Phytoremediation in Western Canada

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and *University of Waterloo

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Earthmaster Environmental Strategies Inc.

A Canadian environmental technologies company:

- Based in Calgary, Alberta founded in 1998.
  - Team of environmental consultants consisting of professional agrologists, biologists, chemists, ecologists, engineers, geoscientists, soil scientists, plant scientists, aquatic specialists, and foresters.
- Specialize in providing environmental services.
  - Commercial and industrial industries.
  - Upstream oil and gas industry in Western Canada.
- Co-developed a commercial phytoremediation system to treat contaminated soil in an eco-friendly and responsible manner (PEPSystems).

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What is PEPSystems?

Plant Growth Promoting Rhizobacteria (PGPR) Enhanced Phytoremediation Systems

PEPSystems

PEPSystems was originally developed through collaboration between Dr. Bruce Greenberg at the University of Waterloo and Earthmaster.

Earthmaster has assumed control of the PEPSystems technology and now manages all PGPR testing, selection, seed treating and overall site specific remedial system design in Calgary.

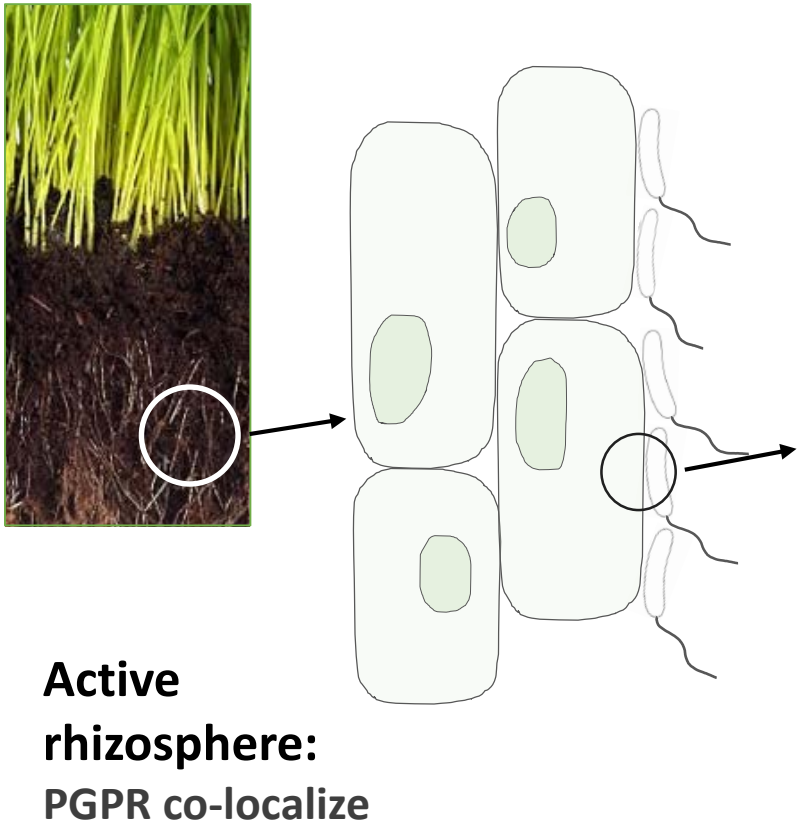
We continue to collaborate with Dr. Greenberg.

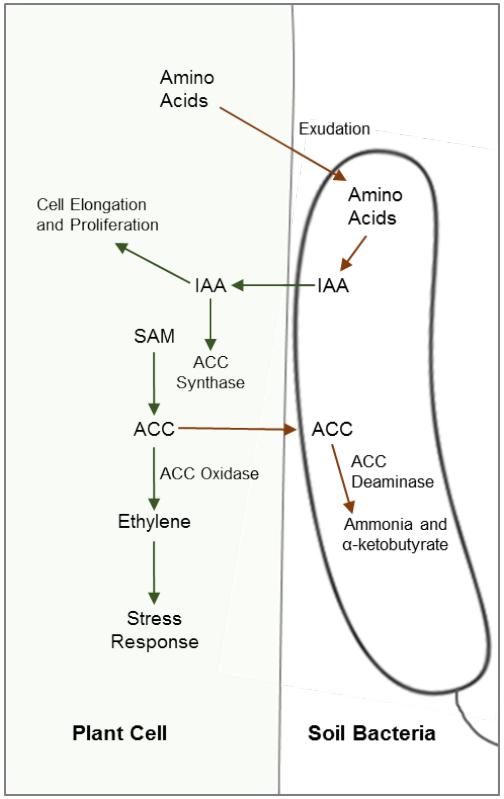
Development and Full Scale Application of PEPSystems

Research is the cornerstone of PEPSystems:

- Peer reviewed research published in a variety of scientific journals.
  - 15+ years of research
- 13+ years of full-scale commercial field remediation at >30 sites across Canada and in northern USA.
- We've been successful in the remediation of both petroleum hydrocarbon (PHC) and salt impacted sites in 7 Canadian provinces and territories.

PGPR – Facilitating Plant Growth in Challenging Conditions





Active rhizosphere:
PGPR co-localize with developing roots

- Stress ethylene
- Plant vigor
- Root development
- Rhizobacteria
- Leaves
- Salt and metals uptake
- Degradation of petroleum hydrocarbon (PHC)

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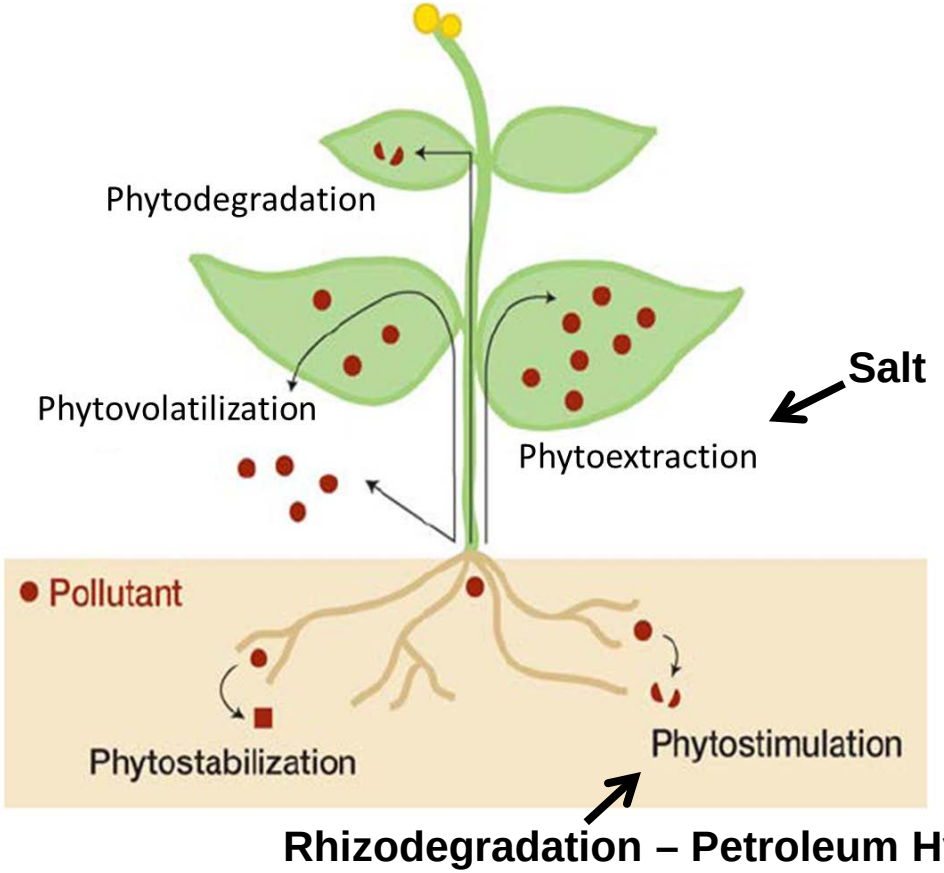
Phytoremediation – How it Works



- Improved rhizosphere
  - Soil
  - Organic matter
  - Bacteria
  - Water
  - Roots
- Phytostimulation
  - Petroleum Hydrocarbons
- Phytoextraction
  soil→root→foliage
  - Salts
  - Metals

Challenge – getting the plants to grow.

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Bacteria / Seed Selection for Remediation

Bacteria (*Pseudomonas sp.)* are isolated from area soil:

- Naturally occurring soil/water bacteria.
- Ubiquitous, geographically relevant, and frequently associated with plants.
- Not genetically modified.
- In general, they are classified as biosafety level 1 – no threat to humans, wildlife, or the environment.

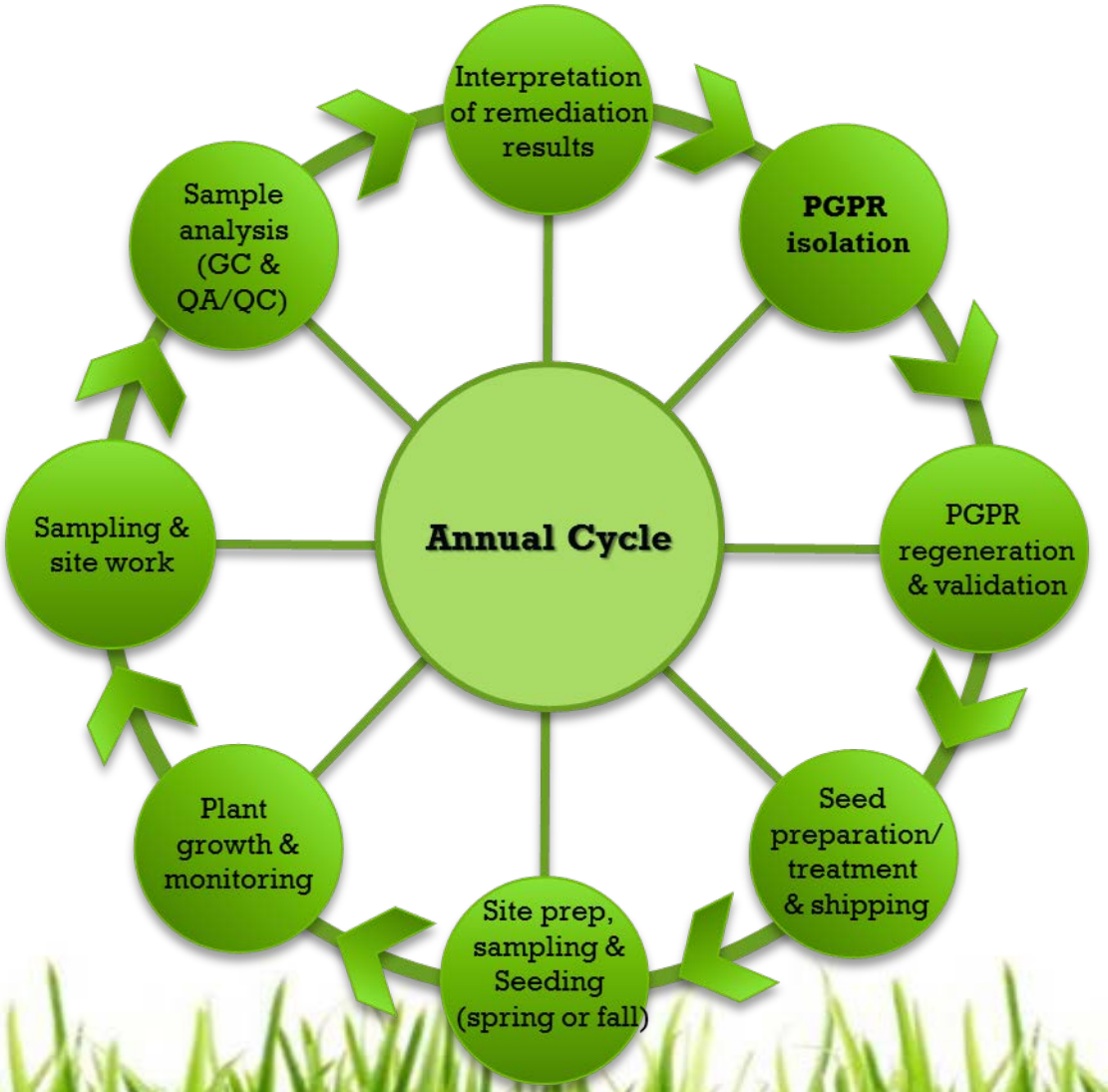
PGPR are cultured in the lab:

- Tested and selected for ACC deaminase and auxin (IAA) levels.
- Cultured and tested in greenhouse trials as individual species.

Grasses or plants are selected based on surrounding area:

- Suitable for the geographic area and not a prohibited species.
- Must produce high biomass.

PEPSystems is a Process

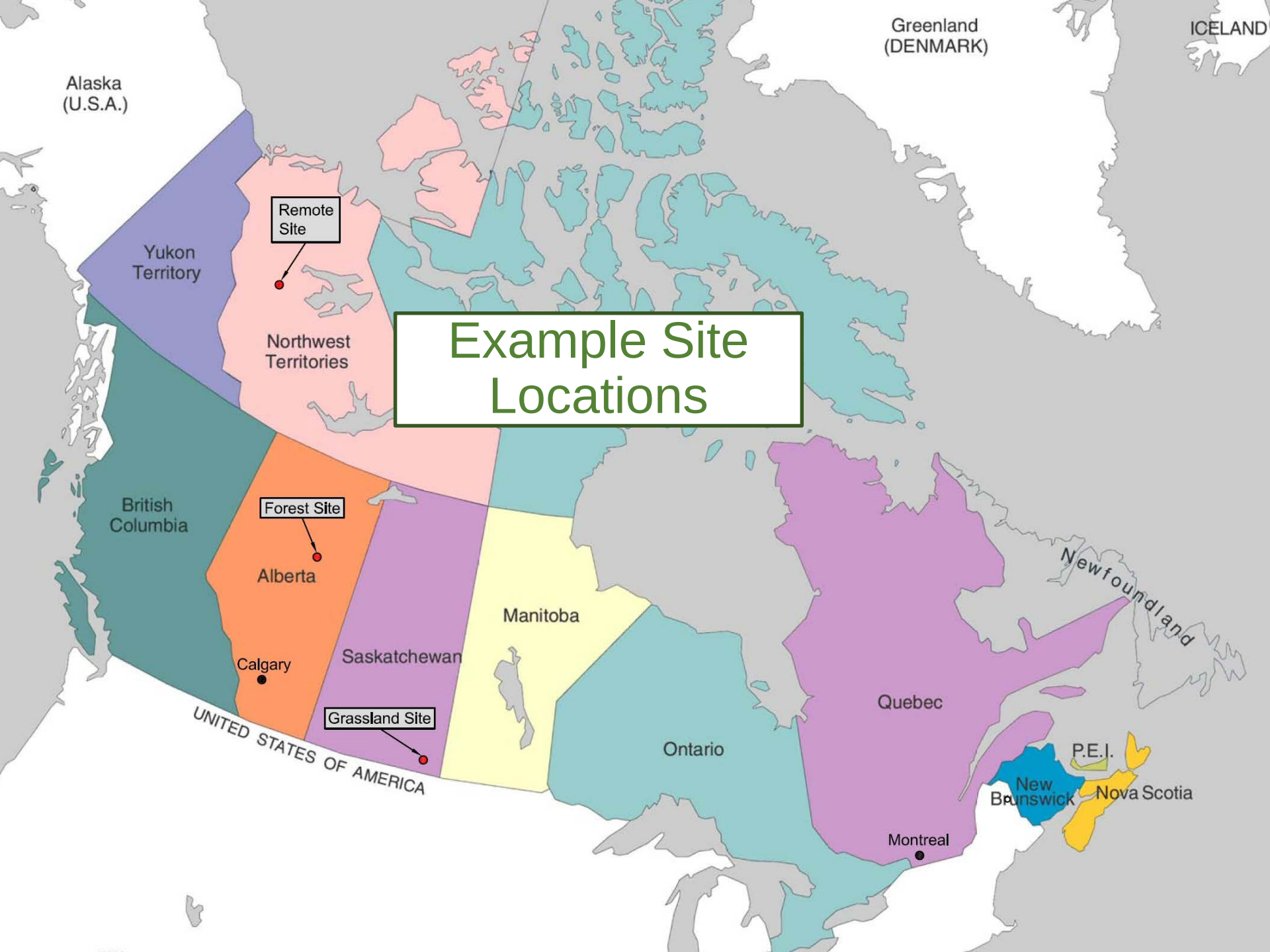


PGPR Types:

- Bacteria isolated from similar geographic area.

Seed Types:

- Variety of annual and perennial plants suitable for the region and soil conditions.

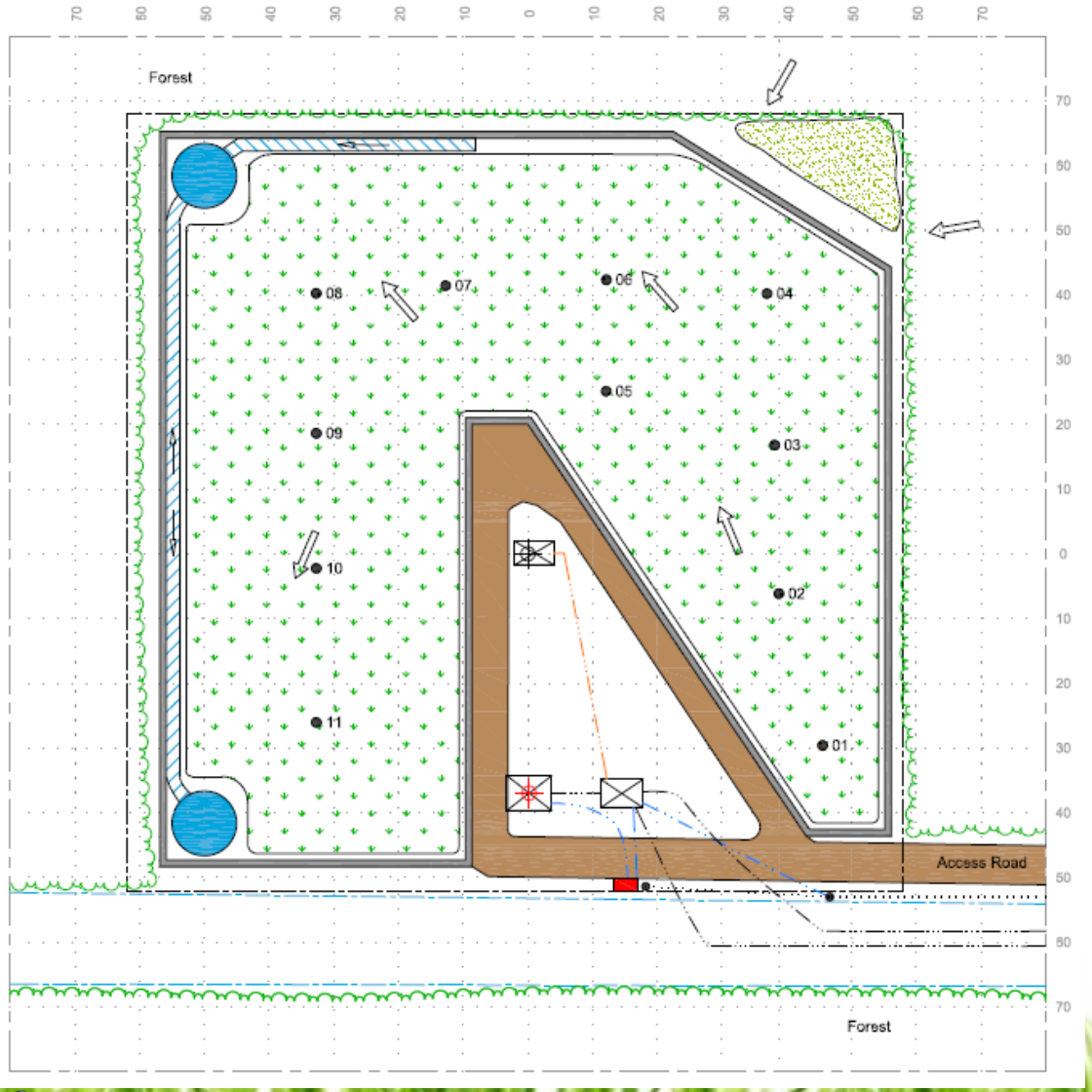

Greenland
(DENMARK)
ICELAND
Alaska
(U.S.A.)
Remote
Site
Yukon
Territory
Northwest
Territories
Example Site
Locations
British
Columbia
Forest Site
Alberta
Manitoba
Newfoundland
Calgary
Saskatchewan
Quebec
Grassland Site
UNITED STATES OF AMERICA
Ontario
P.E.I.
New
Brunswick
Nova Scotia
Montreal

Northern Alberta – Forest Site - PHC Contamination

Red Earth Creek oilfield emulsion spills

- 9,200 m³ of PHC impacted soil from historical spill sites - numerous treatment methods had been attempted previously.
- Earthmaster constructed 3 soil treatment facilities:
  - Engineered clay pad minimum 0.60 m thick
  - Perimeter clay berm to contain material
  - Surface water run off collection system
    - Channels
    - Collection sumps with poly liners
  - Regulatory compliance
- Impacted soil was spread across the clay liners
  - ~0.45 m thick

Forest Site – PHC Treatment Area



- Clay treatment pads
- Collection channels and sumps
- Containment berms
- Permanent assessment points

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Forest Site - Starting Material

Impacted soil guideline value exceedances (as compared to Alberta Tier 1 criteria):

- F1: 310 to 1,100 mg/kg
- F2: 170 to 3,000 mg/kg
- F3: 1,500 to 7,500 mg/kg
- F4: complied
- Benzene: 0.062 to 0.880 mg/kg
- Ethylbenzene: 0.190 to 1.200 mg/kg
- Toluene: 0.63 mg/kg

Stockpiled Impacted Soil Before Treatment

Treatment Area Clay Liner Construction

Impacted Soil Transferred to Treatment Pad

Seed Bed Preparation

Seeding and Fertilizing

First Year Growth – October 2012

Second Year Growth – October 2013

Re-Seeding Activities – July 2014

Fourth Year Growth – June 2015

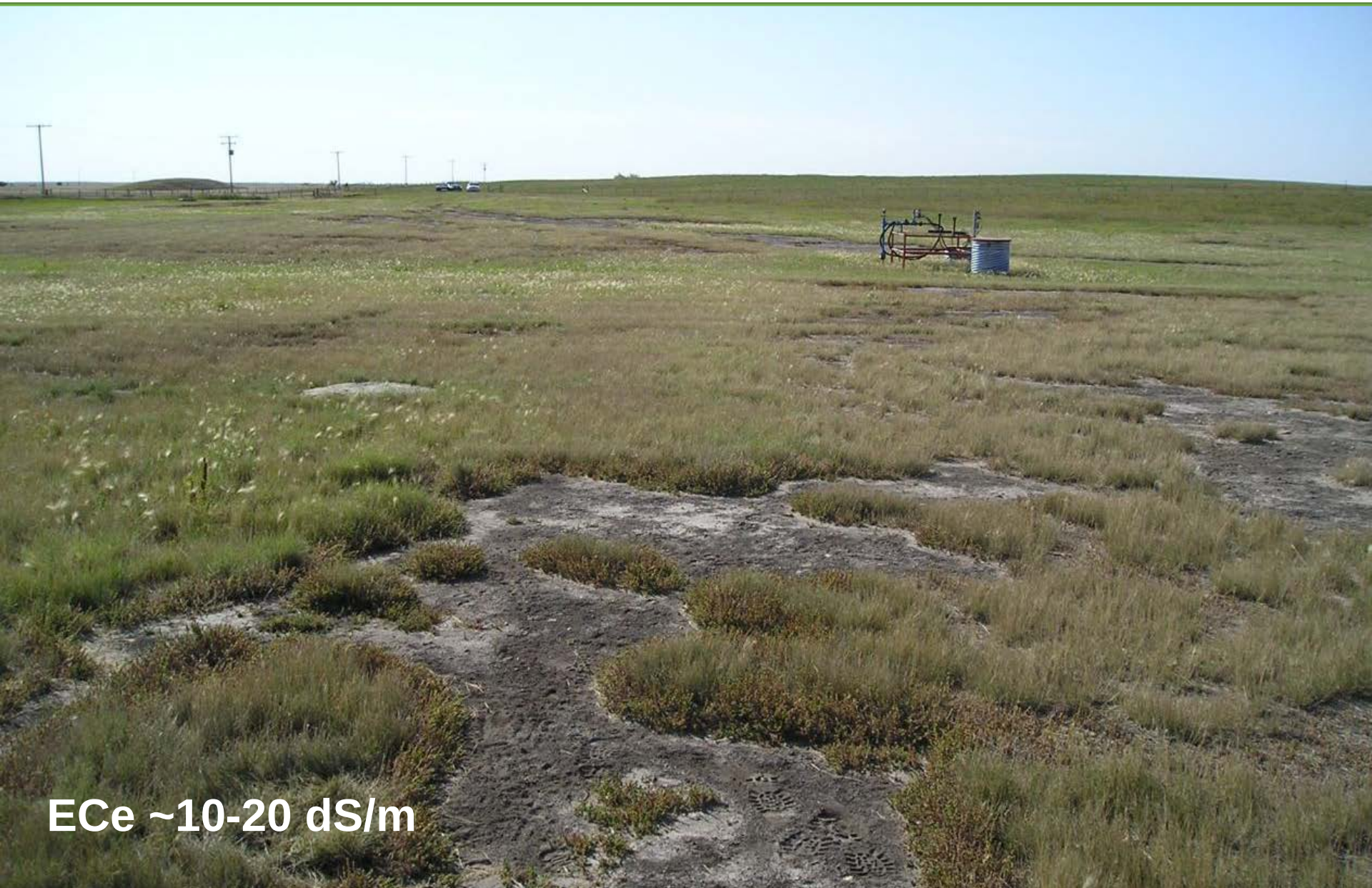
Stripping Treated Soil – July 2015

Forest Site – Phytoremediation Summary

Soil treatment was completed in 2016:

- Impacted soil met all remediation goals after five growing seasons.
- All soil was remediated to the ‘most stringent’ Alberta remediation criteria.
- Soil treatment pads were decommissioned in the summer of 2017.
- Treated or ‘clean’ soil remains onsite for future re-use as surface soil.
- Cost over 5 years was significantly less than if all material had been landfilled in Year 1.

Grassland Site - Historical Salt Spill in Southern Saskatchewan



Grassland Site - Phytoremediation of Salt

Historical Salt Water Spill (Oil and Gas)

- 48,000 m^2 of salt impacted surface area with very poor growth.
- Salt (i.e. NaCl) impacts to 6.00 m bgl^+.
- Since early 1990's numerous unsuccessful attempts had been made to re-vegetate the area.
- Groundwater recovery system was installed in 1997.
- Laboratory analyses showed elevated ECe (up to 45.3 dS/m), chloride (up to 12,000 mg/kg), SAR (up to 34.7), and boron (up to 23 mg/kg) levels.

Grassland Site - Phytoremediation of Salt

Project Goals:

- Re-vegetate the grassland site to at least 70% of background levels.
- Reduce soil salt levels over time to allow for sustainable plant growth.
- PEPSystems was deployed in the summer of 2010 using a combination of perennial and annual grasses treated with PGPR.
- Treatment area soils were managed over three growing seasons to re-vegetate the area.

Grassland Site – Salt Contamination (Before)

Grassland Site - Seed Bed Preparation

Grassland Site - Surface Mulch Amendment

Grassland Site – Post Seeding

Grassland Site - One Month After Seeding

Grass species suitable for the area

Grassland Site - Two Months After Seeding

Grassland Site Year 1 – Post Harvest

Grassland Site Year 2 – Substandard Growth Areas Tilled

Grassland Site - Plant Growth Year 2

Grassland Site - Plant Growth Year 3

Grassland Site - Healthy Roots for Salt Uptake

Grassland Site – Vegetation/Salt Removal

Grassland Site – Typical Salt Remediation by PEPSystems

Parameter	Value
Annual Decrease in EC_e	1 dS/m
Na^+ and Cl^- Uptake into Foliage	29 g/kg dry mass
Na^+ : Cl^- Ratio in Plant Foliage (mass basis)	25:75
Na^+ and Cl^- Removed from Project Sites in Foliage	150 kg/ha
Change in EC_e Accounted for by Foliar Uptake of Salt	Up to 95%

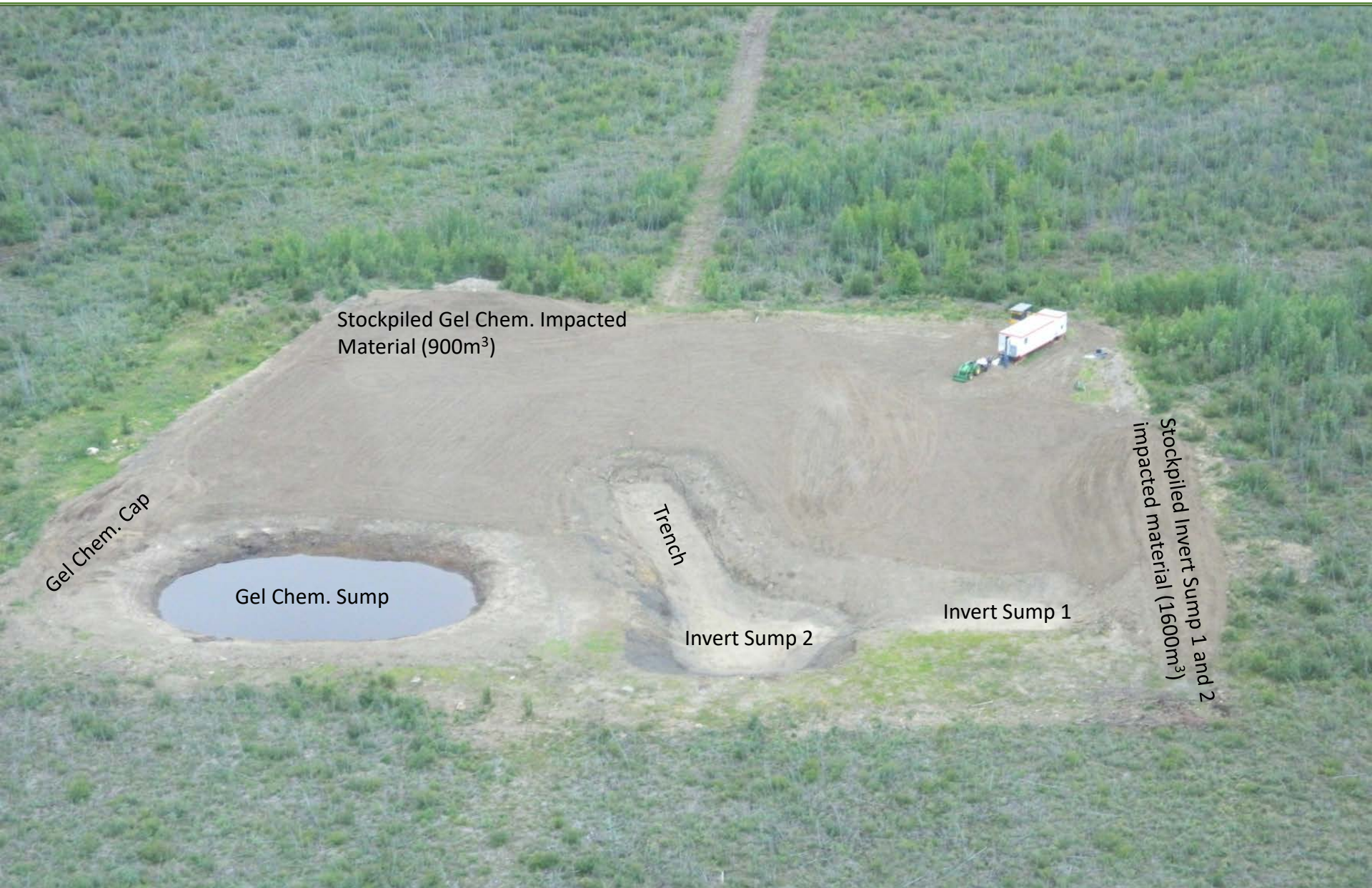
Northern Canada Remote Site – Pre-Deployment (2007)

Remote Site

Site Background:

- Former drill site: located ~30 km southeast of Norman Wells, Northwest Territories.
- Site contained several contaminated drill sumps and pits.
- Soil contained salts, BTEX, PHC fractions F1 to F4, and trace metals from drilling activities.
- 5000-6000 m^3 of impacted soil identified.
- PEPSystems was first deployed to treat surface soil salt in 2008.

Remote Site – Treatment Pad Construction



Remote Site – Spreading Contaminated Soil

Remote Site – Seedbed Preparation

Remote Site – Seeding Activities

Remote Site – Fall Growth

Remote Site – Excellent Biomass Production

Remote Site - Phytoremediation Summary

- 4,300 m^3 of impacted soil has been treated in 4 soil treatment layers.
- Impacted soil contained BTEX, PHC F1 to F4, salts (sodium and chloride), and some metals.
- Following treatment all soil met applicable remediation criteria.
- Approximately 1,100 m^3 of PHC impacted soil remains on-site currently in the treatment area (treatment layer 5).
- All soil treatment should be complete in 2018 and final site restoration can proceed (i.e. contouring and re-vegetation).

Advantages of PEPSystems

Environmentally Responsible

- Green technology
- Driven by solar energy
- Soil is conserved and reused
- Soil quality is improved
- Greenhouse gas capture
- Small carbon footprint (no offsite disposal; minimal heavy equipment usage)

Suitable for remote locations

- Fly in seed and amendments, etc.
- No large scale equipment requirements or hauling requirements reducing truck traffic on roads

Advantages of PEPSystems

Effective for challenging contaminants

- PHC fractions F3 and F4.
- Salts and metals.

Economic advantages

- Low cost as compared to other technologies.
- Overall remediation cost spread out over a number of years.

Economics of PEPSystems

PHC fractions F1 to F4, BTEX, PAH, and salt

- The larger the soil volume, the cheaper the unit cost.
- $30.00 → $100.00/m³.

Unit costs depend on:

- Material chemistry and remediation endpoint.
- Site/treatment area conditions.
- Geographic location.
- Costs are spread out over multiple years.

Economics of PEPSystems

Forest Site – PHC Contamination

- 9,200 m^3 of PHC impacted soil was treated in 5 growing seasons.
- Phytoremediation costs were approximately $500,000.
- Landfilling costs were estimated to be approximately $1.4 million.

Economics of PEPSystems

Grassland Site – Salt Contamination

- 48,000 m^2 of salt (sodium and chloride) impacted soil was re-vegetated.
- Phytoremediation costs were $195,000 over 3 years.
- Site was re-vegetated at a cost of $4/$m^2$.
- All previous re-vegetation attempts had been unsuccessful.
- Due to the depth of contamination at this site, landfilling/disposal costs would be astronomical.

Economics of PEPSystems

Remote Site – PHC and Salt Contamination

- 4,300 m^3 of impacted soil has been treated in 4 soil treatment layers.
- Phytoremediation costs have been $540,000 (not including excavation costs or equipment rental costs).
- Landfilling costs were estimated at $3.0 million.

Enhancement of PEPSystems

Research & Development:

- Improve speed to remedial endpoint
- Evaluate and test technology for deployment:
  - Different types of contaminants (e.g. metals and organics)
  - Different soil types
  - Different moisture regimes (e.g. wetlands)
  - Various disturbed soils (i.e. enhanced reclamation)

Enhancement of PEPSystems

Research & Development:

- We are conducting both lab and field research trials.
- We've partnered with clients, universities and various government agencies.

Select Publications

Chang, P, KE Gerhardt, X-D Huang, X-M Yu, BR Glick, PD Gerwing, and BM Greenberg. (2014) Plant Growth-Promoting Bacteria Facilitate the Growth of Barley and Oats in Salt-Impacted Soil: Implications for Phytoremediation of Saline Soils, International Journal of Phytoremediation, 16:1133-1147.

Cowie, BR, BM Greenberg and GF Slater. (2010) Determination of microbial carbon sources and cycling during remediation of petroleum hydrocarbon impacted soil using natural abundance 14C analysis of PLFA. Environmental Science & Technology, 44:2322-2327.

Gerhardt, KE, X-D Huang, BR Glick and BM Greenberg. (2009) Phytoremediation of organic soil contaminants: potential and challenges. Plant Science. 176:20-30.

Gerhardt, KE, GJ MacNeill, PD Gerwing, and BM Greenberg. (2017) Phytoremediation of Salt-Impacted Soils and Use of Plant Growth-Promoting Rhizobacteria (PGPR) to Enhance Phytoremediation in Phytoremediation Management of Environmental Contaminants Volume 5. Ansari, A.A., Gill, S.S., Gill, R., Lanza, G., Newman, L. (Eds.). Springer. Pages 19-51.

Gurska, J, W Wang, KE Gerhardt, AM Khalid, DM Isherwood, X-D Huang, BR Glick and BM Greenberg. (2009) Three year field test of a plant growth promoting rhizobacteria enhanced phytoremediation system at a land farm for treatment of hydrocarbon waste. Environmental Science & Technology, 43:4472-4479.

Acknowledgements

National Research Council – Industrial Research Assistance Program (IRAP).

Clients who have allowed Earthmaster to conduct field trials to advance the PEPSystems technology.

Come visit us:

- at the Earthmaster booth
- at our Phytoremediation of Hydrocarbons presentation – session 5B1 at 14:00 (Sep 27th)
- www.earthmaster.ca

Thank You

Questions?

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