Successful field and laboratory tests of advanced phytoremediation systems for decontamination of petroleum and salt impacted soils


Partners: Imperial Oil; Talisman Energy; TAQA North; PennWest; EBA, Seaway Project Management; Stantec; Northwind; TerraLogix; Strata Environmental; Shell; Wardrop; Matrix Solutions, NSERC
1. Advantages of phytoremediation
2. Overview of our phytoremediation system
3. Field tests of our phytoremediation system for petroleum and salt remediation
Examples of remediation methods

- **Dig and dump** - Any contaminant type - $200-600/m³
- **Soil incineration** - On or off site - Organic contamination - $600-800/m³
- **Chemical extraction** - Any type of contamination - $300/m³
- **Electrokinetic separation** - Metals/Salts - $200/m³
- **Soil flushing/fracturing** - Any contaminant type - $250/m³
- **Land farming** - Natural attenuation - Small organics - $50/m³
- **Bioremediation** - Organics - $100/m³
- **Phytoremediation** - Any contaminant type - $75/m³
Advantages of Phytoremediation

1. Improves the natural structure and texture of soil
2. It is driven by solar energy and suitable to most regions and climates
3. It is cost effective and technically feasible
4. Plants can provide sufficient biomass for rapid remediation; promote high rhizosphere activity
5. Restoration in a reasonable time frame - 2 to 5 years
6. Can be used effectively at remote sites
7. > 30,000 sites in Canada where such technology is needed, > 300,000 sites in the US
Development and Proof of PGPR Enhanced Phytoremediation Systems (PEPS)

Over 10 years of research with field studies at each stage of development

1. PHC, Imperial Oil Land Farm, Sarnia, ON 2004-08
2. PHC, several sites in Alberta 2005-08
3. DDT, Simcoe, ON 2005-07
4. Brownfield, Toronto, PCBs, PAHs & metals 2007-08
5. Fully remediated a gas station site in 1 summer (2007) – Gary Millard - Next talk
6. Salt, Saskatchewan, Alberta and Northwest Territories 2007-08
Description of the PGPR Enhanced Phytoremediation Systems (PEPS)

<table>
<thead>
<tr>
<th>Physical soil treatment:</th>
<th>Till the soil: exposure to sunlight and air Exposure to sunlight photooxidizes contaminants</th>
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</thead>
<tbody>
<tr>
<td>Bioremediation:</td>
<td>Inoculation of PAH/PHC degrading bacteria (generally skipped in the field → already present)</td>
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<tr>
<td>Phytoremediation:</td>
<td>Growth of plants with PGPR</td>
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</tbody>
</table>

- **PGPR**: Plant growth promoting rhizobacteria.
- Prevent the synthesis of stress ethylene.
- **PGPR** are applied to the seeds prior to sowing → NOT Bioaugmentation
Interaction of a PGPR containing ACC deaminase with a plant seed or root

Plant growth promoting rhizobacteria (PGPR)

Natural, non-pathogenic strains PGPR (usually *Pseudomonads*)

We have isolated PGPRs from ON, AB, SK and the NWT

PGPR are applied to seeds prior to planting
Research and Development of the PEPS for PHC Remediation

1. Sarnia, ON – Land farm – 4 year study
2. Turner Valley, AB – 3 year study
3. Hinton, AB – 2 year study
Fall Rye overseeded with Rye/Fescue + PGPR

Rye/Fesc/Barley + PGPR

June 19, 2006
• Planted Barley/Fescue/Rye Grass
• Plants were treated with PGPR (UW3 and UW4) using a mechanical seed treater

40 days after planting

~ 11 % TPH
Rye/Fescue
- PGPR
+ PGPR

10 E (~6% TPH)
Barley/Rye/Fescue
+ PGPR

Petroleum Remediation 2004 to 2007 at the Sarnia Land Farm

- **F3:** ~ 60% of TPH  
  ~ 15000 mg/kg

- **F4:** ~ 30% of TPH  
  ~ 7500 mg/kg

*Petroleum, %*
Turner Valley, AB
Phytoremediation of a biopile 2005-07
Turner Valley TPH remediation from 2005 to 2007 (3 years)

- F3: ~ 50% of TPH
  - ~ 1500 mg/kg

- F4: ~ 20% of TPH
  - ~ 650 mg/kg

Nearly remediated for fine grain soils
Conclusions on Development of the PEPS

- 30 to 100 % improvement in plant growth with PEPS
- 30 to 40 % remediation per year
- Rhizosphere activity (esp. PHC degraders) elevated 10 to 100 fold with the PEPS
- Very low $^{14}$C in detected in soil microbial fatty acids – Carbon came from PHC metabolism as PHC has no $^{14}$C
- Very low $^{14}$C in CO$_2$ that evolves from soil – PHC has been mineralized to CO$_2$
- No PHC is detected in plant tissue as it disappears from the soil
- Developing advanced GC-MS techniques – Tracking of biomarkers as measures of PHC remediation – e.g. showed hopanes and chrysenes are degraded
Phytoremediation of PHC

(A) Bioavailability of PHC
(B) General processes affecting rhizoremediation
(C) Microbial aerobic PHC degradation – rhizosphere supported by plants
(D) Possible microbial oxygenation pathway of PHC to form a fatty acid

[Diagram of phytoremediation processes]

Roots penetrate into soil grains freeing oil droplets.
Application of the PEPS for PHC Remediation – Proof of Concept

All sites planted with Oats, Tall Fescue and Rye grass treated with PGPR

1. Hinton 1, AB – 1st year of a full scale remediation
2. Hinton 2, AB – 2nd year of a full scale remediation
3. Edson, AB – 2nd year of a full scale remediation
4. Peace River, AB – 2nd Year of a full scale remediation
Hinton - Full Scale Use of the PEPS,

Approximately 30 d after planting

Invert Drilling Mud – Wood chips  With Neil Reid at EBA
Hinton

~ 120 days after planting

Soil Bank
F3 Phytoremediation at Hinton 2
(Start of season, June 2008)

These 4 points are located in the site soil bank
Only 2 above Tier 1 standards in June 08
Should reach Tier 1 standards at end of 2008
Edson – Diesel Invert

June 5, 2008 Tilling Planting

July 31, 2008

With Perry Gerwing and Glen Pullishy at Earthmaster
Edson site, AB

Contaminant: TPH
Area: $120 \times 100 = 12000 \text{ m}^2 = 3 \text{ acre}$

Sampling points

Contaminant: TPH
Area: $120 \times 100 = 12000 \text{ m}^2 = 3 \text{ acre}$
Edson Site PHC Remediation

~ 70 % F3. Site may be fully remediated at end of the season.
Peace River Full Scale Use of the MPPS, 2007

Invert Drilling Mud Impacts

June 2007 before planting and $t_0$ sampling

With P Gerwing at Earthmaster and M Lansing at TerraLogix
Plants: Barley (ACR) + Mix (InfernoTF + Annual RG)
In June: F2: < 150 mg/kg except one point (180 mg/kg)
F3 was at 1500 to 2500 mg/kg in 2006
F3 at all Points < 1000 mg/kg in 2008
Remediation successful
Bottom Line from Application of the PEPS

- Fine grain soils with F3 from 2000 to 10,000 mg/kg
  - Site can be phytoremediated in 2 to 4 years
  - Tier I standards can be met using CCME methods
- Fine grain soils with F3 above 10,000 mg/kg
  - Site can be phytoremediated in 3 to 6 years
  - Tier II approach may be required to differentiate petrogenic hydrocarbons from phytogenic hydrocarbons
- Coarse grain soils with F3 above 3000 mg/kg
  - Phytoremediation will bring petroleum hydrocarbons down significantly
  - However, a Tier II approach may be required because remediation targets are very low and phytogenic hydrocarbons could interfere with analyses
Development of the PEPS for Salt Impacted Sites
Plant responses to salinity

- Inhibited germination
- Decreased water uptake → Low water potential (drought)
- Unbalanced sodium/potassium ratios
- Inhibition of photosynthesis
- Increased reactive oxygen species (ROS)
- Increased ethylene production

<table>
<thead>
<tr>
<th>Salinity Effects mostly negligible (or salt deprived)</th>
<th>Yields of very sensitive crops may be restricted</th>
<th>Yields of many crops diminished</th>
<th>Only tolerant plants grow</th>
<th>Only a few very tolerant plants can grow</th>
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$EC_e$ (dS/m)
Sites for Development of the PEPS for Salt Remediation

1. Cannington Manor, SK
2. Alameda, SK
3. Kindersley, SK
4. Brezeau, AB
5. Norman Wells, NWT
Barley – Lab Work Example

Saskatchewan High Salt Soil
EC = 18 dS/m, SAR = 11, Cl = 2000 mg/kg
Lab Research Summary of the PEPS for Salt Impacted Soils

- 50 to 100% increases in plant growth due to PGPR
- Plants can grown on soils with ECe ~ 25 dS/m
- ON, SK and NWT PGPRs all worked well
- PGPRs protected against inhibition of photosynthesis and plant membrane damage
- Levels of salt up-take to plant foliage: 60 to 80 g NaCl per kg dry weight
- Phytoremediation is feasible: For soils with ECe of 15 to 20 dS/m in about 5 yrs
Field Work
Cannington Manor sites

Cannington Manor (North)
Medium Salt

Cannington Manor (South)
High Salt
### Characteristics of soils

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<th>Parameters\Sites</th>
<th>CMN</th>
<th>CMS</th>
<th>AL</th>
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<td>ECₑ(dS/m) Avg</td>
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<td>K (mg/kg)</td>
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<td>B (mg/kg)</td>
<td>36</td>
<td>47</td>
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Plant growth on Cannington Manor North (CMN) – 3 months

Tall wheatgrass

No PGPR
EC\(_e\) = 9 dS/m
DW(g)/0.25m\(^2\) = 23 g
Salt (NaCl)/DW = 18.1 g/kg

CMH3
EC\(_e\) = 8 dS/m
DW(g)/0.25m\(^2\) = 58 g
Salt (NaCl)/DW = 21.5 g/kg
Cannington Manor South - High Salt (CMS) – Aug 08
Plant growth on Cannington Manor South (CMS) – 3 months

Oats + Inferno tall fescue + Tall wheatgrass

No PGPR
EC\textsubscript{e} = 3 dS/m
DW(g)/0.25m\textsuperscript{2} = 40 g
Salt(NaCl)/DW = 20.0 g/kg

UW4+UW3
EC\textsubscript{e} = 5 dS/m
DW(g)/0.25m\textsuperscript{2} = 55 g
Salt(NaCl)/DW = 16.0 g/kg

CMH3
EC\textsubscript{e} = 5 dS/m
DW(g)/0.25m\textsuperscript{2} = 40 g
Salt(NaCl)/DW = 23.6 g/kg
EC<sub>e</sub> of Cannington Manor South (CMS) site

2007
Site Avg
EC<sub>e</sub>
17.6±1.4

2008
Site Avg EC<sub>e</sub>
May - 14.5±1.6
Aug - 15.2±1.6

EC<sub>e</sub> Avg
May
15 m
2007
2008
90 m
15 m
Alameda battery (AL) – 0.4 Acre
Plant biomass (dry weight) per 0.25m² of Alameda battery site (AL) – Aug 08

Mix: Oats (common oats)/Inferno tall fescue/Tall Wheatgrass (1:1:1)
Plant growth on Alameda battery- 3 months

Oats + Inferno tall fescue + Tall wheatgrass

No PGPR
$EC_e = 11 \text{ dS/m}$
$DW(g)/0.25m^2 = 49 \text{ g}$
$\text{Salt(NaCl)/DW} = 20.4 \text{ g/kg}$

UW4+UW3
$EC_e = 24 \text{ dS/m}$
$DW(g)/0.25m^2 = 30 \text{ g}$
$\text{Salt(NaCl)/DW} = 26.2 \text{ g/kg}$

CMH3
$EC_e = 34 \text{ dS/m}$
$DW(g)/0.25m^2 = 45 \text{ g}$
$\text{Salt(NaCl)/DW} = 40.6 \text{ g/kg}$
## Kindersley – May 29/July 29, 2008

### EC<sub>e</sub> Values

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All plots planted with Oats, Tall Fescue and Tall Wheatgrass
Kindersley – Before Planting
May 29, 2008
Kindersley – July 29, 2008

Plot 2: – PGPR
25 g DW/0.25 m²

Plot 1: CMH3
48 g DW/0.25 m²
<table>
<thead>
<tr>
<th>Site</th>
<th>EC&lt;sub&gt;e&lt;/sub&gt; (dS/m)</th>
<th>Block</th>
<th>PGPR</th>
<th>Plant</th>
<th>Na</th>
<th>Cl</th>
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INF: Inferno tall fescue; OT: Baler oats; BL: Ranger barley. Units: mg/kg
## Summary of salt uptake in plants Aug 2008 (mg/kg DW)

<table>
<thead>
<tr>
<th>Site</th>
<th>Plot EC&lt;sub&gt;e&lt;/sub&gt; (dS/m)</th>
<th>Treatment</th>
<th>Plant</th>
<th>Na (mg/kg)</th>
<th>Cl (mg/kg)</th>
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<th>Cl/Na ratio</th>
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O = Common oats  
TF = Inferno tall fescue  
WG = Tall wheatgrass
CONCLUSIONS

• The PEPS has great potential for efficient remediation of organic, salt and metal contaminated sites
• PGPR is the key: healthy plants with vigorous roots in PAH, PHC, salt and metal contam. soils
• PGPR alleviate stress and promote growth: Low ethylene and high auxin
• 5 years of fields tests successful: PEPS removed 20 % to 40 % of recalcitrant PHCs per year
• PHC metabolized and/or degraded
• 50 to 100 % increases in plant growth on salt impacted sites
• Salt impacted sites can be remediated in about 5 years
• Great promise for restoration of oil and salt impacted sites as well as brownfields
Colleagues and partners

- The people that do all the work
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