Phytoremediation defined:

‘a diverse group of green technologies that use either naturally occurring or genetically engineered plants to remove, reduce, degrade, or immobilize contaminants from soil, sediment, air or water’

- 1991 – term ‘phytoremediation’ coined
- 1999 – 1st issue of International Journal of Phytoremediation published
5 Broad Categories

<table>
<thead>
<tr>
<th>Mechanism</th>
<th>Process Goal</th>
<th>Media</th>
<th>Typical Contaminants</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phytostabilization</td>
<td>Containment</td>
<td>Soils, sediments, sludges</td>
<td>As, Cd, Cr, Cu, Pb, Zn</td>
</tr>
<tr>
<td>Enhanced Rhizosphere</td>
<td>Remediation by destruction</td>
<td>Soils, sediments, sludges, groundwater</td>
<td>TPH, PAHs, BTEX, pesticides, chlorinated solvents, PCBs</td>
</tr>
<tr>
<td>Biodegradation</td>
<td>Remediation by extraction and capture</td>
<td>Soils, sediments, sludges</td>
<td>Ag, Au, Cd, Co, Cr, Cu, Hg, Mn, Mo, Ni, Pb, Zn, Radionuclides</td>
</tr>
<tr>
<td>Phytoextraction</td>
<td>Remediation by extraction</td>
<td>Soils, sediments, sludges</td>
<td>Organic compounds, chlorinated solvents, phenols, pesticides, numitions</td>
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<tr>
<td>Phytovolatilization</td>
<td>Remediation by extraction</td>
<td>Soils, sediments, sludges, groundwater</td>
<td>Chlorinated solvents, MTBE, Se, Hg, As</td>
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<td>from media and release to air</td>
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Phytoextraction

- *in situ* volume reduction technology
- leaves soil on site intact

Adapted from Nascimento and Xing, 2008
State of the Science

http://www.cluin.org/products/phyto/

US EPA – database summarizing known phytoremediation applications:

as of Dec 09 – 170 phyto projects included:
  – 63 full-scale
    • 13 (21%) complete
  – 101 demonstration-scale
    • 68 (67%) complete
  – 6 large greenhouse-scale
    • 4 (67%) complete

<1% of all projects involved PCBs, DDTs, aldrin &/or dieldrin

Phytoextraction of POPs

- some of most difficult molecules for plants to take up
  - low solubility in water (hydrophobic)

- despite being highly hydrophobic, CAN be taken up by some plants
**Proposed Uptake Mechanisms**

1. **Root exudates** $\uparrow$ solubility of POPs?
   - Roots produce molecules that interact with POPs & $\uparrow$ water solubility, thereby $\uparrow$ uptake & transfer

2. **Soil structure disruption?**
   - Organic acids cause partial dissolution of soil matrix, thereby releasing bound pollutants

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**Advantages**

- **Safety**
  - Minimized emissions & effluent, low secondary waste volume
  - Control erosion, runoff, rain infiltration & dust emissions

- **Ecological**
  - Habitat creation, promotes biodiversity
  - Sequesters greenhouse gases (CO$_2$)

- **Public / Regulatory**
  - Acceptable brownfields applications
  - Aesthetics, green technology
  - Increasing regulatory approval & standardization

- **Cost-Effective**
  - Multiple & mixed contaminants & media
  - Low maintenance, passive, *in situ*, self-regulating
  - Solar-powered, energy efficient
  - Remote operation, large areas

*Adapted from Dakora and Phillips, 2002*
**Limitations**

**Depth**
- Only effective within relative rooting depth of vegetation

**Time**
- Requires longer periods to become effective (establishment) and to reach clean-up targets
- Seasonal effects

**Phytotoxicity**
- Applicable for low - moderate contaminant concentrations
  - In most cases, vegetation must survive in order to be effective

**Media Transfer / Food Chain Impacts**
- Fate and transport often unclear
- Air emissions, leaf litter
- Harvesting, hazardous waste?

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**Recent Advancements in POPs Phytoextraction**

1. Plant performance over repeated field seasons
2. Enhancement of POPs phytoextraction by the addition of soil amendments
3. Simple agricultural practices to increase plant biomass
4. Potential use of native plant species for effective POPs phytoextraction
5. On-site treatment of POPs-contaminated plant waste
Site #1 - Etobicoke, ON
former transformer manufacturing facility
Aroclors 1254 & 1260
[PCB]_{soil} = ~30 \mu g/g
Site #2 - Lindsay, ON
former industrial chemical plant
Aroclor 1248
$[PCB]_{soil} = \sim 4.7 \ \mu g/g$

**Cucurbita pepo ssp. pepo var. Howden (pumpkin)**

- known phytoextractor
- exhibits vigorous growth
- long diffuse root system (>1 m length) to access greater volume of soil
- accumulates significant above ground biomass & hence extracts high volumes of contaminant
**PCB vs. DDT Phytoextraction**

![Graph showing PCB vs. DDT phytoextraction](image)


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**2. Soil Amendments to Increase Plant Biomass**

- Numerous amendments tried over the years in greenhouse & field including:
  - various surfactants
  - fertilizers
  - mycorrhizal fungi
  - root exudates
3. Agricultural Practices to Increase Plant Biomass

1. **Pruning**
   - to ↑ biomass of plant near base to maximize PCB uptake

2. **Encouraging Nodal Roots**
   - to ↑ # of PCB uptake pathways

4. Use of Native Plant Species for PCB phytoextraction

27 species of free-growing weeds harvested in triplicate from 2 field sites
- [PCB] weed shoot compared to [PCB] pumpkin shoot

Density Effects

to compare plant extraction efficiencies, determine amount of PCB extracted per unit area of soil; – this will vary based on optimal plant density
- e.g. *Cucurbita pepo* grows optimally at 1 plant per m²
6. On-site Treatment of PCB-Contaminated Plant Waste

- How much volume reduction can be achieved?

Compost Over 1 Field Season

April 24th  | April 24th  | May 28th  | June 5th  
June 12th  | June 19th  | June 26th | July 3rd  
Summary

1. PCB phytoextraction appears to be constant over time
2. Use of fertilizer and simple cultivation techniques can be used to create larger plants & phytoextract more PCBs
3. Many weed species have potential to extract ≥ quantities of PCBs than C. pepo per m²
4. Composting is effective means of significantly reducing plant biomass prior to disposal

Conclusions

• new work shows phytoextraction to be viable remediation technology for some POPs- contaminated soils
  – slow, but effective
  – useful in areas with limited resources
  – most applicable for large areas with low level contamination
  – leaves soil matrix intact
  – less expensive than traditional remediation technologies
Questions

Natural Sciences and Engineering Research Council of Canada
Conseil de recherches en sciences naturelles et en génie du Canada