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# Phytoremediation and Bioremediation : Pioneering Technologies

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**ABSTRACT:** Phytoremediation technologies use living plants to clean up soil, air and water contaminated with hazardous contaminants.<sup>[1]</sup> It is defined as "the use of green plants and the associated microorganisms, along with proper soil amendments and agronomic techniques to either contain, remove or render toxic environmental contaminants harmless".<sup>[2]</sup> The term is an amalgam of the Greek phyto (plant) and Latin remedium (restoring balance). Although attractive for its cost, phytoremediation has not been demonstrated to redress any significant environmental challenge to the extent that contaminated space has been reclaimed. Bioremediation broadly refers to any process wherein a biological system (typically bacteria, microalgae, fungi, and plants), living or dead, is employed for removing environmental pollutants from air, water, soil, flue gasses, industrial effluents etc., in natural or artificial settings.<sup>[1]</sup> The natural ability of organisms to adsorb, accumulate, and degrade common and emerging pollutants has attracted the use of biological resources in treatment of contaminated environment.<sup>[1]</sup> In comparison to conventional physicochemical treatment methods bioremediation may offer considerable advantages as it aims to be sustainable, eco-friendly, cheap, and scalable.<sup>[1]</sup> Most bioremediation is inadvertent, involving native organisms. Research on bioremediation is heavily focused on stimulating the process by inoculation of a polluted site with organisms or supplying nutrients to promote the growth. In principle, bioremediation could be used to reduce the impact of byproducts created from anthropogenic activities, such as industrialization and agricultural processes.<sup>[2][3]</sup> Bioremediation could prove less expensive and more sustainable than other remediation alternatives.<sup>[4]</sup>

**KEYWORDS:** phytoremediation, bioremediation, ecofriendly, sustainable, environmental conataminants, native, resources

## I.INTRODUCTION

Phytoremediation is proposed as a cost-effective plant-based approach of environmental remediation that takes advantage of the ability of plants to concentrate elements and compounds from the environment and to detoxify various compounds. The concentrating effect results from the ability of certain plants called hyperaccumulators to bioaccumulate chemicals. The remediation effect is quite different. Toxic heavy metals cannot be degraded, but organic pollutants can be, and are generally the major targets for phytoremediation. Several field trials confirmed the feasibility of using plants for environmental cleanup.<sup>[3]</sup> Other methods of soil remediation are very expensive because they require a much more complicated process. The contaminated soil would need to be removed, sent to a laboratory to be cleansed of the toxic metals and then brought back to the site from which it was extracted.<sup>[4]</sup> Phytoremediation is a more cost effective solution.<sup>[5]</sup> Phytoremediation may be applied to polluted soil or static water environment. This technology has been increasingly investigated and employed at sites with soils contaminated heavy metals like with cadmium, lead, aluminum, arsenic and antimony. These metals can cause oxidative stress in plants, destroy cell membrane integrity, interfere with nutrient uptake, inhibit photosynthesis and decrease plant chlorophyll.<sup>[6]</sup>

Phytoremediation has been used successfully include the restoration of abandoned metal mine workings, and sites where polychlorinated biphenyls have been dumped during manufacture and mitigation of ongoing coal mine discharges reducing the impact of contaminants in soils, water, or air. Contaminants such as metals, pesticides, solvents, explosives,<sup>[7]</sup> and crude oil and its derivatives, have been mitigated in phytoremediation projects worldwide. Many plants such as mustard plants, alpine pennycress, hemp, and pigweed have proven to be successful at hyperaccumulating contaminants at toxic waste sites.

Not all plants are able to accumulate heavy metals or organics pollutants due to differences in the physiology of the plant.<sup>[8]</sup> Even cultivars within the same species have varying abilities to accumulate pollutants.<sup>[8]</sup>

UNICEF, power producers, bulk water suppliers and local governments are early adopters of low cost bioremediation, such as aerobic bacteria tablets which are simply dropped into water.<sup>[5]</sup>

Organic pollutants are generally more susceptible to biodegradation than heavy metals. Typical bioremediations involves oxidations. Oxidations enhance the water-solubility of organic compounds and their susceptibility to further degradation by further oxidation and hydrolysis. Ultimately biodegradation converts hydrocarbons to carbon dioxide and water.<sup>[6]</sup> For heavy metals, bioremediation offers few solutions. Metal-containing pollutant can be removed or reduced with varying bioremediation techniques.<sup>[7]</sup> The main challenge to bioremediations is rate: the processes are slow.<sup>[8]</sup>

Bioremediation techniques can be classified as (i) in situ techniques, which treats polluted sites directly, vs (ii) ex situ techniques which are applied to excavated materials.<sup>[9]</sup> In both these approaches, additional nutrients, vitamins, minerals, and pH buffers are added to enhance the growth and metabolism of the microorganisms. In some cases, specialized microbial cultures are added (biostimulation). Some examples of bioremediation related technologies are phytoremediation, bioventing, bioattenuation, biosparging, composting (biopiles and windrows), and landfarming. Other remediation techniques include thermal desorption, vitrification, air stripping, bioleaching, rhizofiltration, and soil washing. Biological treatment, bioremediation, is a similar approach used to treat wastes including wastewater, industrial waste and solid waste. The end goal of bioremediation is to remove or reduce harmful compounds to improve soil and water quality.<sup>[10]</sup>

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## II.DISCUSSION

- Advantages:
  - the cost of the phytoremediation is lower than that of traditional processes<sup>[which?]</sup> both in situ and ex situ
  - the possibility of the recovery and re-use of valuable metals (by companies specializing in "phyto mining")
  - it preserves the topsoil, maintaining the fertility of the soil<sup>[9]</sup>
  - Increase soil health, yield, and plant phytochemicals<sup>[10]</sup>
  - the use of plants also reduces erosion and metal leaching in the soil<sup>[9]</sup>
- Limitations:
  - phytoremediation is limited to the surface area and depth occupied by the roots.

- with plant-based systems of remediation, it is not possible to completely prevent the leaching of contaminants into the groundwater (without the complete removal of the contaminated ground, which in itself does not resolve the problem of contamination)
- the survival of the plants is affected by the toxicity of the contaminated land and the general condition of the soil
- bio-accumulation of contaminants, especially metals, into the plants can affect consumer products like food and cosmetics, and requires the safe disposal of the affected plant material
- when taking up heavy metals, sometimes the metal is bound to the soil organic matter, which makes it unavailable for the plant to extract

Phytoextraction (or phytoaccumulation or phytosequestration) exploits the ability of plants or algae to remove contaminants from soil or water into harvestable plant biomass. It is also used for the mining of metals such as copper(II) compounds. The roots take up substances from the soil or water and concentrate them above ground in the plant biomass.<sup>[9]</sup> Organisms that can uptake high amounts of contaminants are called hyperaccumulators.<sup>[12]</sup> Phytoextraction can also be performed by plants (e.g. *Populus* and *Salix*) that take up lower levels of pollutants, but due to their high growth rate and biomass production, may remove a considerable amount of contaminants from the soil.<sup>[13]</sup> Phytoextraction has been growing rapidly in popularity worldwide for the last twenty years or so. Typically, phytoextraction is used for heavy metals or other inorganics.<sup>[14]</sup> At the time of disposal, contaminants are typically concentrated in the much smaller volume of the plant matter than in the initially contaminated soil or sediment. After harvest, a lower level of the contaminant will remain in the soil, so the growth/harvest cycle must usually be repeated through several crops to achieve a significant cleanup. After the process, the soil is remediated

Bioventing is a process that increases the oxygen or air flow into the unsaturated zone of the soil, this in turn increases the rate of natural in situ degradation of the targeted hydrocarbon contaminant.<sup>[12]</sup> Bioventing, an aerobic bioremediation, is the most common form of oxidative bioremediation process where oxygen is provided as the electron acceptor for oxidation of petroleum, polyaromatic hydrocarbons (PAHs), phenols, and other reduced pollutants. Oxygen is generally the preferred electron acceptor because of the higher energy yield and because oxygen is required for some enzyme systems to initiate the degradation process.<sup>[8]</sup> Microorganisms can degrade a wide variety of hydrocarbons, including components of gasoline, kerosene, diesel, and jet fuel. Under ideal aerobic conditions, the biodegradation rates of the low- to moderate-weight aliphatic, alicyclic, and aromatic compounds can be very high. As molecular weight of the compound increases, the resistance to biodegradation increases simultaneously.<sup>[8]</sup> This results in higher contaminated volatile compounds due to their high molecular weight and an increased difficulty to remove from the environment.

Most bioremediation processes involve oxidation-reduction reactions where either an electron acceptor (commonly oxygen) is added to stimulate oxidation of a reduced pollutant (e.g. hydrocarbons) or an electron donor (commonly an organic substrate) is added to reduce oxidized pollutants (nitrate, perchlorate, oxidized metals, chlorinated solvents, explosives and propellants).<sup>[6]</sup> In both these approaches, additional nutrients, vitamins, minerals, and pH buffers may be added to optimize conditions for the microorganisms. In some cases, specialized microbial cultures are added (bioaugmentation) to further enhance biodegradation.

Approaches for oxygen addition below the water table include recirculating aerated water through the treatment zone, addition of pure oxygen or peroxides, and air sparging.<sup>[13]</sup> Recirculation systems typically consist of a combination of injection wells or galleries and one or more recovery wells where the extracted groundwater is treated, oxygenated, amended with nutrients and re-injected.<sup>[14]</sup> However, the amount of oxygen that can be provided by this method is limited by the low solubility of oxygen in water (8 to 10 mg/L for water in equilibrium with air at typical temperatures). Greater amounts of oxygen can be provided by contacting the water with pure oxygen or addition of hydrogen peroxide ( $H_2O_2$ ) to the water. In some cases, slurries of solid calcium or magnesium peroxide are injected under pressure through soil borings. These solid peroxides react with water releasing  $H_2O_2$  which then decomposes releasing oxygen. Air sparging involves the injection of air under pressure below the water table. The air injection pressure must be great enough to overcome the hydrostatic pressure of the water and resistance to air flow through the soil.<sup>[13][14]</sup>

Of course many pollutants kill plants, so phytoremediation is not a panacea. For example, chromium is toxic to most higher plants at concentrations above  $100 \mu M \cdot kg^{-1}$  dry weight.<sup>[15]</sup>

Mining of these extracted metals through phytomining is a conceivable way of recovering the material.<sup>[16]</sup> Hyperaccumulating plants are often metallophyte. Induced or assisted phytoextraction is a process where a conditioning fluid containing a chelator or another agent is added to soil to increase metal solubility or mobilization so that the plants can absorb them more easily.<sup>[17]</sup> While such additives can increase metal uptake by plants, they can also lead to large amounts of available metals in the soil beyond what the plants are able to translocate, causing potential leaching into the subsoil or groundwater.<sup>[17]</sup>

Examples of plants that are known to accumulate the following contaminants:

- Arsenic, using the sunflower (*Helianthus annuus*),<sup>[18]</sup> or the Chinese Brake fern (*Pteris vittata*).<sup>[19]</sup>
- Cadmium, using willow (*Salix viminalis*): In 1999, one research experiment performed by Maria Greger and Tommy Landberg suggested willow has a significant potential as a phytoextractor of cadmium (Cd), zinc (Zn), and copper (Cu), as willow has some specific characteristics like high transport capacity of heavy metals from root to shoot and huge amount of biomass production; can be used also for production of bio energy in the biomass energy power plant.<sup>[20]</sup>
- Cadmium and zinc, using alpine pennycress (*Thlaspi caerulescens*), a hyperaccumulator of these metals at levels that would be toxic to many plants. Specifically, pennycress leaves accumulate up to 380 mg/kg Cd.<sup>[21]</sup> On the other hand, the presence of copper seems to impair its growth
- Chromium is toxic to most plants.<sup>[15]</sup> However, tomatoes (*Solanum lycopersicum*) show some promise.<sup>[22]</sup>
- Lead, using Indian mustard (*Brassica juncea*), ragweed (*Ambrosia artemisiifolia*), hemp dogbane (*Apocynum cannabinum*), or poplar trees, which sequester lead in their biomass.
- Salt-tolerant (moderately halophytic) barley and/or sugar beets are commonly used for the extraction of sodium chloride (common salt) to reclaim fields that were previously flooded by sea water.
- Caesium-137 and strontium-90 were removed from a pond using sunflowers after the Chernobyl accident.<sup>[23]</sup>
- Mercury, selenium and organic pollutants such as polychlorinated biphenyls (PCBs) have been removed from soils by transgenic plants containing genes for bacterial enzymes.<sup>[24]</sup>
- Thallium is sequestered by some plants.<sup>[25]</sup>

### III.RESULTS

Phytostabilization reduces the mobility of substances in the environment, for example, by limiting the leaching of substances from the soil.<sup>[8]</sup> It focuses on the long term stabilization and containment of the pollutant. The plant immobilizes the pollutants by binding them to soil particles making them less available for plant or human uptake. Unlike phytoextraction, phytostabilization focuses mainly on sequestering pollutants in soil near the roots but not in plant tissues. Pollutants become less bioavailable, resulting in reduced exposure. The plants can also excrete a substance that produces a chemical reaction, converting the heavy metal pollutant into a less toxic form.<sup>[9]</sup> Stabilization results in reduced erosion, runoff, leaching, in addition to reducing the bioavailability of the contaminant.<sup>[14]</sup> An example application of phytostabilization is using a vegetative cap to stabilize and contain mine tailings.<sup>[26]</sup> Some soil amendments decrease radiocesium mobility – while at some concentrations the same amendments will increase mobility.<sup>[27][28]</sup> Vidal et al. 2000 find the root mats of meadow grasses are effective at demobilising radiocesium materials especially with certain combinations of other agricultural practices.<sup>[27][28]</sup> Vidal also find that the particular grass mix makes a significant difference.<sup>[27][28]</sup> As plants are able to translocate and accumulate particular types of contaminants, plants can be used as biosensors of subsurface contamination, thereby allowing investigators to quickly delineate contaminant plumes.<sup>[45][46]</sup> Chlorinated solvents, such as trichloroethylene, have been observed in tree trunks at concentrations related to groundwater concentrations.<sup>[47]</sup> To ease field implementation of phytoscreening, standard methods have been developed to extract a section of the tree trunk for later laboratory analysis, often by using an increment borer.<sup>[48]</sup> Phytoscreening may lead to more optimized site investigations and reduce contaminated site cleanup costs. Bioremediation can be carried out by bacteria that are naturally present. In biostimulation, the population of these helpful bacteria can be increased by adding nutrients.<sup>[7][16]</sup>

Bacteria can in principle be used to degrade hydrocarbons.<sup>[17][18]</sup> Specific to marine oil spills, nitrogen and phosphorus have been key nutrients in biodegradation.<sup>[19]</sup> The bioremediation of hydrocarbons suffers from low rates.

Bioremediation can involve the action of microbial consortium. Within the consortium, the product of one species could be the substrate for another species.<sup>[20]</sup>

Anaerobic bioremediation can in principle be employed to treat a range of oxidized contaminants including chlorinated ethylenes (PCE, TCE, DCE, VC), chlorinated ethanes (TCA, DCA), chloromethanes (CT, CF), chlorinated cyclic hydrocarbons, various energetics (e.g., perchlorate,<sup>[21]</sup> RDX, TNT), and nitrate.<sup>[7]</sup> This process involves the addition of an electron donor to: 1) deplete background electron acceptors including oxygen, nitrate, oxidized iron and manganese and sulfate; and 2) stimulate the biological and/or chemical reduction of the oxidized pollutants. Hexavalent chromium (Cr[VI]) and uranium (U[VI]) can be reduced to less mobile and/or less toxic forms (e.g., Cr[III], U[IV]). Similarly, reduction of sulfate to sulfide (sulfidogenesis) can be used to precipitate certain metals (e.g., zinc, cadmium). The choice of substrate and the method of injection depend on the contaminant type and distribution in the aquifer, hydrogeology, and remediation objectives. Substrate can be added using conventional well installations, by direct-push technology, or by excavation and backfill such as permeable reactive barriers (PRB) or biowalls.<sup>[22]</sup> Slow-release products composed of edible oils or solid substrates tend to stay in place for an extended treatment period. Soluble substrates or soluble fermentation products of slow-release substrates can potentially migrate via advection and diffusion, providing broader but shorter-lived treatment zones. The added organic substrates are first fermented to hydrogen (H<sub>2</sub>) and volatile fatty acids (VFAs). The VFAs, including acetate, lactate, propionate and butyrate, provide carbon and energy for bacterial metabolism.<sup>[7][6]</sup>

Heavy metals become present in the environment due to anthropogenic activities or natural factors.<sup>[7]</sup> Anthropogenic activities include industrial emissions, electronic waste, and ore mining. Natural factors include mineral weathering, soil erosion, and forest fires.<sup>[7]</sup> Heavy metals including cadmium, chromium, lead and uranium are unlike organic compounds and cannot be biodegraded. However, bioremediation processes can potentially be used to reduce the mobility of these material in the subsurface, reducing the potential for human and environmental exposure.<sup>[31]</sup> Heavy metals from these factors are predominantly present in water sources due to runoff where it is uptake by marine fauna and flora.<sup>[7]</sup>

The mobility of certain metals including chromium (Cr) and uranium (U) varies depending on the oxidation state of the material.<sup>[32]</sup> Microorganisms can be used to reduce the toxicity and mobility of chromium by reducing hexavalent chromium, Cr(VI) to trivalent Cr (III).<sup>[33]</sup> Uranium can be reduced from the more mobile U(VI) oxidation state to the less mobile U(IV) oxidation state.<sup>[34][35]</sup> Microorganisms are used in this process because the reduction rate of these metals is often slow unless catalyzed by microbial interactions.<sup>[36]</sup> Research is also underway to develop methods to remove metals from water by enhancing the sorption of the metal to cell walls.<sup>[36]</sup> This approach has been evaluated for treatment of cadmium,<sup>[37]</sup> chromium,<sup>[38]</sup> and lead.<sup>[39]</sup> Genetically modified bacteria has also been explored for use in sequestration of Arsenic.<sup>[40]</sup> Phytoextraction processes concentrate contaminants in the biomass for subsequent removal.

#### IV. CONCLUSIONS

Bioremediation can be used to completely mineralize organic pollutants, to partially transform the pollutants, or alter their mobility. Heavy metals and radionuclides are elements that cannot be biodegraded, but can be bio-transformed to less mobile forms.<sup>[41][42][43]</sup> In some cases, microbes do not fully mineralize the pollutant, potentially producing a more toxic compound.<sup>[43]</sup> For example, under anaerobic conditions, the reductive dehalogenation of TCE may produce dichloroethylene (DCE) and vinyl chloride (VC), which are suspected or known carcinogens.<sup>[41]</sup> However, the microorganism Dehalococcoides can further reduce DCE and VC to the non-toxic product ethene.<sup>[44]</sup> The molecular pathways for bioremediation are of considerable interest.<sup>[41]</sup> In addition, knowing these pathways will help develop new technologies that can deal with sites that have uneven distributions of a mixture of contaminants.<sup>[24]</sup>

Biodegradation requires microbial population with the metabolic capacity to degrade the pollutant.<sup>[24][42]</sup> The biological processes used by these microbes are highly specific, therefore, many environmental factors must be taken into account and regulated as well.<sup>[24][41]</sup> It can be difficult to extrapolate the results from the small-scale test studies into big field operations.<sup>[24]</sup> In many cases, bioremediation takes more time than other alternatives such as land filling and incineration.<sup>[24][41]</sup> Another example is bioventing, which is inexpensive to bioremediate contaminated sites, however, this process is extensive and can take a few years to decontaminate a site.<sup>[45]></sup>

In agricultural industries, the use of pesticides is a top factor in direct soil contamination and runoff water contamination. The limitation or remediation of pesticides is the low bioavailability.<sup>[46]</sup> Altering the pH and temperature of the contaminated soil is a resolution to increase bioavailability which, in turn, increased degradation of harmful compounds.<sup>[46]</sup>

The compound acrylonitrile is commonly produced in industrial setting but adversely contaminates soils. Microorganisms containing nitrile hydratases (NHase) degraded harmful acrylonitrile compounds into non-polluting substances.<sup>[47]</sup>

Since the experience with harmful contaminants are limited, laboratory practices are required to evaluate effectiveness, treatment designs, and estimate treatment times.<sup>[45]</sup> Bioremediation processes may take several months to several years depending on the size of the contaminated area.<sup>[48]</sup>

The use of genetic engineering to create organisms specifically designed for bioremediation is under preliminary research.<sup>[49]</sup> Two category of genes can be inserted in the organism: degradative genes, which encode proteins required for the degradation of pollutants, and reporter genes, which encode proteins able to monitor pollution levels.<sup>[50]</sup> Numerous members of *Pseudomonas* have been modified with the lux gene for the detection of the polyaromatic hydrocarbon naphthalene. A field test for the release of the modified organism has been successful on a moderately large scale.<sup>[51]</sup>

There are concerns surrounding release and containment of genetically modified organisms into the environment due to the potential of horizontal gene transfer.<sup>[52]</sup> Genetically modified organisms are classified and controlled under the Toxic Substances Control Act of 1976 under United States Environmental Protection Agency.<sup>[53]</sup> Measures have been created to address these concerns. Organisms can be modified such that they can only survive and grow under specific sets of environmental conditions.<sup>[52]</sup> In addition, the tracking of modified organisms can be made easier with the insertion of bioluminescence genes for visual identification.<sup>[54]</sup>

Genetically modified organisms have been created to treat oil spills and break down certain plastics (PET).<sup>[55]</sup>

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