Phytoremediation of PAHs: Designing for Success

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Outline

- Phytoremediation Primer
  - Benefits
  - Mechanisms
  - Limitations
- Design Considerations
- Case Study #1: Former Foundry
- Case Study #2: Burn and Burial Pit

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Potential Benefits

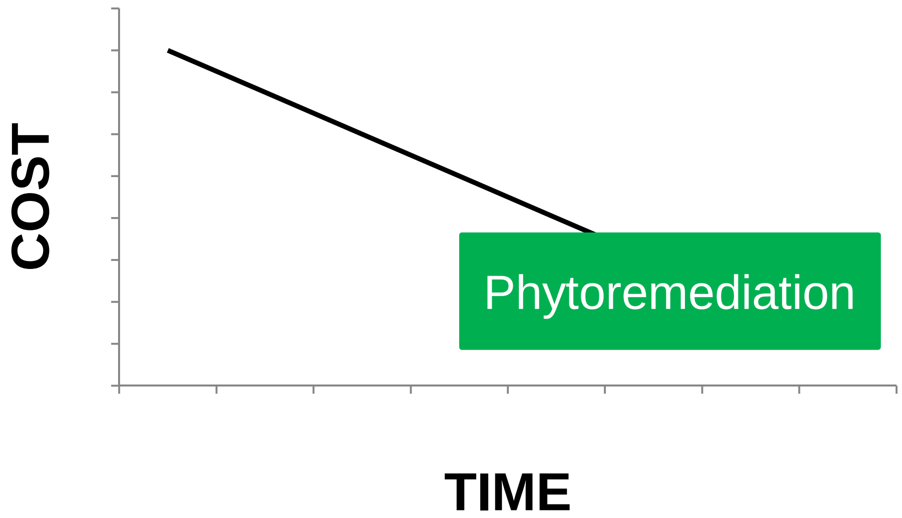
- **Cost savings** of up to 50 to 80 percent
- Less invasive and destructive than other technologies
- Ecological benefits (increase biodiversity, habitat, etc.)
- Aesthetic improvements
- May educe erosion
- Shade from plants may reduce energy needs
- Vegetation can help **sequester carbon**

Mechanisms

- Phytosequestration
- Phytohydraulics
- Phytoextraction
- Phytodegradation
- Phytovolatilization
- **Rhizodegradation**
  - breakdown of contaminants within the plant root zone
  - plant exudes sugars, amino acids, enzymes that stimulate bacteria
  - roots provide additional surface area for microbes to grow
  - roots provide a pathway for oxygen transfer
  - best used in soil
  - PAHs, chlorinated solvents, pesticides, PCBs, BTEX

Limitations

- High concentrations may be toxic
- Impacts need to be **accessible** to plants
- **O&M** requirements
- Concern with introduction of **non-native species**
- Remediation timeframe may be **slow**



Frequency of Use

- Remedy selection for superfund sites:
  - phytoremediation was selected for **<2% of remedies**

- Why?
  - Limitations
  - Few vendors to partner with
  - **Inconsistent track record**:

In an evaluation of 20 sites, only 9 sites had significant declines in concentrations compared with unvegetated controls (EPA 2006)

- **Decreases Client Confidence**

Reasons for Poor Performance

- Poor CSMs
- Biological Systems ≠ Mechanical Systems

- in some cases though, it is not a limitation or failure of the technology … **it's a failure of the design**

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- Phytoremediation Primer
- Design Considerations
  - Treatability Studies
  - Plant Selection
  - Installation
  - Operation and Maintenance
- Case Study #1: Former Foundry
- Case Study #2: Burn and Burial Pit

Design Considerations

Conceptual Site Model

- COCs (co-mingled)
- Concentrations
- Weathered
- Distribution
- Depth to groundwater
- Existing site use

Implications

- Treat entire suite?
- Phytoxicity?
- Recalcitrant?
- Can Plants Access?
- Installation method?
- Competition?

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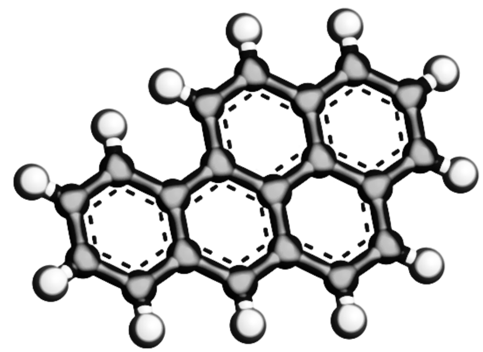
Polycyclic Aromatic Hydrocarbons

- Organic compound with multiple aromatic rings
- Properties
  - Low solubility
  - Heavy compounds
  - Low volatility
  - Recalcitrant



- Low MW PAHs can **biodegrade aerobically**
- **Weathered PAHs** less likely to degrade via rhizodegradation
- Large PAHs (3+ rings) are more **recalcitrant**

Depth of Impacts

- Root Depth = COC Depth
- Grasses/Legume ~1 ft
- Prairie Grass 10+ ft
- Trees 5-10+ ft

- **70-80% in upper 2 ft**
- Installation methods
  - Poles
  - Cased boreholes
- Roots reach max of 5 ft into of saturated zone

Plant Selection

- Grasses

- Prairie Grasses

- Legumes

- Trees

Considerations …

- Degradation mechanism
- native plants – well adapted
- hybrid species – special attributes
- monoculture vs. multiple species
- fruit/vegetables/flowers
- annual v. perennial
- deciduous vs. evergreen
- O&M requirements
- climate
- soil

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Plant Species for PAHs

- Mixed grasses
- Fescue
- Alfalfa
- Switchgrass
- Sudangrass
- Prairie grasses
- Perennial ryegrass
- Winter rye
- Bermuda grass
- Tall Fescue
- Little bluestem
- Willow trees
- Hybrid poplars

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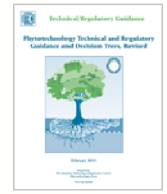
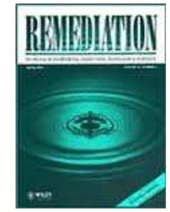
Where to Start?

- Literature
- Case Studies
- A word of caution re: spiked lab studies
  - Dibenzo(a,h)anthracene

Degradation (mg/kg per day)	COCs	Type	Plant	Reference
0.0019	PCP, PAHs	greenhouse	rye grass	Ferro 1997
0.0006	various PAHs	greenhouse	rye grass	Rezek 2008
0.127	spiked	greenhouse	rye grass	Binet 2000

- Lab Success ≠ Field Success

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Toxicity

- 810 mg/kg (C_{5-28}) reduced transpiration 10%
- 3,910 mg/kg (C_{5-28}) reduced transpiration 50%
- Several species **can survive 40,000 mg/kg**
- gasoline > diesel fuel
- unweathered fuel > weathered fuel

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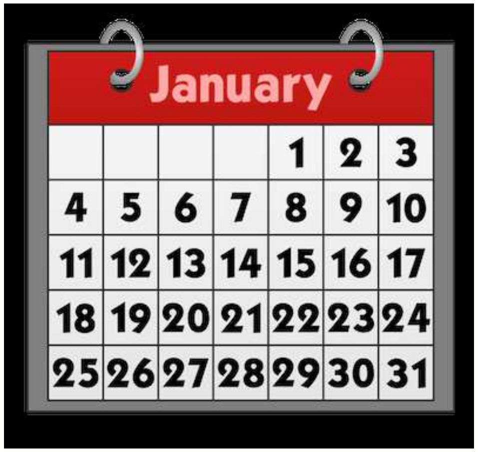
Plant Installation

- **Timing**
- Planting density
- Irrigation
- Fertilization
- Aeration (breather tubes)
- Methods
  - Grasses: broadcast vs. grain drill
  - Trees: Auger vs. DPT vs. container
  - Cased boreholes



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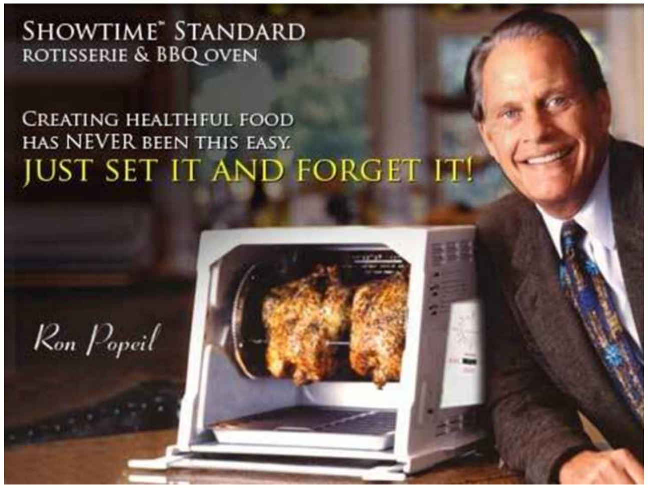
Operations and Maintenance

- Fertilization
- Irrigation
  - 1-2 inches per week
  - drip, spray, vertical drip
  - use of groundwater as source
  - install trees into water table
- Harvest plants (primarily metals)
- Re-planting
  - Mortality
  - Annuals and succession crops
- Weed control: mowing, mulch, spray (compatible)
- Pest, disease, etc



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Time

- Function of:
  - initial concentration
  - remedial goal
  - plant species

Cost

- Function of:
  - Install method
  - Plant type
  - O&M and Irrigation needs
  - Treatment Area

Closure and Contingency

- Performance Monitoring
  - Soil samples
  - Mortality
  - Concentrations trends
  - Control plot
- Future Site Use
- Contingency ….

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Outline

- Phytoremediation Primer
- Design Considerations
- Case Study #1: Former Foundry
  - Background
  - Design
- Case Study #2: Burn and Burial Pit

Case Study #1: Background

- South Beloit, IL
- 1852-2003: **PrimeCast Foundry**
- 1939-1960s: service stations
- **Brownfield site**
- Re-develop as a public green space
- Ductile, gray iron and stainless steel castings
- **PAH impacts in soil**
  – extend over ~5 acres
  – depth of up to 3 feet

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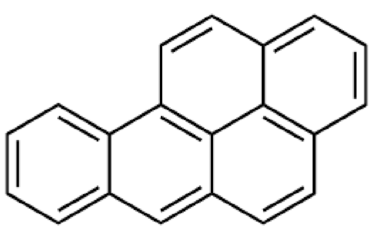
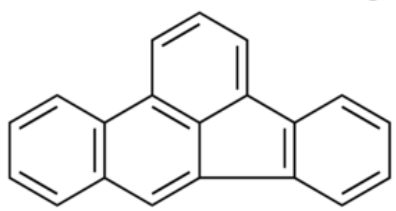
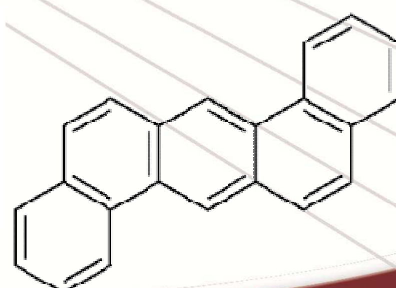
Case Study #1: Background

– benzo(a)pyrene:	up to 130 mg/kg
– benzo(b)fluoranthene:	up to 190 mg/kg
– dibenzo(a,h)anthracene:	up to 40 mg/kg

- **Heavy MW**
- **Relatively insoluble**
- **Recalcitrant**

Case Study #1 : Design

- Goal: re-develop as a **public park**
- **Design Approach**:
  - Phytoremediation
  - Successive Plantings
  - Hot Spot Excavation
  - Calculate site-specific remediation objectives

- **Iterative approach** to determine areas of phytoremediation vs. excavation

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Case Study #1 : Design

- Step 1: establish **remedial objective**
- Step 2: evaluate **plant species**
- Step 3: determine location of phytoremediation
  - **iterative approach** to select timeframe
  - $[A_t] = [A_o] - (k)(t)$

$[A_t]$	remedial objective	*calculate site specific*
$[A_o]$	max initial concentration	*soil analytical*
t	length of active remediation	*3, 5, 7, 10, 20 years*
k	decay rate	*literature*

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Case Study #1 : Design

- Estimate **decay rate** (k)
- Example: benzo(a)pyrene

Degradation (mg/kg per day)	COCs	Type	Plant	Reference
0.023	PCP, PAHs	greenhouse	rye grass	Ferro 1997
0.01	various PAHs	greenhouse	rye grass	Rezek 2008
0.30	MGP site	greenhouse	willow	Spriggs 2005

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Case Study #1 : Design

- Calculate Maximum Initial Concentration (mg/kg)

$[A_o] = [A_t] - (k)(t)$

Remediation Timeframe	3	5	7	10	20
Benzo(a)pyrene	13.1	20.4	27.7	38.6	75.1
Benzo(b)fluoroanthene	29.9	44.5	59.1	81.0	154.0
Dibenzo(a,h)anthracene	1.5	1.9	2.3	3.0	5.2

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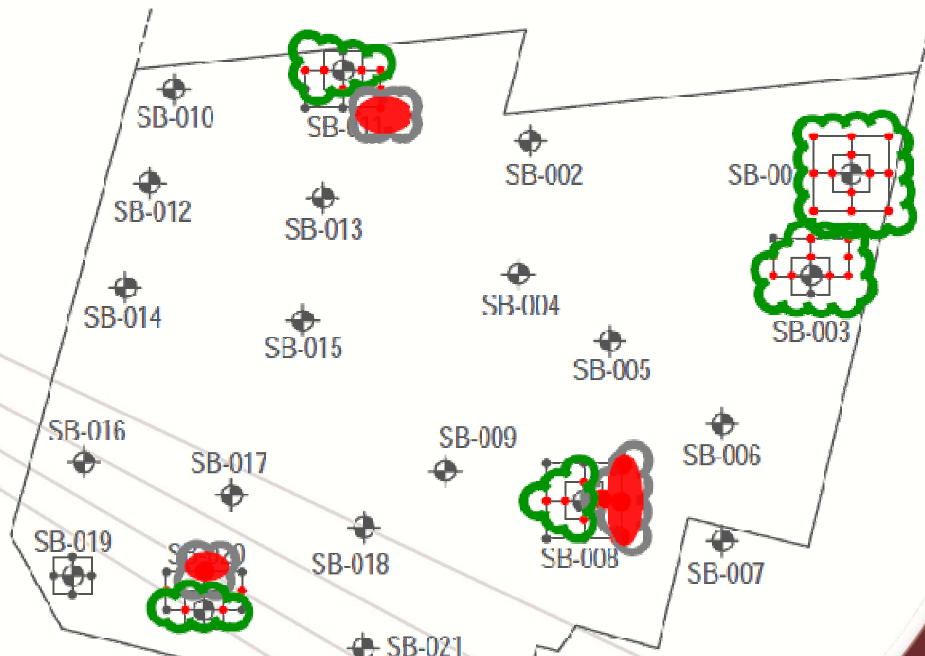
Case Study #1 : Design

- Planting Areas

  vs.

- Excavation Areas



Potential Excavation Extent

Proposed Phyto Planting Area

Exceeds ROs after 3 years of Phytoremediation

Case Study #1 : Design

- **Conventional Cover Crops**
  - Buckwheat (dense roots)
  - Rye Grain (winter cover)
- **Successive Plantings**
  - Multiple buckwheat plantings
  - Rye extends growing season
- Established planting methods
- Readily available equipment
- **Contingency Plan**

June 2015

August 2015

October 2015

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- Case Study #2: Burn and Burial Pit
  - Background
  - Design
  - Preliminary Results

Case Study #2: Background

- USCG Air Station
- Located on Pasquotank River
- Unlined **burn and burial pit**
- Occurred from 1939-1950
- Groundwater: ~6 ft bls
- Soils: mainly silty sands
- COCs:
  - **PAHs (0-6 ft bls)**
  - As and Pb (upper 2 ft)

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Case Study #2 : Design

- Detected 17 PAHs
- Total PAHs up to 646 mg/kg
- Benzo(a) anthracene up to 48 mg/kg
- Benzo(a) pyrene up to 49 mg/kg
- Benzo(a) fluoranthene up to 65 mg/kg

- **No time constraints**
- Selected trees to access impacts **up to 6 ft bls**
- Mixture of black and white **willows**

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Case Study #2: Design

- Estimate decay rate (k)
- Benzo(a)pyrene

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0.023	PCP, PAHs	greenhouse	rye grass	Ferro 1997
0.01	various PAHs	greenhouse	rye grass	Rezek 2008
0.30	MGP site	greenhouse	willow	Spriggs 2005

- Estimate 20-25 years to reach ROs

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Case Study #2 Installation

- Plant on 10-centers
- Plant as '**poles**'
- Use **breather tubes**
- **Auger** boreholes to water
- Roots extend outward
- Planted 2007

Case Study #2 Results

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