

Phytoremediation and sustainable urban design methods (Low Carbon Cities through Phytoremediation)

1.Introduction

During the same period of time human activities, The atmospheric concentration of carbon dioxide, the major greenhouse gas directly affected by human activities, has increased by about 30% since the beginning of the pre- industrial era around 1750 because of the combustion of fossil fuels and changes in land- use practices. Have also increased the atmospheric concentrations of other greenhouse gases such as methane and nitrous oxide, and regional pollutants such as sulfate aerosols. Increased atmospheric concentrations of greenhouse gases tend to warm the atmosphere, while increased concentrations of aerosols tend, in some regions, to cool the atmosphere. The Earth's climate, which has been relatively stable during the past 10,000 years, is now changing. The Earth's surface temperature this century is as warm as or warmer than any other century during the six hundred years; the Earth's surface temperature has increased by about one degree Fahrenheit over the last century; and the last few decades have been the hottest this century. Computational models that take into account the observed increases in the atmospheric concentrations of greenhouse gases and aerosols simulate the observed changes in temperature quite well, suggesting that there is a discernible human influence on the Earth's climate.

Greenhouse gas concentrations are projected to increase significantly during the next century in the absence of policies specifically designed to address the issue of climate change. Climate models project that the global mean surface temperature could increase another 1.5 to 6.5 off by 2100: a rate significantly faster than observed changes over the last 10,000 years.

Sea level is projected to increase by another 15 - 95 cm by 2100. While the incidence of extreme temperature events, floods, droughts, fires and pest outbreaks is expected to increase in some regions, it is unclear whether there will be changes in the frequency and intensity of tropical storms, cyclones, and tornadoes.

The overwhelming majority of scientific experts believe that human-induced climate change is inevitable. The question is not whether climate will change in response to human activities, but rather where (regional patterns), when (the rate of change) and by how much (magnitude).

It is also clear that climate change will adversely affect human health (especially increases in vector-borne diseases such as malaria, dengue and yellow fever); ecological systems (changes in the composition and geographic distribution of many ecosystems, especially forests and coral reefs, with likely reductions in biological diversity); socio-economic sectors, including: agriculture (regional disruptions in food production, especially in the tropics and sub-tropics), human settlements (the loss of land and the displacement of tens of millions of people).

In summary, human-induced climate change is an important new stress, particularly on ecological and socio-economic systems that are already affected by pollution, increasing resource demands, and non-sustainable management practices; most ecological and socio- economic systems are sensitive to both the magnitude and rate of climate change; successful adaptation to climate change depends upon technological advances, institutional arrangements, availability of financing and information exchange; and developing countries are more vulnerable to climate change than developed countries. Worldwide, sea level rise threatens the integrity of many coastal cities while extreme weather events will increase in their intensity.

On the other hand, some regions might benefit in the medium term, in terms of crop yields, for example, before negative effects become more general.

- *The aspects to be concerned with planning low carbon cities include the following:*

Aspect 1 – Study the realities about the effects of climate change on our cities and the ways to mitigate them.

Aspect 2 – Declare strategies for sustainable land and nature uses.

Aspect 3 – The management and designing plans to have low carbon cities in future, which is the domain of the related discipline of urban design and Open space and landscape strategies, to have low carbon cities.

Aspect 4 – Transport systems, community energy strategies.

Aspect 5 – Declare strategies for recycling wastes and environmental organic contaminants.

Increasing the atmospheric concentration of carbon dioxide, not only augments the risk of greenhouse gas effects, but also increases the environmental organic contaminants. By measuring the concentration of carbon monoxide and carbon dioxide of atmosphere, it will be possible to evaluate the gaseous pollutants like ethylene. Organic substances comprise a potentially large group of air pollutants, particularly in urban environments.

Motor vehicle emissions are a major source of these pollutants together with the petroleum and chemical industries, emissions from waste incinerators, service stations, domestic solid fuel and gas combustion, spray painting, dry-cleaning and other solvent usage, and cigarette smoke. Even at low levels, some of these organic pollutants can be hazardous to human health, particularly if the exposure is long term.

If we are to reduce our demands on the planet, it's necessary to study the new and additional topics that accompany it; Like:

1. The roles of sustainable waste strategies and integrated waste management play in the move towards low carbon cities.
2. Economic, social and environmental benefits that can be drawn from treating waste as a resource.
3. The part that can urban design and landscaping play as counterparts to sustainable urban development.
4. The way to expand and enhance our urban green space as an integral part of low carbon cities.

2.Objectives:

We have to reduce our impact on the environment very seriously. And we have to be committed to taking action on this important issue. We should take steps to preserve the environment through responsible management; and develop programs and initiatives to evaluate and address environmental challenges.

One big step to have low carbon cities is the plant elements of urban design program which is developed to support the landscape design process by providing designers and architects the opportunity to select plants with specific characteristics.

As befits the title Low Carbon Cities, our aim is that this should be a 'Green seminar'.

3.What is Phytoremediation?

Phytoremediation is the use of living green plants for in situ risk reduction and/or removal of contaminants from contaminated soil, water, sediments, and air specially selected or engineered plants are used in the process. Risk reduction can be through a process of removal, degradation of, or containment of a contaminant or a combination of any of these factors.

Phytoremediation is an energy efficient, pleasing method of remediation sites with low to moderate levels of contamination and it can be used in conjunction with other more traditional remedial methods as a finishing step to the remedial process.

One of the main advantages of phytoremediation is that of its relatively low cost compared to other remedial methods such as excavation. (In many cases phytoremediation has been found to be less than half the price of alternative methods.)

The cost of phytoremediation has been estimated as \$25 - \$100 per ton of soil, and \$0.60 - \$6.00 per 1000 gallons of polluted water with remediation of organics being cheaper than remediation of metals.

Example Cost Comparisons

Problem	Phytoremediation Application	Cost (\$ thousand)	Conventional Treatment	Cost (\$ thousand)	Projected Savings
Lead in soil, 1 acre ^a	Extraction, harvest disposal	\$150-250	Excavate and landfill	\$500	50-65%
Solvents in groundwater, 2.5 acres ^b	Degradation and hydraulic control	\$200 install and initial maintenance	Pump and treat	\$700 annual running cost	50% cost saving by third year
TPH in soil, 1 acre ^c	In situ degradation	\$50-100	Excavate and landfill incinerate	\$500	80%

^a Phytotech estimate for Magic Marker site (Blaylock et al. 1997).

^b PRP estimate for Solvent Recovery Systems of New England site.

^c PERF estimate (Drake 1997)

Table 1: Example Cost Comparisons

However phytoremediation is not without its faults, it is a process which is dependent on the depth of the roots and the tolerance of the plant to the contaminant.

Root Depth for Selected Phytoremediation Plants

Plant	Maximum Root Depth	Target Contaminants
Indian mustard	To 12 inches	Metals
Grasses	To 48 inches	Organics
Poplar trees	To 15 feet	Metals, organics, chlorinated solvents

Table 2: Root Depth for Selected Phytoremediation Plant

Exposure of animals to plants which act as hyperaccumulators can also be a concern to environmentalists as herbivorous animals may accumulate contaminates particles in their tissues which could in turn affect a whole food web.

As different plant have different abilities to uptake and withstand high levels of pollutants many different plants may be used. This is of particular pollutants than most other species) are used on many sites due to their tolerance of relatively extreme levels of pollution. Once the plants have grown and absorbed the pollutants they are harvested and disposed of safely.

Some plants which are recommended to be used as a Hyperaccumulator, landscape plant species are Alfalfa, poplar, juniper, Fescue, Hybrid poplar, grasses, Sunflower, Indian mustard, cabbage, which can be used for soil and groundwater medium which are polluted by petroleum and hydrocarbons.

3-1. How Does It Work?

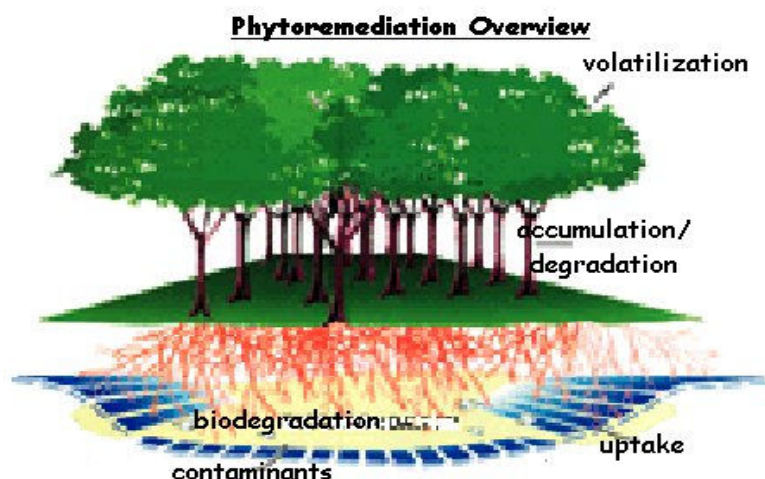


Fig. 1: Phytoremediation Overview

Phytoremediation is actually a generic term for several ways in which plants can be used to clean up contaminated soils and water. Plants may break down or degrade organic pollutants. This may be done through one of or a combination of the methods.

The methods used to phytoremediate metal contaminants are slightly different to those used to remediate sites polluted with organic contaminants.

Metal	Organic
Phytoextraction	Phytodegradation
Rhizofiltration	Rhizodegradation
Phytostabilisation	Phytovolatilisation

Table 3: The methods used to phytoremediate

Phytoremediation Overview					
Mechanism	Process Goal	Media	Contaminants	Plants	Status
Rhizodegradation	Contaminant destruction	Soil, sediment, sludges, groundwater,	Organic compounds (TPH, PAHs, pesticides, chlorinated solvents, PCBs)	Red mulberry, grasses, hybrid poplar, cattail, rice	Field application
Phytodegradation	Contaminant destruction	Soil, sediment, sludges, groundwater, surface water	Organic compounds, chlorinated solvents, phenols, herbicides, munitions	Algae, stonewort, hybrid poplar, black willow, bald cypress	Field demonstration

Table 4: Phytoremediation Overview

3-2. Phytoremediation System Selection and Design Considerations

3-2-1. Contaminated Media Considerations Soil, Sediment, and Sludge Groundwater

3-2-1-1. The following phytoremediation technologies are used in the treatment of groundwater

3-2-1-1-1. Phytodegradation

3-2-1-1-2. Phytovolatilization

3-2-1-1-3. Rhizofiltration

3-2-2. Contaminant Considerations

3-2-2-1. Organic Contaminants

The hydrophobicity of an organic compound will affect the uptake and translocation of the compound.

In general, moderately hydrophobic organic compounds, are most readily taken up by and translocated within plants.

Hydrophobic (lipophilic) compounds also can be bound to root surfaces or partition into roots but not be further translocated within the plant (Schnoor et al., 1995a; Cunningham et al., 1997).

3-2-2-2. Waste Mixtures

3-2-2-3. Contaminant Concentrations

3-2-2-4. Contaminant Depth and Distribution in the Soil Profile

3-2-2-5. Contaminant Characteristics

3-2-3. Plant Considerations

3-2-3-1. Phytoremediation Plant Selection

3-2-3-1-1. Root Type

3-2-3-1-2. Root Depth

3-2-3-1-3. Growth Rate

3-2-3-1-4. Transpiration Rate

3-2-3-1-5. Allelopathy

3-2-4. Site Considerations

3-2-4-1. Site Activities

3-2-4-1-1. Former Site Activities

3-2-4-1-2. Current Site Activities

3-2-4-1-3. Proposed Site Activities

3-2-5. Climatic Considerations

3-2-6. Water Considerations

3-2-7. Potential Adverse Effects/Neighborhood Concerns

3-2-8. Agronomic Considerations for System Installation and Maintenance

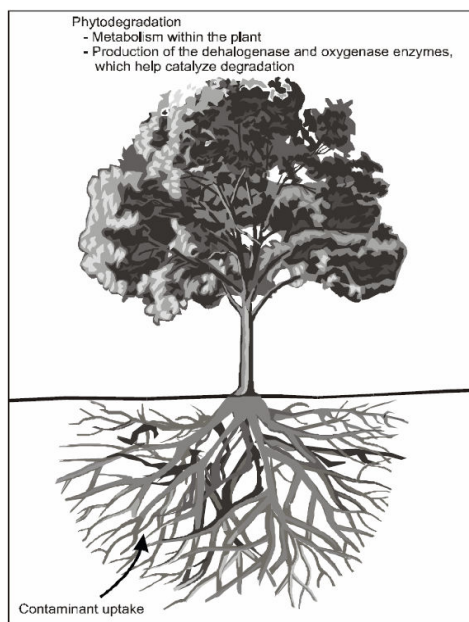
3-2-9. Disposal Considerations

3-3. Methods of Phytoremediation of organic contaminants Phytoremediation of organic polluted sites

3-3-1. Phytodegradation (Phytotransformation)

Phytodegradation is the degradation or breakdown of organic contaminants by internal and external metabolic processes driven by the plant.

Ex) planta metabolic processes hydrolyze organic compounds into smaller units that can be absorbed by the plant.



Phytodegradation.

Fig. 2: Phytodegradation

Some contaminants can be absorbed by the plant and are then broken down by plant enzymes.

These smaller pollutant molecules may then be used as metabolites by the plant as it grows, thus becoming incorporated into the plant tissues.

Plant enzymes have been identified that breakdown ammunition wastes, chlorinated solvents such as TCE (Trichloroethane), and others which degrade organic herbicides.

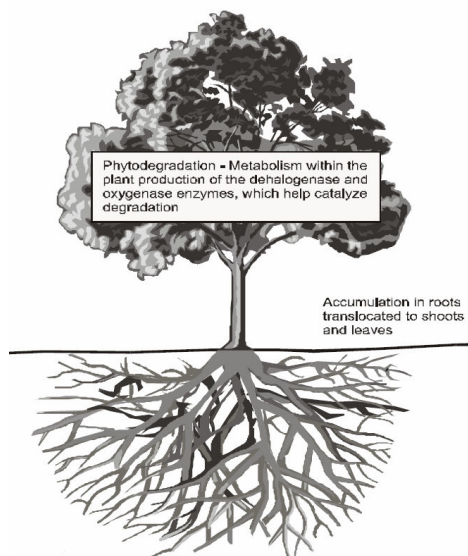


Fig. 3: plant enzymes for Phytodegradation

3-3-1-1. Metabolism

Metabolism within plants has been identified for a diverse group of organic compounds, including the herbicide Atrazine (Burken and Schnoor 1997), the chlorinated solvent TCE (Newman et al. 1997a), and the munition TNT (Thompson et al. 1998).

Other metabolized compounds include the insecticide DDT, the fungicide hexachlorobenzene (HCB), PCP, and PCBs in plant cell cultures (Komossa et al. 1995).

Plant-Formed Enzymes

Plant-formed enzymes have been identified for their potential use in degrading contaminants such as munitions, herbicides, and chlorinated solvents.

Immunoassay tests have been used to identify plants that produce these enzymes (McCutcheon 1996).

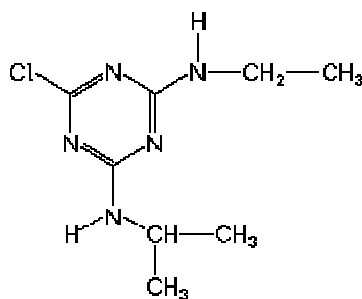
The following are examples of plants capable of Phytodegradation:

The aquatic plant parrot feather (*Myriophyllum aquaticum*) and the algae stonewort (Nitella) have been used for the degradation of TNT. The nitroreductase enzyme has also been identified in other algae, ferns, monocots, dicots, and trees (McCutcheon 1996).

Degradation of TCE has been detected in hybrid poplars and in poplar cell cultures, resulting in production of metabolites and in complete mineralization of a small portion of the applied TCE (Gordon et al. 1997; Newman et al. 1997a).

Atrazine degradation has also been confirmed in hybrid poplars (*Populus deltoides* x *nigra* DN34, *Imperial Carolina*) (Burken and Schnoor 1997).

Poplars have also been used to remove nutrients from groundwater (Licht and Schnoor 1993).



ATRAZINE

Fig. 4: Atrazine structure

Black willow (*Salix nigra*), yellow poplar (*Liriodendron tulipifera*), bald cypress (*Taxodium distichum*), river birch (*Betula nigra*), Cherry bark oak (*Quercus falcata*), and live oak (*Quercus virginiana*) were able to support some degradation of the herbicide bentazon (Conger and Portier 1997).

3-3-2. Rhizodegradation

Rhizodegradation is the breakdown of organic contaminants in the soil by soil dwelling microbes which is enhanced by the rhizosphere's presence.

Certain soil dwelling microbes digest organic pollutants such as fuels and solvents, producing harmless products through a process known as Bioremediation.

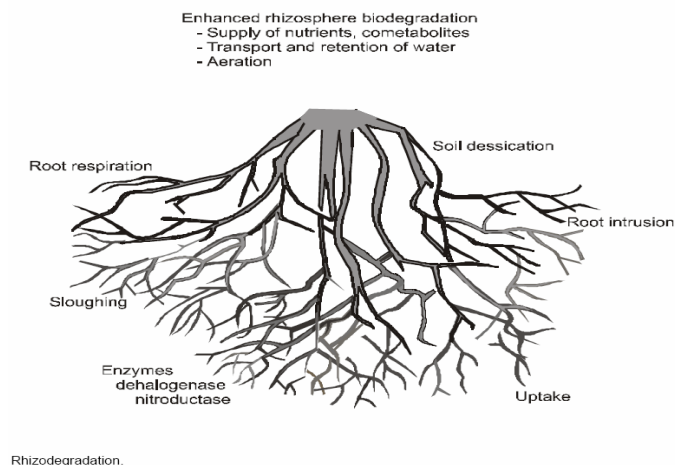
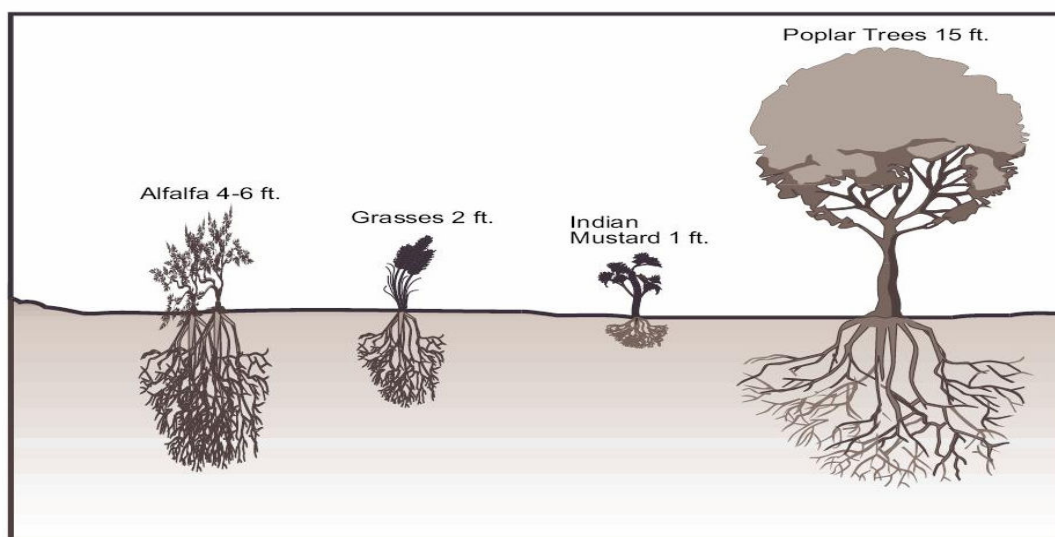


Fig. 5: Rhizodegradation

Plant root exudates such as sugars, alcohols, and organic acids act as carbohydrate sources for the soil micro flora and enhance microbial growth and activity. Some of these compounds may also act as chemo tactic signals for certain microbes. The plant roots also loosen the soil and transport water to the rhizosphere thus additionally enhancing microbial activity.



Example root depths.

Fig. 6: Example root depths

Plants that produce exudates that have been shown to stimulate growth of degrading microorganisms or stimulate co-metabolism will be of more benefit than plants without such directly useful exudates. The type, amount, and effectiveness of exudates and enzymes produced by a plant's roots will vary between species and even within subspecies or varieties of one species.

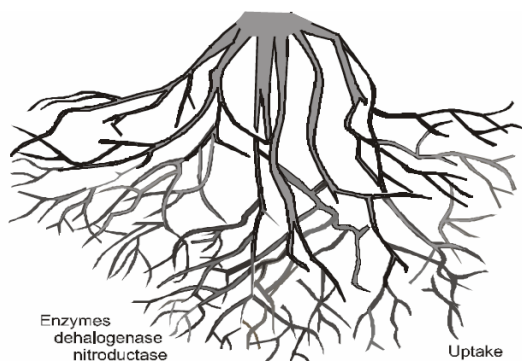


Fig. 7: Rhizodegradation through Plant's roots

The following are examples of plants capable of rhizodegradation:

Red mulberry (*Morus rubra* L.), crabapple (*Malus fusca* Raf.) Schneid, and Osage orange (*Maclura pomifera* Raf.) Schneid, produced exudates containing relatively high levels of phenolic compounds, at concentrations capable of stimulating growth of PCB-degrading bacteria (Fletcher and Hegde 1995).

Spearmint (*Mentha spicata*) extracts contained a compound that induced co metabolism of a PCB (Gilbert and Crowley 1997).

Alfalfa (*Medicago sativa*) appears to have contributed to the dissipation of TCE and TCA through exudates on soil bacteria (Narayanan *et al.*, 1995).

A legume (*Lespedeza cuneata* Dumont), Loblolly pine (*Pinus taeda* L.)), and soybean (*Glycine max* L.) Merr., cv Davis, increased TCE mineralization compared to non-vegetated soil (Anderson and Walton 1995).

At a Gulf Coast field site, the use of annual rye and St. Augustine grass led to greater TPH disappearance after 21 months than that experienced with the use of sorghum or a non-vegetated plot (Schwab, 1998).

At one field site, although white clover did not survive the second winter, concentrations of TPH were reduced more than with tall fescue or bermudagrass with annual rye, or bare field (Schwab, 1998).

PAH degradation occurred through the use of the following mix of prairie grasses: big bluestem (*Andropogon gerardi*), little bluestem (*Schizachyrium scoparius*), Indian grass (*Sorghastrum nutans*), switchgrass (*Panicum virgatum*), Canada wild rye (*Elymus canadensis*), western wheatgrass (*Agropyron smithii*), side oats grama (*Bouteloua curtipendula*), and blue grama (*Bouteloua gracilis*) (Aprill and Sims 1990).

Fescue (*Festuca arundinacea* Schreb), a cool-season grass: sudangrass (*Sorghum vulgare* L.) and switchgrass (*Panicum virgatum* L.), warm-season grasses; and alfalfa (*Medicago sativa* L.), a legume, were used to study PAH disappearance; greater disappearance was seen in the vegetated soils than in non-vegetated soils (Reilley *et al.* 1996).

Hycrest crested wheatgrass [*Agropyron desertorum* (Fischer ex Link) Schultes, increased mineralization rates of PCP and pyrene relative to unplanted controls (Ferro *et al.*, 1994a, 1994b).

In PAH- and PCP-contaminated soil, a mix of fescues: hard fescue (*Festuca ovina* var. *duriuscula*), tall fescue (*Festuca arundinacea*), and red fescue (*Festuca rubra*) had higher germination rates and greater biomass relative to controls than did a mix of wheatgrasses: western wheatgrass (*Agropyron smithii*) and slender wheatgrass (*Agropyron trachycaulum*) and a mix of little bluestem (*Andropogon scoparius*), Indiangrass (*Sorghastrum nutans*), and switchgrass (*Panicum virgatum*) (Pivet *et al.* 1997).

Bush bean (*Phaseolus vulgaris* cv. "Tender Green") rhizosphere soil had higher parathion and diazinon mineralization rates than non-rhizosphere soil (Hsu and Bartha 1979).

Rice (*Oryza sativa* L.) rhizosphere soil had increased numbers of gram-negative bacteria, which were able to rapidly transform propanil (Hoagland et al. 1994).

Kochia sp. rhizosphere soil increased the degradation of herbicides relative to non-rhizosphere soil (Anderson et al. 1994).

Cattail (*Typha latifolia*) root microorganisms produced greater mineralization rates of LAS and LAE than did non-rhizosphere sediments (Federle and Schwab 1989).

Hybrid poplar tree (*Populus deltoides* X *nigra* DN-34, Imperial Carolina) rhizosphere soil contained significantly higher populations of total heterotrophs, denitrifiers, pseudomonads, BTX degraders, and atrazine degraders than did non-rhizosphere soil (Jordahl et al. 1997).

3-3-3. Phytovolatilization

Phytovolatilization is the process where plants uptake contaminants which are water soluble and release them into the atmosphere as they transpire the water.

The contaminant may become modified along the way, as the water travels along the plant's vascular system from the roots to the leaves, whereby the contaminants evaporate or volatilize into the air surrounding the plant.

There are varying degrees of success with plants as phytovolatilizers with one study showing poplar trees to volatilize up to 90% of the TCE they absorb.

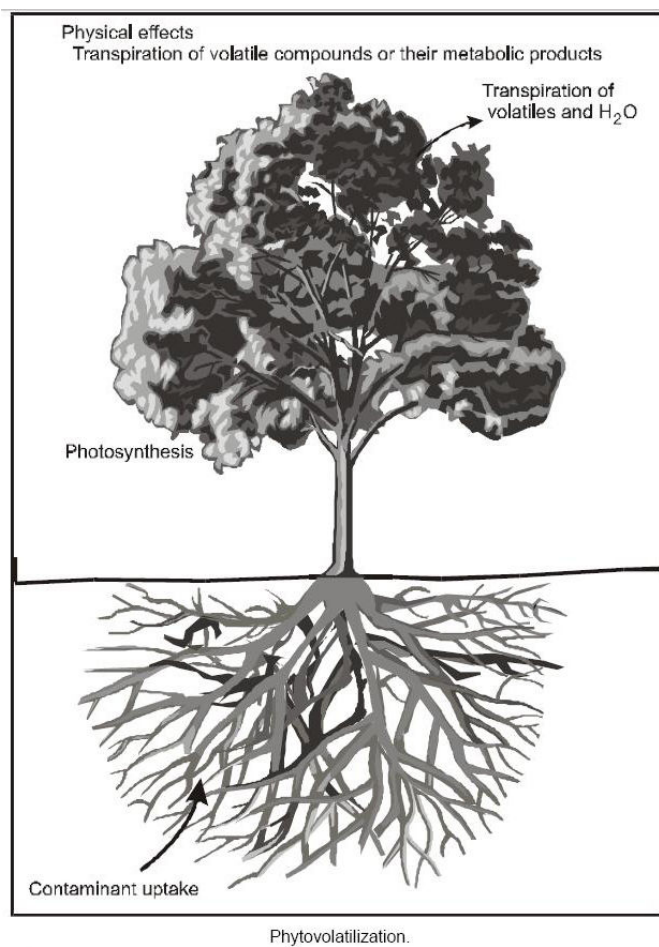


Fig. 7: Phytovolatilization

Plants used for phytovolatilization include:

University of Washington researchers have extensively studied the use of poplars in the phytoremediation of chlorinated solvents. In these studies, transformation of TCE was found to occur within the trees (Newman et al. 1997a).

Alfalfa (*Medicago sativa*) has been studied by Kansas State University researchers for its role in the phytovolatilization of TCE.

Black locust species were studied for use in remediating TCE in groundwater (Newman et al. 1997b).

Indian mustard (*Brassica juncea*) and canola (*Brassica napus*) have been used in the phytovolatilization of Se. Selenium (as selenate) was converted to less toxic dimethyl selenite gas and released to the atmosphere (Adler, 1996).

Kenaf (*Hibiscus cannabinus* L. cv. Indian) and tall fescue (*Festuca arundinacea* Schreb. cv. Alta) have also been used to take up Se, but to a lesser degree than canola (Bañuelos et al. 1997b).

A weed from the mustard family (*Arabidopsis thaliana*) genetically modified to include a gene for mercuric reductase converted mercuric salts to metallic mercury and released it to the atmosphere (Meagher and Rugh 1996).

3-4. Advantages of phytoremediation

1. It is more economically viable using the same tools and supplies as agriculture.
2. It is less disruptive to the environment and does not involve waiting for new plant communities to re colonize the site.
3. Disposal sites are not needed.
4. It is more likely to be accepted by the public as it is more aesthetically pleasing than traditional methods.
5. It avoids excavation and transport of polluted media thus reducing the risk of spreading the contamination.
6. It has the potential to treat sites polluted with more than one type of pollutant.

3-5. Disadvantages of phytoremediation

1. It is dependant on the growing conditions required by the plant (i.e. climate, geology, altitude, temperature).
2. Large scale operations require access to agricultural equipment and knowledge.
3. Success is dependant on the tolerance of the plant to the pollutant.
4. Contaminants collected in senescing tissues may be released back into the environment in autumn.
5. Contaminants may be collected in woody tissues used as fuel.
6. Time taken to remediate sites far exceeds that of other technologies.
7. Contaminant solubility may be increased leading to greater environmental damage and the possibility of leaching.
8. The low cost of phytoremediation (up to 1000 times cheaper than excavation and reburial) is the main advantage of phytoremediation, however many of the pro's and cons of phytoremediation applications depend greatly on the location of the polluted site, the contaminants in question, and the application of phytoremediation.
9. It is unknown what ecological effects hyper accumulator plants may have if ingested by animals
10. Fall out from senescing tissues in autumn may also re-enter the food chain
11. Do volatilized contaminants remain at 'safe' levels in the atmosphere
12. Exposure of the ecosystem to contaminants is prolonged as phytoremediation is a relatively slow process.

References:

- Newman, M. Ruszaj, T. Shang, B. Shurtleff, S. Stanley, S. E. Strand, X. Wang, J. Wilmoth, M. Yost, and M. PGordon. 1997b. Abstract: Phytoremediation of Trichloroethylene and Carbon Tetrachloride: Results from Bench to Field. Presentation 55. In 12th Annual Conference on Hazardous Waste Research - Abstracts Book, May 19-22, 1997, Kansas City, MO.
- Pivetz, B., R. Cochran, and S. Huling. 1997. Abstract: Phytoremediation of PCP and PAH-Contaminated Soil. Poster 54. In 12th Annual Conference on Hazardous Waste Research-Abstracts Book, May 19-22, 1997, Kansas City, MO.
- Reilley, K. A., M. K. Banks, and A. P. Schwab. 1996. Dissipation of Polycyclic Aromatic Hydrocarbons in the Rhizosphere. *J. Environ. Qual.* 25:212-219.

Selected References for Rhizodegradation:

- Anderson, T. A., and B. T. Walton. 1995. Comparative Fate of [¹⁴C]trichloroethylene in the Root Zone of Plants from a Former Solvent Disposal Site. *Environ. Toxicol. Chem.* 14:2041-2047.
- Anderson, T. A., and J. R. Coats (eds.). 1994. *Bioremediation Through Rhizosphere Technology*, ACS Symposium Series, Volume 563. American Chemical Society, Washington, DC. 249 pp.
- Aprill, W., and R. C. Sims. 1990. Evaluation of the Use of Prairie Grasses for Stimulating Polycyclic Aromatic Hydrocarbon Treatment in Soil. *Chemosphere.* 20:253-265.
- Ferro, A. M., R. C. Sims, and B. Bugbee. 1994a. Hycrest Crested Wheatgrass Accelerates the Degradation of Pentachlorophenol in Soil. *J. Environ. Qual.* 23:272-279.
- Fletcher, J. S., and R. S. Hegde. 1995. Release of Phenols by Perennial Plant Roots and their Potential Importance in Bioremediation. *Chemosphere.* 31:3009-3016.
- Schnoor, J. L., L. A. Licht, S. C. McCutcheon, N. L. Wolfe, and L. H. Carreira. 1995a. Phytoremediation of Organic and Nutrient Contaminants. *Environ. Sci. Technol.* 29:318A-323A.
- Schwab, A. P. 1998. Phytoremediation of Soils Contaminated with PAHs and Other Petroleum Compounds. Presented at: Beneficial Effects of Vegetation in Contaminated Soils Workshop, Kansas State University, Manhattan, KS.

Selected References for Phytodegradation:

- Burken, J. G., and J. L. Schnoor. 1997. Uptake and Metabolism of Atrazine by Poplar Trees. *Environ. Sci. Technol.* 31:1399-1406.
- McCutcheon, S. 1996. Phytoremediation of Organic Compounds: Science Validation and Field Testing. In W. W. Kovalick and R. Olexsey (eds.), *Workshop on Phytoremediation of Organic Wastes*, December 17-19, 1996, Ft. Worth, TX. An EPA unpublished meeting summary.
- Newman, L. A., S. E. Strand, N. Choe, J. Duffy, G. Ekuan, M. Ruszaj, B. B. Shurtleff, J. Wilmoth, P. Heilman, and M. P. Gordon. 1997a. Uptake and Biotransformation of Trichloroethylene by Hybrid Poplars. *Environ. Sci. Technol.* 31:1062-1067.
- Thompson, P. L., L. A. Ramer, and J. L. Schnoor. 1998. Uptake and Transformation of TNT by Hybrid Poplar Trees. *Environ. Sci. Technol.* 32:975-980.

Selected References for Phytovolatilization:

- Bañuelos, G. S., H. A. Ajwa, B. Mackey, L. L. Wu, C. Cook, S. Akohoue, and S. Zambruski. 1997b. Evaluation of Different Plant Species Used for Phytoremediation of High Soil Selenium. *J. Environ. Qual.* 26:639-646.
- Meagher, R. B., and C. Rugh. 1996. Abstract: Phytoremediation of Mercury Pollution Using a Modified Bacterial Mercuric Ion Reductase Gene. International Phytoremediation Conference, May 8-10, 1996, Arlington, VA. International Business Communications, Southborough, MA.
- Newman, L. A., S. E. Strand, N. Choe, J. Duffy, G. Ekuan, M. Ruszaj, B. B. Shurtleff, J. Wilmoth, P. Heilman, and M. P. Gordon. 1997a. Uptake and Biotransformation of Trichloroethylene by Hybrid Poplars. *Environ. Sci. Technol.* 31:1062-1067.