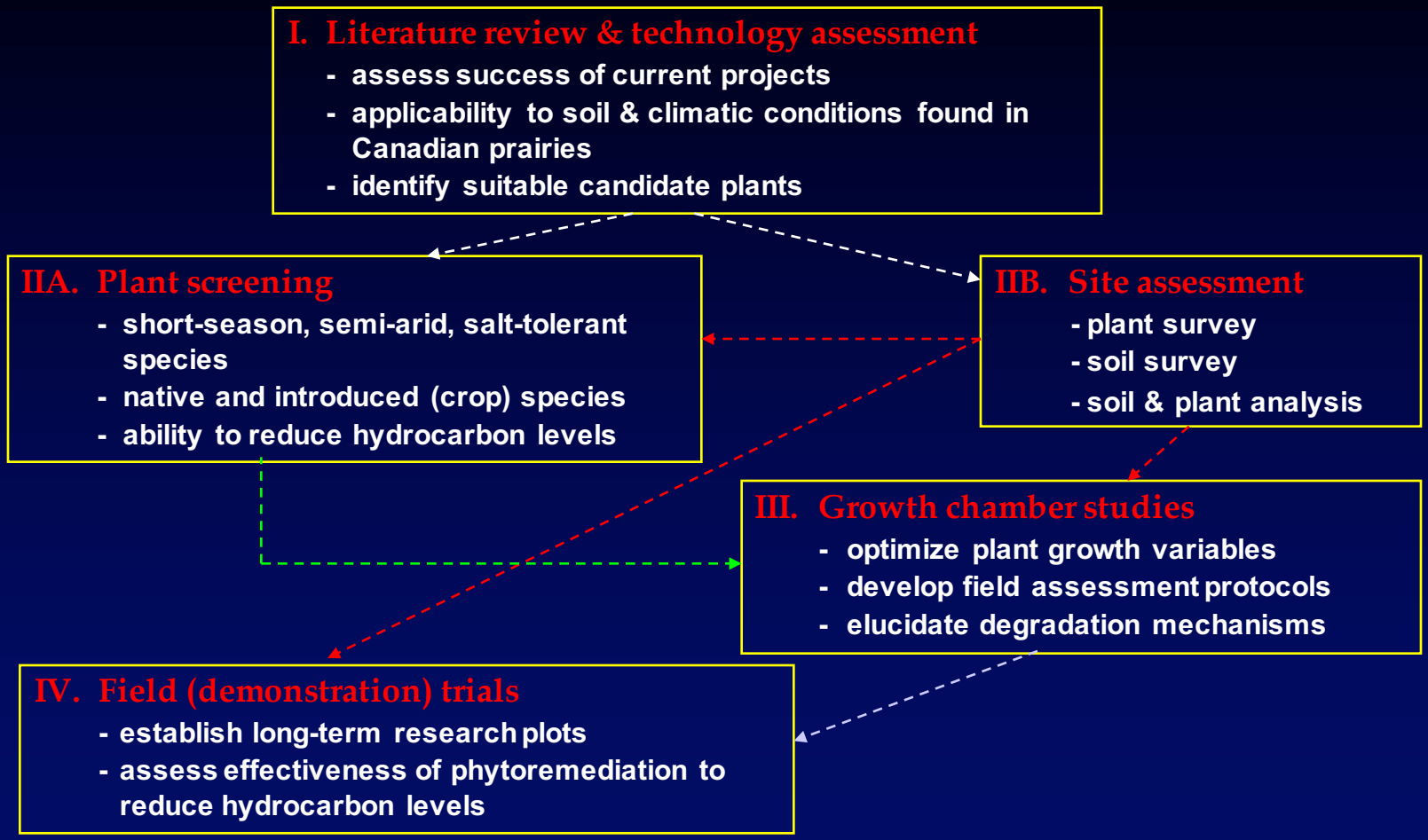
Assessment of Phytoremediation as an *In Situ* Technique for Cleaning Oil-Contaminated Sites

Cherie Frick, Richard Farrell, & James Germida
Department of Soil Science
University of Saskatchewan
Saskatoon, SK, Canada
S7N 5A8

----- Project Overview -----



Literature Review
&
Tecchnology Assessment

1. Introduction

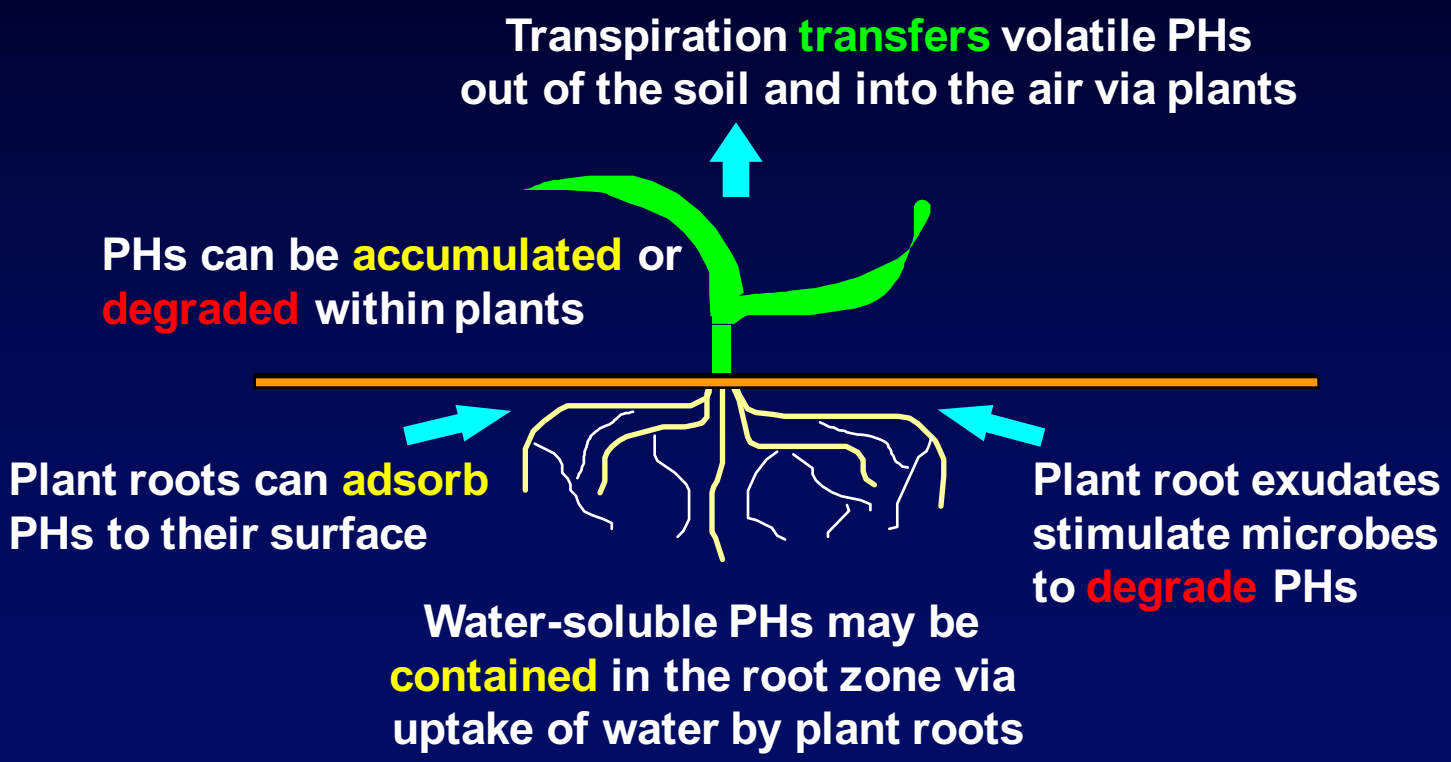
- **Define phytoremediation**
- **List several studies on phytoremediation of various contaminants including:**
  - petroleum hydrocarbons (alkanes, BTEX, PAHs)
  - herbicides (atrazine)
  - fertilizers (nitrate in groundwater)
  - explosives
  - metals (selenium, copper, cadmium,zinc)
  - radionuclides (cesium, strontium)
- **List contents of PhytoPet - a database of plants that phytoremediate or tolerate petroleum hydrocarbons**

2. Phytoremediation of Petroleum Hydrocarbons

- **Give examples of studies showing that phytoremediation of petroleum hydrocarbons works**
- **List plants that have the potential to phytoremediate or tolerate petroleum hydrocarbons**
- **Most research has been conducted on grass or legume species**
  - Grass advantage = extensive, fibrous root system
  - Legume advantage = nitrogen fixation

3. Mechanisms of Petroleum Hydrocarbon Phytoremediation

(Degradation, Containment, Transfer)



4. Influence of Environmental Factors on Phytoremediation

- **Soil characteristics may limit bioavailability:**
  - → high organic matter (>5%)
  - → clay versus silt or sand
  - → presence of nanopores (diameter < 100 nm)
- **Water and oxygen availability**
- **Temperature**
- **Nutrient availability**
- **Sunlight**
- **Weathering**

5. Special Considerations Associated with Phytoremediation

- Establishment of appropriate plants & microorganisms
- Concentrations of petroleum hydrocarbons
- Biotransformation, bioaccumulation and disposal
- Mixtures of contaminants
- Techniques used to enhance phytoremediation

6. Alternatives to Phytoremediation

- **Natural Attenuation**
  - "hands off" approach
- **Engineering**
  - Ex situ - excavation, landfilling, incineration
  - In situ - vapour extraction, solidification, chemical treatment, pump and treat, etc.
- **Bioremediation**
  - Ex situ - slurry phase and solid phase (landfarming, biopiles, compost)
  - In situ - no excavation

7. Comparison of Phytoremediation to Alternative Remediation Strategies

Benefits of Phytoremediation

- *in situ* - no excavation
- solar driven
- well-suited to treat large areas
- enjoys a favorable public perception
- good esthetics
- use a variety of plants to remediate a mixture of contaminants

Limitations of Phytoremediation

- generally limited to shallow contamination
- plants may not grow if contaminant concentrations are too high
- may be too slow when contamination presents immediate danger to humans and environment
- environmental conditions have to be right

Comparison to Alternative Techniques continued...

- Phytoremediation is faster than natural attenuation but slower than engineering and bioremediation
- Phytoremediation is less expensive than engineering and bioremediation, but slightly more expensive than natural attenuation

Phytoremediation	-	\$3 to \$100 per m^3
Engineering	-	\$10 to \$1000 per m^3
Bioremediation	-	\$50 to \$133 per m^3
Natural Attenuation	-	monitoring costs

8. Summary and Conclusions

- Phytoremediation of petrochemicals is a steadily emerging technology
- Phytoremediation involves **degradation**, **containment**, and **transfer** of petroleum hydrocarbons in soil and groundwater
- Several Prairie and Boreal Plain Ecozone plants have the potential to phytoremediate petroleum hydrocarbons
  - **phytoremediation potential demonstrated primarily under lab conditions**
- Little published data exists on the application of phytoremediation to oil-contaminated sites in Canada
  - **need to confirm potential under conditions representative of western Canada**

Remaining Material

- 9. Acknowledgements
- 10. Literature Cited
- 11. Glossary
- Appendix A - Types and Behavior of Petroleum Hydrocarbons
- Appendix B - Potential Application of Phytoremediation
- Appendix C - Internet Resources on Phytoremediation

PhytoPet

A database for the plant-assisted remediation of hydrocarbon contaminated soils

PhytoPet Database

Serves as an inventory of plants with a demonstrated potential to phytoremediate (or tolerate) petroleum hydrocarbons

- To date, 61 plant species have been recorded in the database (represents results from 33 experimental studies)
- Information included in the database:

General

- → common & scientific name of plant
- → petroleum hydrocarbon of concern
- → interaction of plant & contaminant (phytoremediation vs. tolerance)
- → mechanism(s) of phytoremediation

PhytoPet continued...

- Information included in the database (continued…):

Experimental

- → contaminant concentration (pre- and post-experiment)
- → soil characteristics
- → storage sites in the plant; age of plant at first exposure

Plant-Specific Information

- → family
- → growth form & morphology
- → growth period
- → habitat, salinity tolerance
- → occurrence in western Canada

Plant Survey: Literature review

Phytoremediation in the Prairie and Boreal Plain Ecozones of Western Canada

Oil production in western Canada takes place in both the Prairie and Boreal Plains Ecozones

Prairie Ecozone

- extends from the Rocky mountains in the west to the deciduous forests in the east; from the boreal forest in the north to the Gulf of Mexico in the south

Boreal Plain Ecozone

- extends north of the Prairie ecozone from the Rocky mountains to Newfoundland

Potential for Phytoremediation in the Prairie Ecozone

Native plant species (12)

- western wheatgrass
- big bluestem
- side oats grama
- common buffalograss
- Canada wild rye
- poplar trees
- switchgrass
- little bluestem
- blue grama
- Prairie buffalograss
- red fescue [Alberta only]
- Indiangrass

Introduced plant species (5)

- alfalfa
- soybean
- red fescue [Manitoba/SK]
- annual and perennial ryegrass

Plants that tolerate petroleum hydrocarbons (15)

crested wheatgrass, oat, quackgrass, wheat, barley, maize, birdsfoot trefoil, black medick, field pea, alsike clover, red clover, white clover, fababean, soybean, and canola

Potential for Phytoremediation in the Boreal Plain Ecozone

Native plant species (2) - red fescue & poplar trees

Introduced plant species (1) - carrot

Plants that tolerate petroleum hydrocarbons (16)

alpine bluegrass, oat, wheat, jack pine, snow willow, black medick, field pea, alsike clover, red clover, white clover, water sedge, round sedge, rock sedge, tall cotton-grass, cattail, reed canarygrass

Plant Survey: Site Assessment

Inventory plant communities occupying areas contaminated with hydrocarbons

Identify plant species with a potential for phytoremediation

Preliminary Results

- **Nine (9) sites with soils contaminated with oil or gas production wastes**
  - Western Alberta Upland (3)
  - Boreal Transition (3)
  - Aspen Parkland (3)
  - Surface contamination (5)
  - Subsurface contamination (4)
  - 85 species of vascular plants growing in contaminated areas

Sites with subsurface contamination

- **Depth to contamination generally > 0.5 m**
- **No significant difference in plant community composition between contaminated and uncontaminated soils**
- **In regions where forest plant communities occur:**
  - adequate moisture for most plants generally restricted to surface soils
  - most plants will be rooted only in the shallow soils above the contamination

Sites with surface contamination

- **Most likely to provide plant species actively invloved in remediationg the soil**
- **Recently disturbed sites (2)**
  - only limited plant succession had occurred
- **Sites with several years since last disturbance (3)**
  - opportunity for adapted perennial species to become established
    - upland (1)
    - upland with some temporarily flooded areas (1)
    - wetland (1)

Sites with surface contamination

- **Surface soil (0-10 cm) apparently hydrocarbon free; strong hydrocarbon odor below 10 cm**
- **Bulk of rooting activity in upper 10 cm with some roots penetrating into the zone of contamination**
- **Wetland site (1)**
  - common cattail (*Typha latofolia*) = dominant species
- **Upland site with periodic flooding (1)**
  - red fescue (*Festuca rubra*) = dominant species
  - plant roots in uncontaminated soil

Sites with surface contamination

- **Upland site (1)**
  - aspen parkland
  - extensive, heavy contamination in the past
  - seeded to perennial forage (*Bromus inermis & Medicago sativa*) for many years
    - poor overall plant growth
    - extensive invasion by Kentucky bluegrass (*Poa pratensis*) and quack grass (*Agropyron repens*)
    - trembling aspen (*Populus tremuloides*) established in a few small areas

Sites with surface contamination

- **Depth to contamination**
  - ca. 5-10 cm in areas vegetated with grasses
  - ca. 25-30 cm in areas vegetated with aspen
  - cause & effect?
- **In one area, aspen suckers have spread to areas with obviously stressed grasses in soils with heavy contamination**
  - opportunity to monitor soil remediation under aspen cover
  - determine whether the aspens
  - source of woody species for use in greenhouse studies

Project status

- **Phase I**
  - literature review and technology assessment: completed
  - PhytoPet database: to be completed (11-12-99)
- **Phase II**
  - site assessment - Plant survey: completed
  - Phase II final report: to be completed (12-15-99)
- **Phase III**
  - preliminary plant screening: pending ($50k)
- **Phase IV**
  - growth chamber & field trials: pending ($25k per site per year)