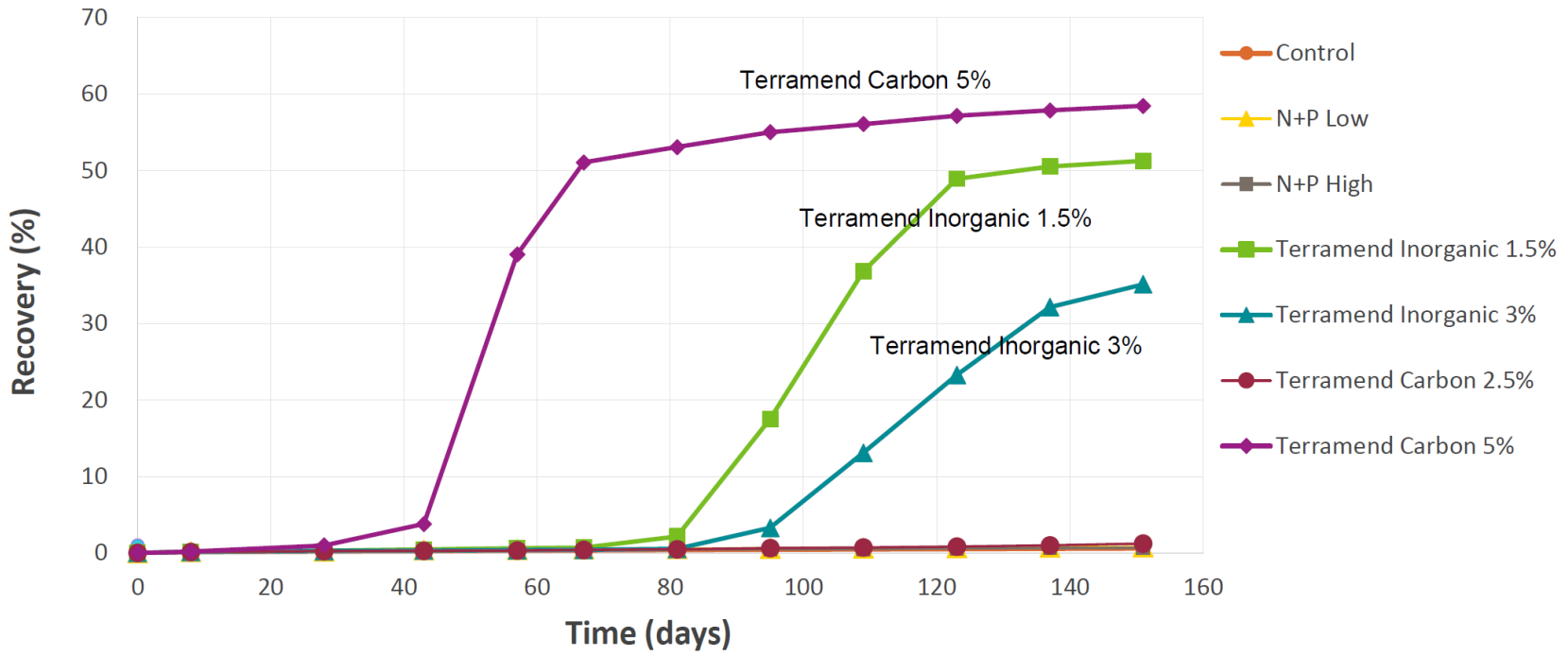
# Bench-scale Treatability Testing for PCP in Soil
# Mineralization of 14C-PCP to 14C-CO2



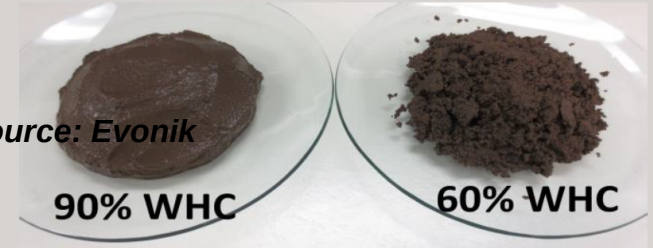




Documents complete biodegradation of PCP

Compares performance of reagents & dosages

Supported by traditional extraction & GC analysis

**Source: Evonik**




*Source: Evonik*

- Terramend® Carbon at 5% w/w performed best
- Order of performance same as increase in soil WHC
- Hydrophobic soil with acutely toxic COI
- Poor response to both N+P nutrient treatments

# *Enhanced Bio-Remediation – Full Scale Pilot tests with Biostimulant*

**Getting to the field**: Preliminary design

- Passive aeration: applicable in remote areas
- Wood chips covering: Isolation, $O_2$ and $NH_3$ exchange, watering, monitoring…
- 1.5m height: reduce compaction

# *Enhanced Bio-Remediation – FS Pilot tests*

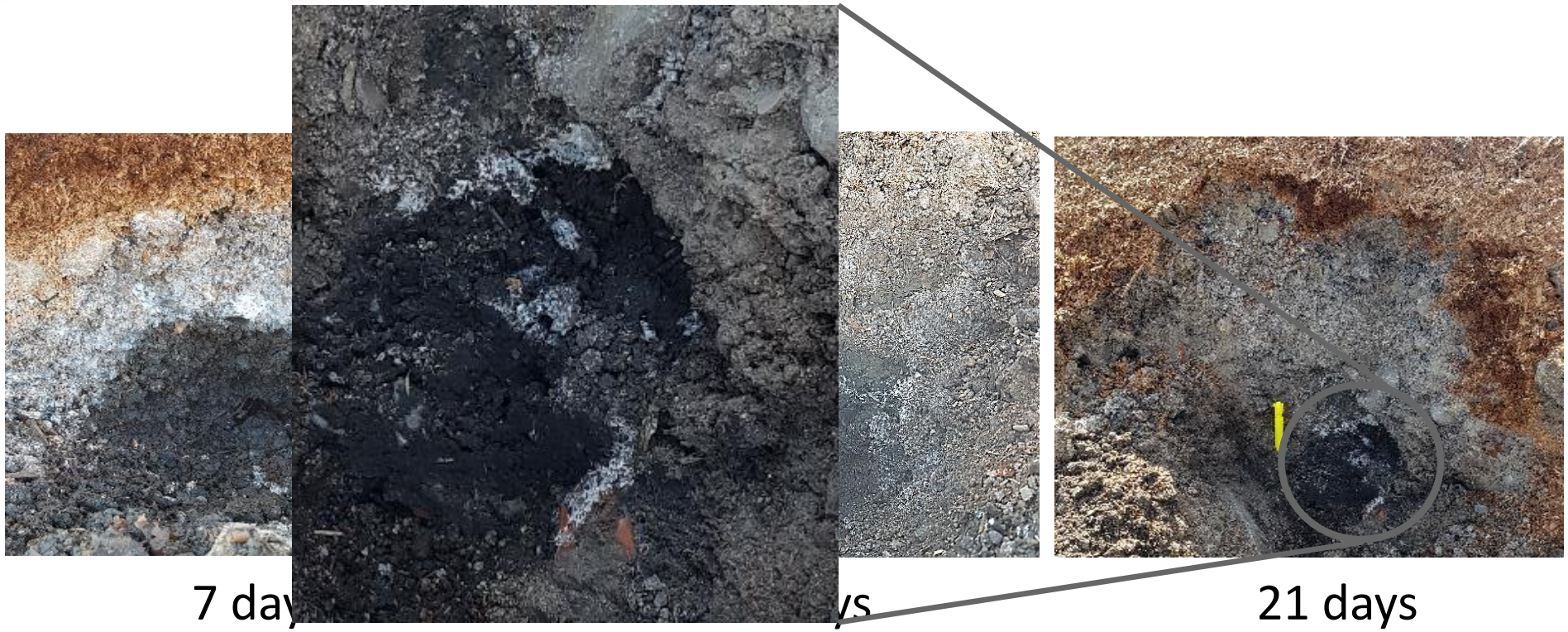
Preliminary results

- Heat


# *Enhanced Bio-Remediation – FS Pilot tests*

Preliminary results

- Two layers of microorganisms populations (Mixte-L01)



7 day ys 21 days

# Terramend® Carbon, Terramend® Inorganic, and Daramend® Reagents

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

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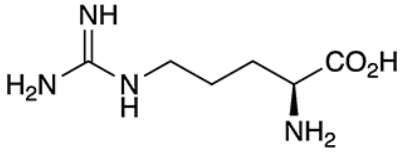
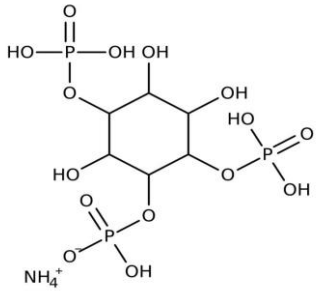
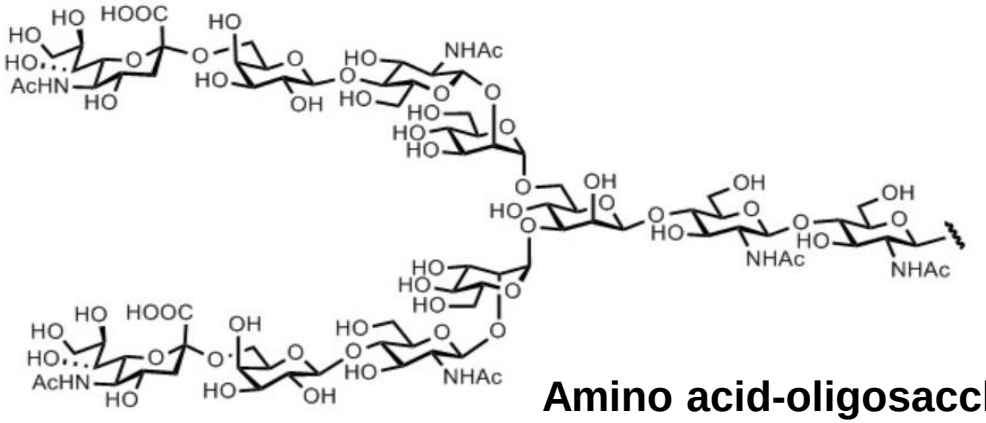
# Rapid & Slow-release Organic Forms of Carbon, Nitrogen & Phosphorus in Terramend® Reagents



Arginine



Phytic acid



Amino acid-oligosaccharide

## Carbon & Nutrients in Terramend® Reagents

- ❑ Between 4% and 10% in rapidly available forms including sugars, polysaccharides, and amino acids.
- ❑ More slowly-released forms including hemicellulose and amino acid-oligosaccharide structures
- ❑ Provides a range of rapidly and slowly released carbon and nutrients to support a variety of aerobic bioremediation applications
- ❑ Natural, sustainable, optimized food source for soil microorganisms

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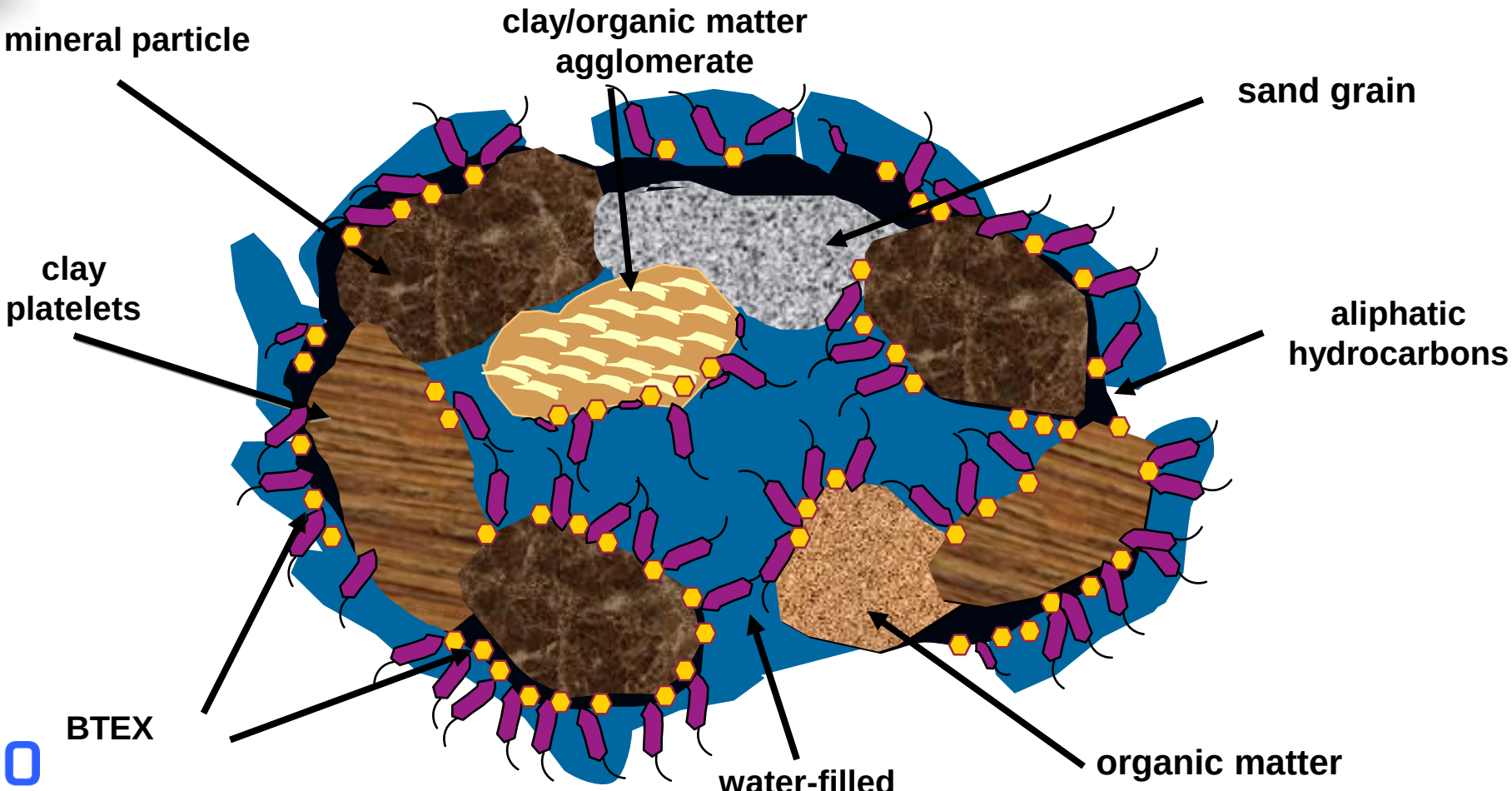
# Terramend® Treatment Mechanism



# Typical - Operations, maintenance, and monitoring schedule for Terramend® treatment of petroleum hydrocarbons in soil

| Tasks | Treatment Time (weeks) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
| Check Soil pH | • | • | | • | | | | • | | | | |
| Terramend® Application #1 | • | | | | | | | | | | | |
| Terramend® Application #2 | | | | | | | | | • | | | |
| Tillage Frequency | ••• | ••• | ••• | ••• | •• | •• | •• | •• | ••• | ••• | •• | •• |
| Check Soil Water Content | • | • | | • | | • | | • | | • | | |
| Irrigation | • | As needed to maintain soil water content equivalent to 60% of soil water holding capacity (*ca.* 20% w/w) | | | | | | | | | | |

**Notes:**

1. The decision on use of Terramend Inorganic versus Terramend Carbon will be based on the results of soil nutrient analysis.
2. Assuming treatment of 250 MT soil, the total Terramend® Inorganic application should be 1.5% w/w. This should be applied as 1.0% w/w (i.e., 2,500 kg) at the start of treatment and an additional 0.5% w/w (i.e., 1,250 kg) on day 60.
3. Assuming treatment of 250 MT soil, the total Terramend® Carbon application should be 2.5% w/w. This should be applied as 2.0% w/w (i.e., 5,000 kg) at the start of treatment and an additional 0.5% w/w (i.e., 1,250 kg) on day 60.
4. Terramend should be applied and thoroughly mixed into the soil **before** addition of water.
5. Addition of water should be done stepwise by addition of 50% of the estimated water first, followed by mixing, then addition of more water as needed until the soil reaches the desired degree of wetness.
6. The best way to achieve correct water content is by visual inspection of the soil as water is added with mixing.

# 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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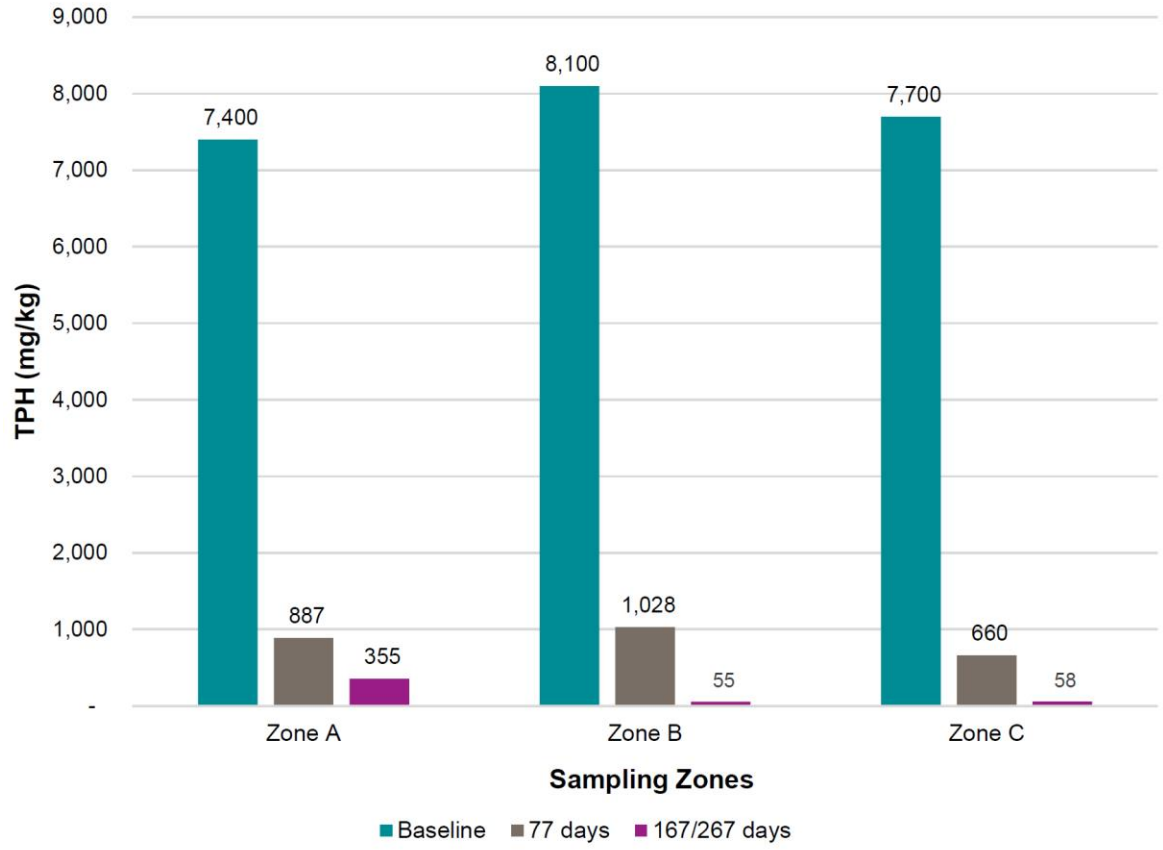
# Terramend® Inorganic Ex Situ Treatment of Hydraulic Oil & Diesel Fuel


# *Bioremediation of Hydraulic Oil + Diesel Fuel Contaminated Soil*




**On-Site Treatment of Industrial Soil**

- 4,400 tons treated in HDPE lined biocell with soil in a layer of 24" (60 cm) thickness
- 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

***Source: Evonik***

# Project Snapshot 2

## Terramend® Carbon Ex Situ Treatment of PAHs, PCP, and Petroleum Hydrocarbons

- Industrial Wood Preserving Site
- On-site treatment of excavated soil in HDPE-lined cell
- 1,200 tons/year in batch system

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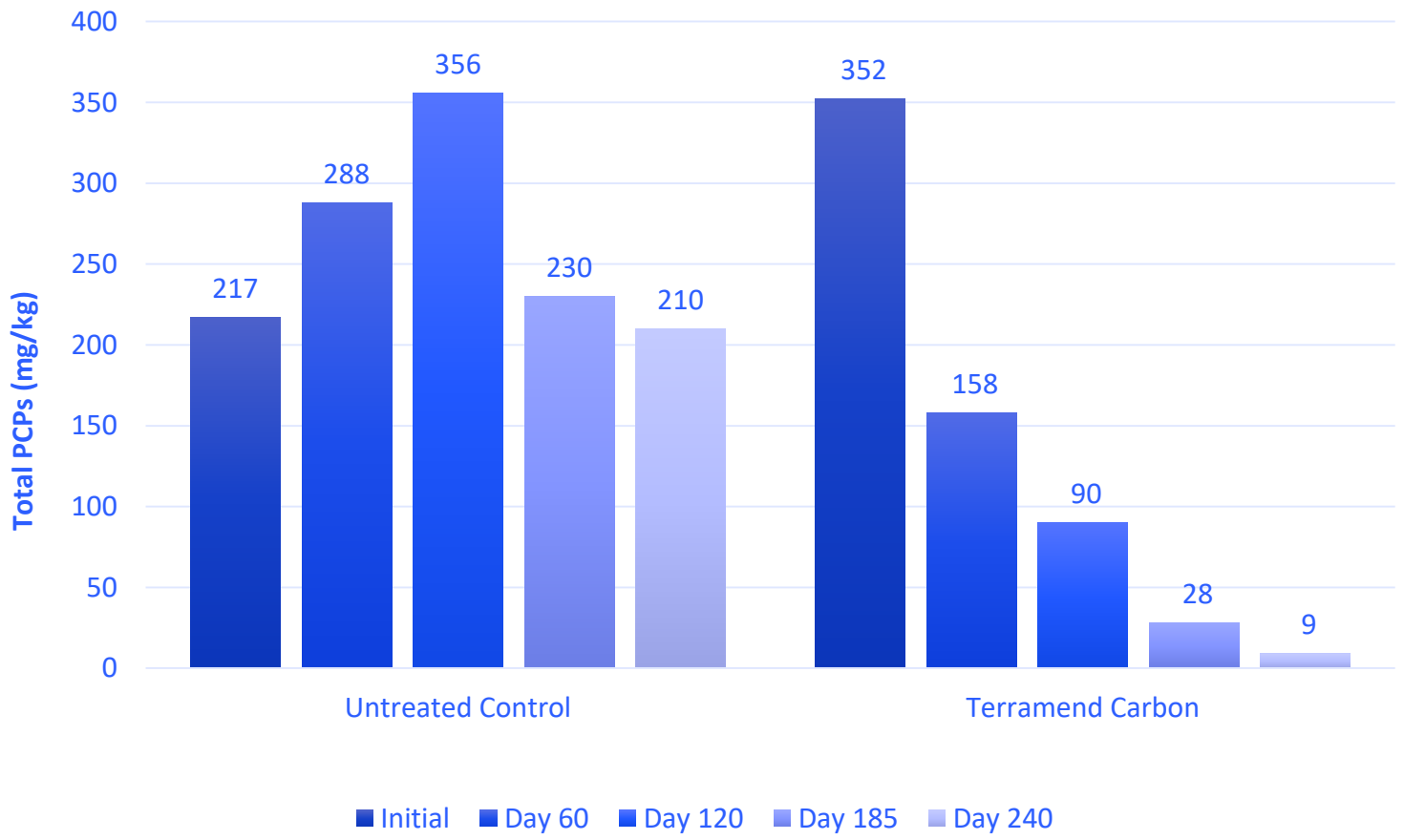
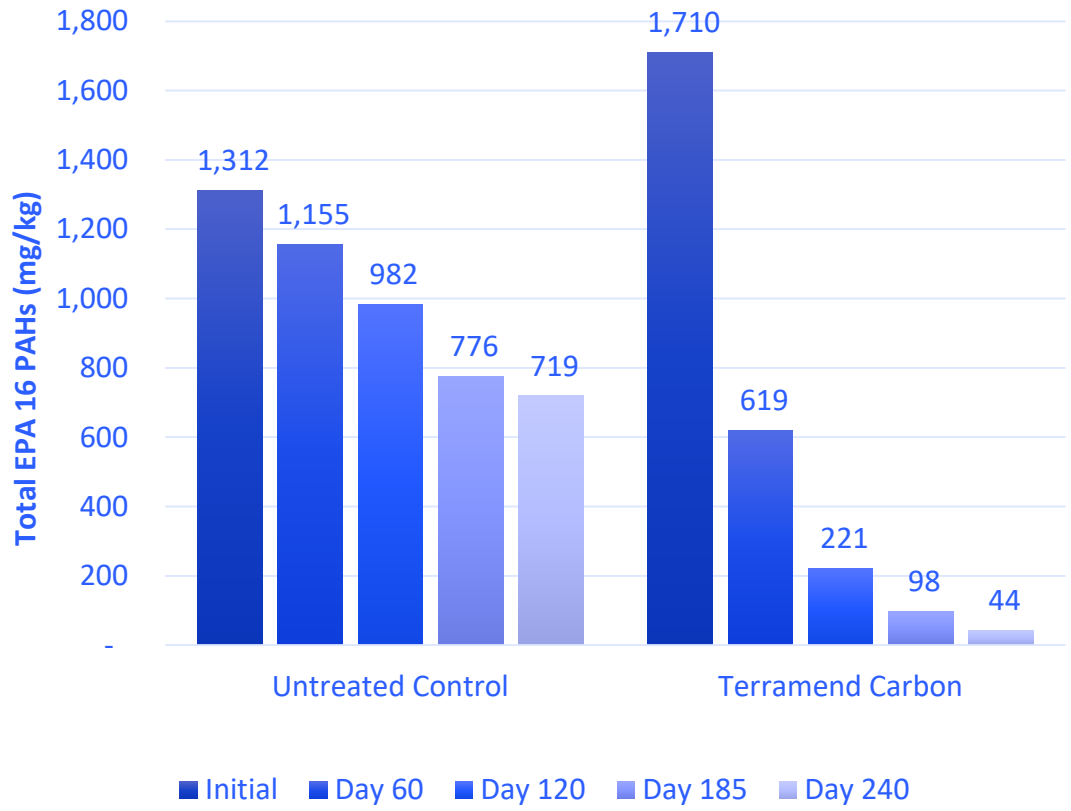
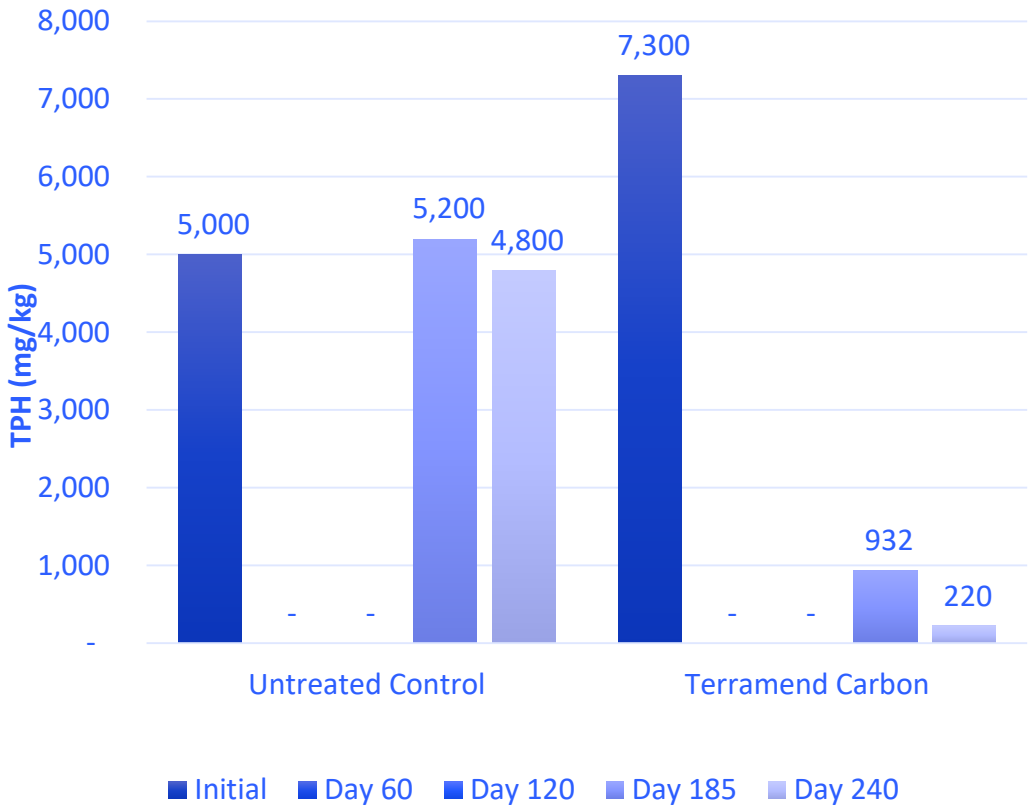
# Ex Situ Bioremediation of Wood Treatment Soil with Terramend® Carbon




- Industrial wood preserving site in operation since 1950
- Pressure treatment using creosote and PCP in mineral oil
- Batch treatment of 1,200 tons/year over three years
- Excavated soil in HDPE-linde bioremediation cell
- Covered to extend treatment season in 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 – 24” bgs)

# Treatment of PAHs and Petroleum Hydrocarbon



# Project Snapshot 3

# Terramend® Carbon Ex Situ Treatment of PAHs at MGP Site

Pacific Northwest Manufactured Gas Plant Site
On-site treatment of excavated soil in biocell

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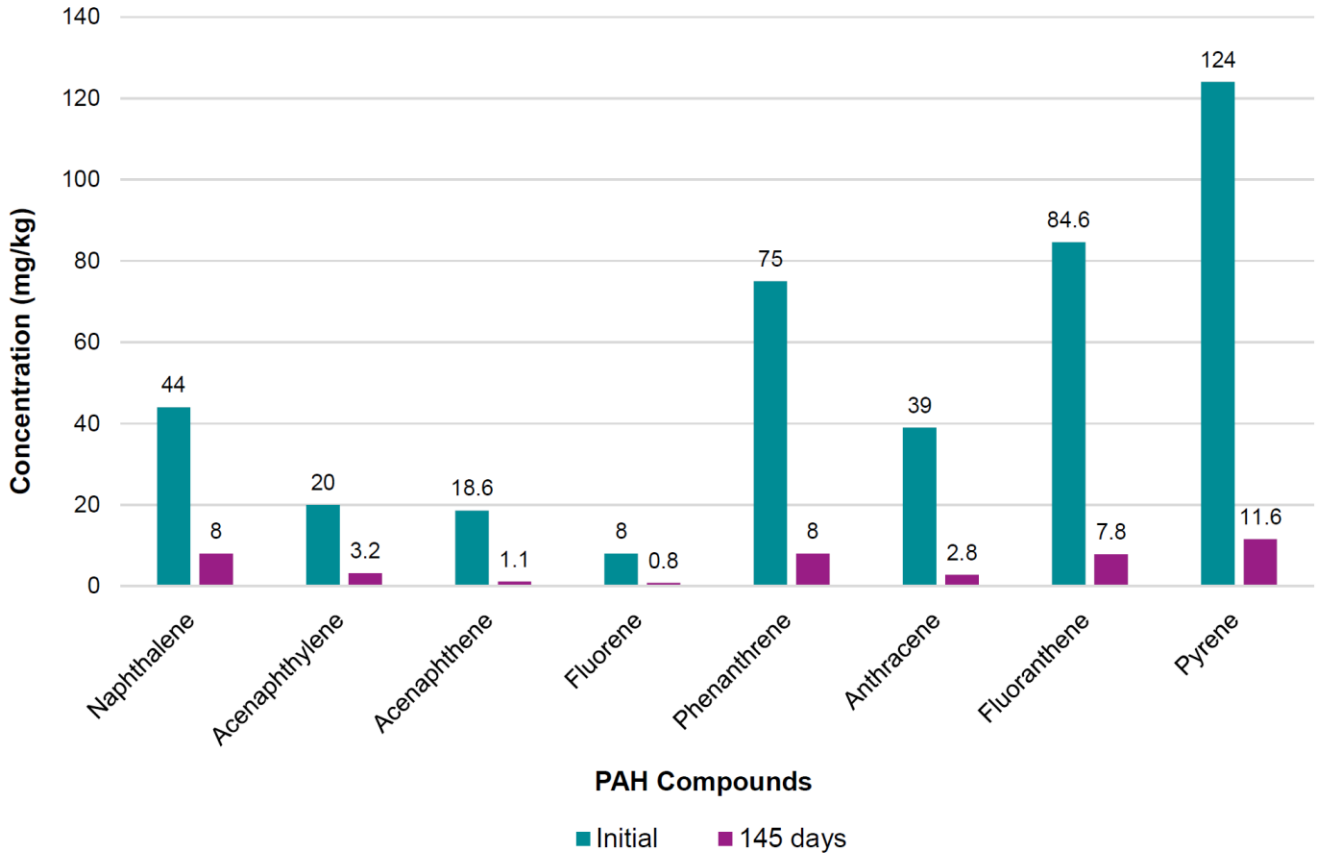
# *Ex situ Terramend ® Treatment of PAHs Pacific Northwest MGP Site with Terramend ® Inorganic Reagent*

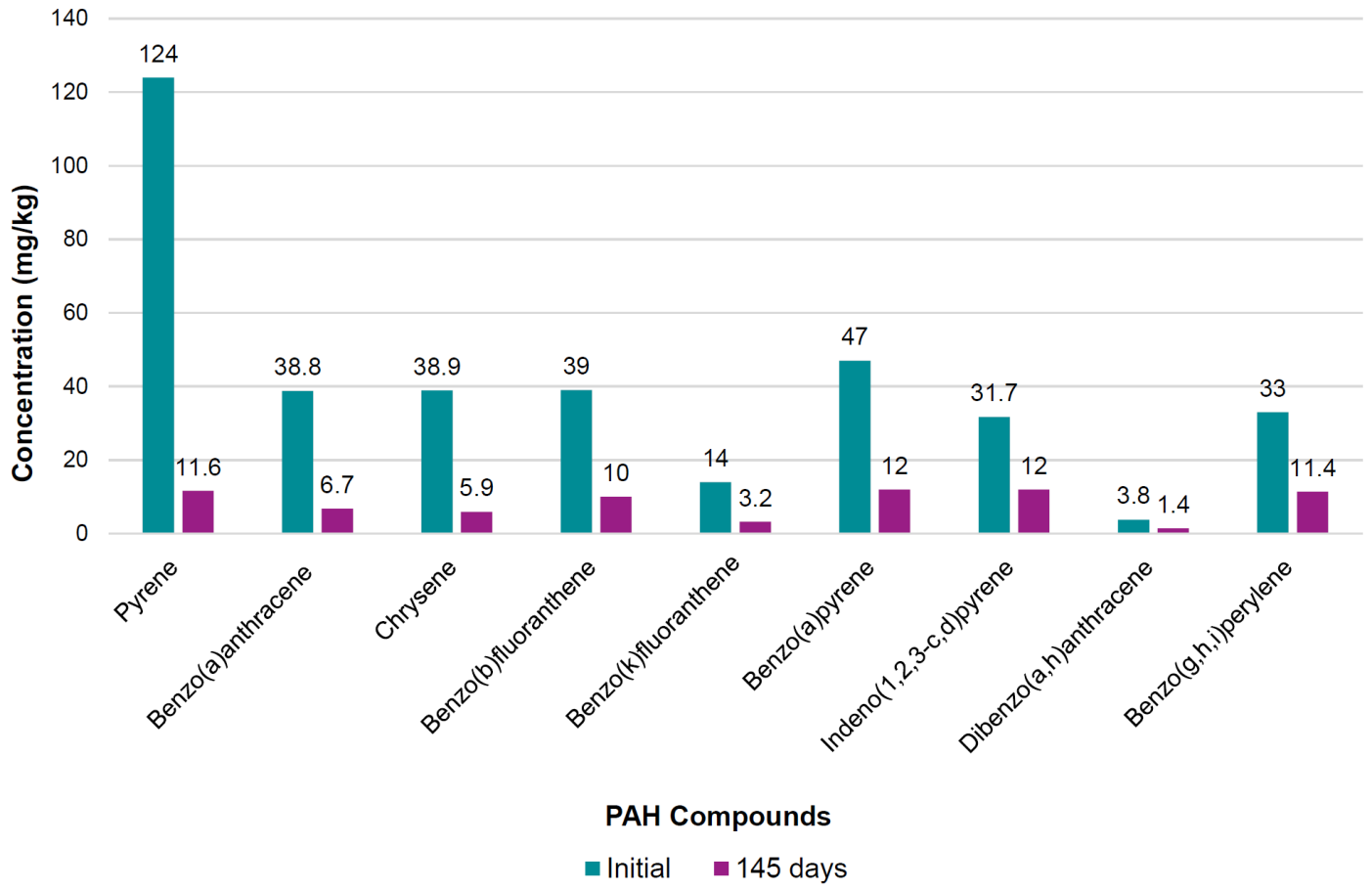



**Lower MW PAH Compounds**

- Pacific Northwest MGP Site
- Excavated soil in HDPE-lined Biocell
- 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

***Source: Evonik***

# *Ex situ Terramend ® Treatment of PAHs Pacific Northwest MGP Site with Terramend ® Inorganic Reagent (cont'd)*




**Higher MW PAH Compounds**

- Good treatment efficiency on even high molecular weight PAHs
- Lower removal efficiencies than for the lower MW (more soluble) 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?

***Source: Evonik***

# *Enhanced Bio-Remediation – Pros*

- A promising **cost effective process** of particular interest for difficult contaminants
- Excellent performance in **simultaneous removal of PCP + PAHs + Petroleum Hydrocarbons**
- A strategy based on the possibility to sequentially harness **different types of microorganisms**
- A **complete formulations** that encompasse many ingredients that cope with the presented principles of Bio-Remediation
- **Recovery of the biological activity after frost** or low temperature events
- Field scale application **proven results** in large scale application with **25-year worldwide track** record in many field-scale applications
- **Sustainable and economical alternative** to off site disposal for many soils, sediments, and even many industrial process wastes

# *Enhanced Bio-Remediation – Cons*

- **Could be difficult to maintain optimal sol structure and low humidity** (Forced ventilation or shelter might be needed.
- **Multiple mixing sequences might be necessary**
- **Prefer lower height pile construction** to optimize amendment contact, aeration and mixing (**space issue**)

# Questions ?!?

Remtech Technology Symposium

October 2022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