Phytoremediation Information Handbook

The Capacity of Houston Wilderness Super Trees to Remediate Houston Soil and Air

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HOUSTON WILDERNESS
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Native Tree & Soil Phytoremediation & Expansion of Native *Super Trees* in Gulf-Houston Region for Improved Ecosystem Services[1]

The Importance of AM & EM Fungi in soil content – particularly around native trees:

Phytoremediation is an ecosystem restoration approach to contaminant (heavy metals/toxins) remediation, which involves the use of trees/plants to extract and remove elemental pollutants or lower their bioavailability in soil.[2] Woody tree species may play a crucial role in the removal of heavy metals from soil and air, thus minimizing pollution potential.[3] Following COP26[4], this year marks the beginning of the United Nation (UN) decade on ecosystem restoration where incentives are being put in place to restore degraded ecosystems, in part through afforestation/reforestation (A/R), to reduce anthropogenic CO_2 emissions, increase carbon sequestration and improve sustainability in all sectors, as reflected globally in the UN's 17 Sustainable Development Goals. Public/private organizations around the Gulf-Houston Region are engaging in large-scale A/R efforts and have been to varying degrees since 2003.[5] One critical ES is the relationship between trees and soil microbes, particularly mycorrhizal fungi, which benefits trees by helping them tolerate drought stress, heavy metals, and pathogens, via both nutritional and direct effects.[6] Adding organic chelating agents such as M. Fungi and/or bacteria spores to newly planted trees can be used to both increase heavy metal bioavailability, which facilitates heavy metal accumulation in the trees and improve soil health and further promote plant growth and fitness.[7] HW adds M. Fungi spores to its large-scale Super Tree plantings – see one-page information sheet attached. Not all the Super Trees species have research on their specific metals/toxins absorption rates, but we know that some of them do and with significant results -see Super Tree Phytoremediation Two Pager. For example, River Birch tree species are known to remediate soil contaminated with PFAs compounds. PFAs are a group of synthetic compounds widely used in manufacturing that break down slowly in the environment. Exposure to PFAs can lead to adverse health effects including cancer, ulcerative colitis, and hypothyroidism. In a study performed by scientists at the University of Georgia, River Birch was shown to hyperaccumulate five PFAs compounds, meaning the concentration of each compound in River Birch leaves was more than ten times the concentration in surrounding soil. This process of phytoaccumulation prevents PFAs compounds from spreading throughout the environment and possibly posing a risk to human health.[8]

Similarities and Differences between AM & EM Fungi:

Today, most tree species require an association with at least one of the two types of M. Fungi to adequately grow and complete their life cycle in natural ecosystems – 1) Arbuscular Mycorrhizal (AM) is the most common (Smith & Read, **2008**) - entering into mutually beneficial symbioses with about 80% of all land plant/tree species (Tedersoo et al, 2020) through the root systems of the plants/trees, and 2) Ectomycorrhizal (EM) Fungi which enter mutually beneficial symbioses with about 60% of trees on Earth attaching to the plant/tree outside the roots (Anthony et al, 2021)(See Figure 2). While double symbioses with both AM and EM (called "Dual Mycorrhization") have been documented for some time (Allen et al., **1999**; Frioni et al., **1999**; Read & Haselwandter, **1981**), it was recently discovered that many tree species are associated with *both* AM and EM, either simultaneously within the same root system or at different life stages or in different environments. In their review on trees that are associated both with AM and EM, Teste et al., (**2020**) counted 238 plant species with dual mycorrhization, belonging to 89 plant/tree genera and 32 families resulting in greater survival, growth, or nutrient uptake, compared with the single-type states.

Tree Species	Mycorrhizal Fungi Relationship (AM or EM)
Live Oak	AM/EM
Black Cherry	AM
River Birch	AM/EM
Box Elder	AM
Laurel Oak	AM/EM
Water Oak	AM/EM
Red Maple	AM
Willow Oak	AM/EM
Sweetgum	AM
Slippery Elm	AM
American Elm	AM
Tulip Tree	AM
American Sycamore	AM
Green Ash	AM/EM
Loblolly Pine	AM/EM
White Ash	AM/EM
Black Walnut	AM+EM

The two mycorrhizal types differ in nutrient acquisition strategies. Uptake of mineral nutrients from soil by AM hyphae has been characterized as 'scavenging', which was defined by Lambers *et al*. (**2008**) as physical exploration and uptake of nutrients without changing their chemical form. By contrast, EM fungi are generally considered capable of also 'mining' nutrients, defined as releasing otherwise unavailable nutrients by excreting enzymes or low molecular weight organic acids (Plassard & Dell, **2010**). This raises the possibility that AM and EM colonization result in complementarity of nutrient acquisition. Based on the rankings of all the native trees in the Greater Gulf-Houston Region,

[1] August 2023
[2] Berti and Cunningham, 2000. "Phytostabilization of metals," in Phytoremediation of Toxic Metals: Using Plants to Clean-up the Environment, eds I. Raskin and B. D. Ensley (New York, NY: John Wiley & Sons, Inc.), 71–88
[3] Shafeeq Ur Rahman, et al, Evaluation of heavy metal phytoremediation potential of six tree species of Faisalabad city of Pakistan during summer and winter seasons, Journal of Environmental Management, 2022, ISSN 0301-4797, https://doi.org/10.1016/j.jenvman.2022.115801
[4] UN Decade on Ecosystem Restoration, IPCC, 2021
[5] https://houstonwilderness.org/46-million-trees-by-2030-goal
[6] Alaux et al., 2021 and Smith & Read, 2008
[7] Yan, An, et al, 2020. Phytoremediation: A Promising Approach for Revegetation of Heavy Metal-Polluted Land, Frontiers Plant Science, https://doi.org/10.3389/fpls.2020.00359; Heklau, et al, February 2021; see also https://www.weforum.org/agenda/2021/09/inoculated-trees-contaminated-land-climate-change/
[8] Huff, David K, et al. 2020. "Accumulation of Six PFAS Compounds by Woody and Herbaceous Plants: Potential for Phytoextraction." International Journal of Phytoremediation 22 (14): 1538–50. https://doi.org/10.1080/15226514.2020.1786004.

the top 14 native Super Trees are now targeted by HW and its partners for large-scale plantings along riparian corridors as part of the *Houston Ship Channel TREES* program, and the *Riverine TUBs* program, among other regional programs.[9] These 14 native *Super Tree* species are ranked in priority based on their respective levels of GHG absorption as well as water absorption and carbon sequestration and provide a multitude of other ecosystem services – including increased water quality, erosion control, phytoremediation and habitat enhancement.[10]

FAQs re: Phytoremediation for various heavy metals/toxins in our region:

A: What types of toxins do EM/AM Fungi and large-scale native tree plantings breakdown? See Research on Specific Metals attached.

B: What is the timing for how long it takes EM/AM Fungi to breakdown toxins? Does the type of toxin make a difference in time to breakdown? Yes, the length of time depends on the type of number of tree species planted and the level toxins contained in the soil, but research does show that phytoremediation can start as soon as the tree species are planted.

C: Provide a corporate example where phytoremediation is occurring (Kinder Morgan's **Hartford Street Terminal in Tampa, Florida** example in Wildlife Habitat Council 2022 white paper) - how are they proving that the toxin reduction is effective?

D: Published case studies - show extent that this work is occurring – a good example is the 20,000 Poplar and Willow trees planted in 16 phytoremediation sites in the Lake Michigan and Lake Superior watersheds and found that planting Poplar trees was successful for reducing runoff, cleaning groundwater, and delivering ecosystem services to the Great Lakes and globally[11](other examples cited in this document).

E: Would it be possible to move native "Super Trees" from one location to another to "clean up" toxins from the soil via EM/AM Fungi relationship with the trees? Research shows that it is preferable to plant and leave them to continue to serve the various ES roles.

Additional benefits of adding EM & AM Fungi to HW's large-scale Super Tree plantings include:

(1) Density - Establishment of different *Super Tree* species in dense tree plantings increases fungal diversity as different tree species are associated with a characteristic fungal community (Unterseher et al, 2008) – See Figure 1.

(2) Secondary forests – M. Fungi plays a key role in soil biodiversity conservation, climate change mitigation and landscape restoration – See Figure 2.

(3) Balancing Carbon Footprint Impacts – Recognizing that HW and its partners emit some carbon in preparing for and planting thousands of native trees, use of M. Fungi spores as an organic chelating agent, organic topsoil and mulch provide an opportunity to offset the GHG emissions associated with establishing large scale tree plantings[12]

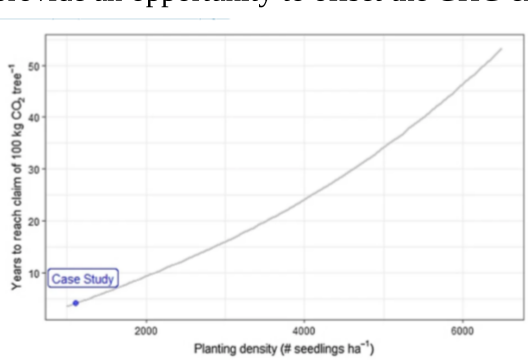


Figure 1: Effect of the planting density on the plot-scale carbon capture rate. No manual thinning and 100% seedling transplant survival are assumed. The blue dot represents the planting of 1111 seedling ha-7 (where the model reached 100kg CO2 captured per tree 4.1 years after planting. (Lefebvre et al, 2021)

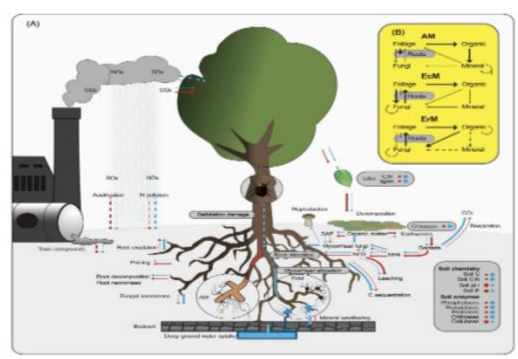


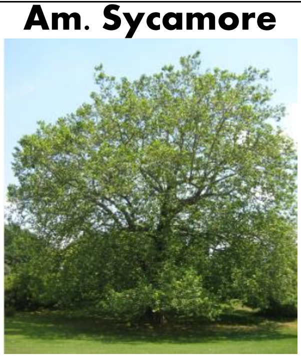
Figure 2: Conceptual scheme of mycorrhizal type effects and response to ecosystem processes: (A) overall effects; (B) simplified model of C allocation and nutrient acquisition. In A, red and blue lines indicate arbuscular mycorrhizal (AM) and ectomycorrhizal (EcM) effects respectively; dashed lines indicate negative effects; line width indicates relative effect strength. SAP, saprotroph. In B, line width indicates relative effect strength. (Tedersoo & Bahram 2019)

[9] See Tree Strategy Implementation Group and 4.6 Million Trees by 2030 Goal - https://houstonwilderness.org/46-million-trees-by-2030-goal
[10] https://houstonwilderness.org/resources-for-native-super-trees-and-hsc-trees-program
[11] Zalesny, Ronald, et al 2021. Establishment of Regional Phytoremediation Buffer Systems for Ecological Restoration in the Great Lakes Basin, USA. https://www.mdpi.com/1999-4907/12/4/430
[12] The carbon footprint for HW's large-scale native Super Tree plantings includes processes from: a) the receipt of the seeds, seedings and/or 5-gallon trees by the tree farms, b) the development into seedlings and transport by HW or tree farmer to the planting site(s), c) receipt of and transportation of M. Fungi supplements and mulch (potential for biochar also) to the planting site(s), d) HW field work necessary before and/or at the time of transplant and for the maintenance, if any, of the seedlings/5-gallon trees up to one year after planting, and e) the transportation of volunteers to the planting site(s).

Super Tree Phytoremediation Chart

*The information in this table represents the known studies done on the remedial abilities of super tree species. If a tree species is not listed, this does not mean that this species cannot perform phytoremediation. Additionally, a tree listed may remediate additional contaminants. As phytoremediation is an emerging field, many plant species have not been studied, and the research that has been done often only measures specific contaminants.**

Tree Species	Contaminant(s)	Explanation
Live Oak 	• Copper (Cu) • Cadmium (Cd) • Zinc (Zn)	Live Oak (Quercus virginiana) shows a high tolerance for HM contaminated soils and an ability to uptake significant amounts of Cu, Zn, and Cd. After Live Oak seedlings were grown for 150 days in soil contaminated with high levels of Cu, Zn, and Cd, Live Oak showed no visible symptoms of metal-stress and biomass only decreased slightly from the control. The seedlings also contained moderate amounts of Zn in its shoots and Cu/Cd in its roots.[1]
Willow Oak 	• Copper (Cu) • Cadmium (Cd) • Zinc (Zn)	The same study that tested Live Oak also concludes that Willow Oak (Quercus phellos) is suitable for phytoremediation in HM contaminated soil. Willow Oak also uptakes moderate amounts of Cd/Cu in its root system and extracts moderate amounts of Zn to its shoots. Additionally, among the six Quercus species tested, Willow Oak had the highest biomass production in the HM contaminated soil after 150 days.[1]
Laurel Oak 	• Tritium (^3H), radioactive isotope of hydrogen	Laurel Oak (Quercus laurifolia) is known to perform phytoremediation in environments contaminated with Tritium. Laurel Oak removes Tritium from the environment by uptaking Tritium from the soil and releasing it into the atmosphere via evapotranspiration. Laurel Oak, along with other tree species like Loblolly Pine, was used at The Tritium Irrigation Project to lower the concentration of Tritium at the Fourmile Branch Creek. Scientists confirmed the presence of Tritium in water transpired from Laurel Oak leaves, and Tritium activity in the Fourmile Creek decreased from 500 pCi/mL to 100 pCi/mL over a one-year period.[2]
Loblolly Pine 	• Tritium (^3H) • Benzene (C_6H_6) • Chlorobenzene (C_6H_5Cl)	Loblolly Pine (Pinus taeda) is known to perform phytoremediation in soils contaminated with Tritium, benzene, and chlorobenzene. Firstly, along with Laurel Oak, Loblolly Pine was used at The Tritium Irrigation Project to lower the concentration of Tritium in the Fourmile Branch Creek. Scientists at the Savannah River National Laboratory measured Tritium in water transpired from Loblolly Pine needles at concentrations even higher than Laurel Oak leaves.[2] Additionally, scientists from the University of Georgia grew Loblolly Pines in soil contaminated with benzene and chlorobenzene. Loblolly Pines exhibited a high tolerance to the contaminants and utilized evapotranspiration and rhizodegradation to remove both contaminants from the soil at more than double the rate of unplanted controls.[3]
Water Oak 	• Cadmium (Cd) • Zinc (Zn)	Water Oak (Quercus nigra) exhibits a high survival rate in HM contaminated soil and an ability to uptake intermediate amounts of Zn and Cd. Scientists in China grew ten species of oak in an industrial field contaminated with high levels of Zn and Cd. At the end of the two-year growth period, Water Oak exhibited intermediate absorption for Zn and Cd in root tissue. The authors of the study recommend Water Oak for heavy metal remediation along with Faber's Oak and Cherrybark Oak.[4]

Red Maple 	• **Variety of HMs (inc. Pb, Zn, & Cd)**	**Red Maple (Acer rubrum) adapts to the stressors present in urban environments by uptaking HMs and transporting them to leaves. At the University of Delaware, scientists determined that Red Maples growing in Philadelphia adapted to high concentrations of HMs, like Pb, Zn, Cd, in soil by uptaking them into foliar tissue. Additionally, the scientists observed higher concentrations of amino acids that help to limit the damaging effects of HMs in Red Maples grown in more contaminated soils.[5]**
Green Ash 	• **Particulate Matter (PM)** • **Polycyclic Aromatic Hydrocarbons (PAHs)**	**Although all trees can sequester some particulate matter via leaves, Green Ash (Fraxinus pennsylvanica) trees can sequester notably high levels of PM. Scientists from Warsaw University tested the ability of 13 woody plant species to collect PM on leaves and within leaf wax. Overall, Green Ash trees had the third most total PM accumulated on average over three years. Green Ash trees were also shown to accumulate the highest amount of fine PM (0.2–2.5 um) because of tiny hairs on the abaxial side of leaves, which can trap small particles. This is particularly important since fine PM represents the greatest threat to human health.[6] Additionally, a research team from Indiana grew green ash saplings in soil cores taken from a gas extraction plant dumping ground. These soil cores were contaminated with multiple PAHs, a toxic bioproduct of fossil fuel extraction. The scientists found that green ash trees supported the growth of microbial communities in the rhizosphere that degraded five out of the six PAHs tested at a higher rate than control.[8]**
River Birch 	• **PFAS (inc. PFPeA, PFHxA, PFHxS, PFOA, & PFOS)**	**River Birch (Betula nigra) can uptake high amounts of a large range of PFAS compounds. When scientists grew six tree species in soil contaminated with six PFAS compounds known to negatively affect human health, River Birch showed the greatest potential to accumulate a wide range of PFAS compounds. River Birch could hyperaccumulate five of the six compounds (PFPeA, PFHxA, PFHxS, PFOA, and PFOS), meaning the contaminant concentration was more than 10 times higher in foliar tissue than soil. Incredibly, the BCF (bioconcentration factor) was 141.5 for PFPeA and 75.9 for PFHxA.[7]**
Tulip Poplar 	• **PFAS (inc. PFBS & PFPeA)**	**Tulip Poplar (Liriodendron tulipfera) exhibits potential to uptake PFAS at a high rate. In the same study that tested River Birch, Tulip Poplar had the highest BCF value for any of the PFAS compounds tested with 176 for PFPeA. While River Birch struggled to uptake high amounts of PFBS, Tulip Poplar recovered 20% of the compound compared to 2% with River Birch. These results demonstrate that a diverse selection of tree species is paramount when remediating soil contaminated with a variety of contaminants.[7]**
Am. Sycamore 	• **PFAS (inc. PFPeA & PFHxA)**	**American Sycamore (Platanus occidentalis) trees can both uptake high amounts of PFAS and produce biomass faster than many other tree species, making it a good candidate for PFAS remediation. Although the BCF for many of the PFAs compounds is lower in American Sycamore, with PFPeA at 90.4 and PFHxA at 35.6, than for example River Birch, the amount of mass recovered for each contaminant is comparable with River Birch. For PFPeA, American Sycamore is even higher than River Birch, with 33.1% recovered when compared to 31.9% with River Birch. These results demonstrate that biomass production is an important factor to consider when choosing a plant for phytoremediation.[7]**

References

1) Cao, Yini, Liangqian Yu, Ning Dang, Lixiang Sun, Pingxuan Zhang, Guangcai Chen, and Jiwu Cao. “Dendroremediation Potential of Six Quercus Species to Polluted Soil In ...” Research Gate, December 29, 2022. https://www.researchgate.net/publication/366668998_Dendroremediation_Potential_of_Six_Quercus_Species_to_Polluted_Soil_in_Historic_Copper_Mining_Sites.

2) Bringmon, Robin, Kenneth W Mcleod, Eric Doman, and John C Seaman. “The Impact of Tritium Phytoremediation on Plant Health as Measured By ...” Research Gate, December 2022. https://www.researchgate.net/publication/363725684_The_impact_of_tritium_phytoremediation_on_plant_health_as_measured_by_fluorescence

3) Morris, Lawrence A, Valentine A Nzengung, Tiango Moura, Nehru Mantripragada, and Aaron Thompson. “Eucalyptus Urograndis and Pinus Taeda Enhance Removal of Chlorobenzene ...” Research Gate, May 2016. https://www.researchgate.net/publication/302592372_Eucalyptus_urograndis_and_Pinus_taeda_Enhance_Removal_of_Chlorobenzene_and_Benzene_in_Sand_Culture_A_Greenhouse_Study.

4) Li, Xiaogang, Jiang Xiao, Mir Md Abdus Salam, and Guangcai Chen. “Evaluation of Dendroremediation Potential of Ten Quercus Spp. for Heavy Metals Contaminated Soil: A Three-Year Field Trial.” Science Direct, December 10, 2022. https://www.sciencedirect.com/science/article/abs/pii/S0048969722053311?via%3Dihub.

5) McDermot, Covel R, Rakesh Minocha, Vince D’Amico, Stephanie Long, and Tara L E Trammell. “Red Maple (Acer Rubrum L.) Trees Demonstrate Acclimation to Urban Conditions in Deciduous Forests Embedded in Cities.” Edited by Mai-He Li. U.S. National Library of Medicine, July 24, 2020. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7380610/ https://www.nature.com/articles/s41598-017-13893-0.

6) Popek, Robert, Helena Gawronska, Mariola Wrochna, Stanislaw Gawronski, and Arne Saebo. “Particulate Matter on Foliage of 13 Woody Species: Deposition On ...” Research Gate, March 2013. https://www.researchgate.net/publication/236044052_Particulate_Matter_on_Foliage_of_13_Woody_Species_Deposition_on_Surfaces_and_Phytostabilisation_in_Waxes_-_a_3-Year_Study.

7) Huff, David K., Lawrence A. Morris, Lori Sutter, Jed Costanza, and Kurt D. Pennell. 2020. “Accumulation of Six PFAS Compounds by Woody and Herbaceous Plants: Potential for Phytoextraction.” International Journal of Phytoremediation 22 (14): 1538–50. https://doi.org/10.1080/15226514.2020.1786004.

8) Spriggs, Thomas, M. Katherine Banks, and Paul Schwab. 2005. “Phytoremediation of Polycyclic Aromatic Hydrocarbons in Manufactured Gas Plant-Impacted Soil.” Journal of Environmental Quality 34 (5): 1755–62. https://doi.org/10.2134/jeq2004.0399.

Houston Soil Contaminants of Concern

Contaminant	Description/Potential Harm	Source(s)	Current Remediation Research
Lead (Pb)	Lead is a naturally occurring metal found in Earth's crust. Even small amounts of lead exposure can cause serious health effects including headache, high blood pressure, trouble concentrating, and joint pain. In children, lead exposure can cause developmental delays and learning difficulties.[1] The EPA has established a limit of 400 ppm in soil for play areas and 1,200 ppm for non-play areas.[4]	Lead-based gasoline and paint continues to contaminate soil, even after a ban.[2] Lead pipes can contaminate tap water.[2] Lead is also a common impurity of fossil fuels, notably coal.[3]	Lead breaks down extremely slowly in soil, with a half-life of 700 years.[6] Traditional methods for remediation involve either hauling away the contaminated soil and bringing in clean soil or covering the soil to reduce exposure. Although phytoextraction has proven difficult without the use of chelating agents, plants can help stabilize lead in soil, reducing bioavailability.[5]
Zinc (Zn)	Zinc is an abundant metal found in Earth's crust. Metallic zinc is used in many industries to make metal alloys and coat iron/steel to prevent rust. Although some zinc is needed in the human body to perform vital functions, exposure to high levels of zinc can cause digestive issues, anemia, and damage to the pancreas.[7]	Metal mining, metal ore purification, and coal burning contribute to most Zinc contamination. Other sources include fertilizer runoff and sludge.[7]	In-situ methods for zinc remediation include covering soil with a waterproof material, flushing soil with an extraction liquid, immobilizing zinc with a chemical solution, and phyto/bio-remediation.[8] Since zinc is needed for plant growth and development, high levels of zinc accumulation have been recorded in many plant species, with 28 hyperaccumulators identified as of 2020.[9]
Arsenic (As)	Arsenic is a naturally occurring metal found in Earth's crust. In the past, arsenic has been used in paint pigments, wood preservatives, and pesticides. Short term exposure can cause vomiting, diarrhea, nausea, and dehydration. Long term exposure to even low levels of arsenic can cause certain skin disorders, high blood pressure, and an increased risk of cancer and diabetes.[10]	People are most often exposed to arsenic through contaminated drinking water. This occurs when mining biproducts or pesticides enter groundwater. Organic forms of arsenic are also present in some shellfish.[11]	The most common method for remediating arsenic contaminated soils is solidification/stabilization. This process involves adding a treatment solution to soil to decrease the bioavailability of arsenic.[12] Phytoremediation is a low-cost option for arsenic remediation. Many species of ferns are hyperaccumulators of arsenic. Although, this method often takes more time than traditional remediation options.[13]

Contaminant	Description/Potential Harm	Source(s)	Current Remediation Research
Cadmium (Cd)	Cadmium is a heavy metal, mostly extracted from Zinc ore. Cadmium is mostly used to coat iron/steel and produce batteries. Short term exposure to high levels of cadmium can cause respiratory irritation and digestive issues. Chronic exposure can damage the kidneys and lungs as well as increase the risk of cancer.[14]	Most cadmium exposure occurs in the workplace, specifically when refining metals, manufacturing batteries, making plastics coatings, and/or constructing solar panels. Cadmium can also enter soils near manufacturing and recycling plants.[15]	Cadmium is both very toxic and relatively difficult to remove from soil. Physical methods to remove Cadmium, like replacing the soil entirely, are quick but economically infeasible over a large area. Chemical remediation, like adding a solidifying agent to reduce bioavailability, can cause secondary pollution. Phytoremediation is an effective, low-cost option for cadmium remediation, but it takes over ten years without the use of chelating agents.[16]
Copper (Cu)	Copper is a heavy metal extracted from Earth's crust. Copper is mostly used in electrical equipment and plumbing. Although copper is an essential nutrient in small amounts, exposure to high levels can cause stomach issues in the short term and kidney/liver damage in the long term.[17]	Most copper exposure occurs from contaminated drinking water when copper plumbing becomes eroded.[17] Copper mining, manure, and fungicides are the most common sources of soil contamination.[18]	Physical methods to remove copper, like soil removal and even electrokinetic technology, are labor intensive but can remediate highly contaminated sites. Chemical methods, like soil washing, are effective but can contribute to further contamination. Phytoremediation can be used in soils with low to moderate copper concentrations, but it takes a longer period.[18]
Dioxins (POPs)	Dioxins are a group of highly toxic chemical compounds that are highly persistent in the environment. In the past, dioxins have been used in the manufacturing of organic compounds, like herbicides, but they were largely phased out. Exposure to even small amounts of dioxins can cause cancer, reproductive and developmental problems, damage to the immune system, and interference with hormones.[19]	Sources of dioxins currently include waste incineration, chlorine bleaching of pulp/paper, and cigarette smoke.[19] High levels of Dioxins were reported in soils near the Union Pacific rail yard in Houston's Fifth Ward.[20]	Incineration is the most widely used method to rid soil of dioxins. Chemical dichlorination is another option, but it needs more field testing to be proven viable. Microorganisms in soil have also been shown to dechlorinate dioxins under the right conditions. Some plants, like spinach, have been shown to uptake dioxins at a high level, but remediation of dioxins using plants is not commonly used in the field.[21]

Contaminant	Description/Potential Harm	Sources(s)	Current Remediation Research
Polycyclic aromatic hydrocarbon (PAHs)	Polycyclic aromatic hydrocarbons (PAHs) are a class of organic compounds that occur naturally in coal, crude oil, and gasoline. PAHs are also generated when coal, oil, gas wood, garbage, and tobacco are burned. While the health effects of exposure to low levels of PAHs are unknown, exposure to large amounts of naphthalene can cause blood and liver abnormalities. Additionally, several PAHs are designated carcinogens.[22]	Workers in the fossil fuel industry are often exposed to PAHs. Breathing in air contaminated with motor vehicle exhaust, cigarette smoke, wood smoke, or fumes from asphalt roads is another common source of exposure.[22]	The most widely used methods to remediate PAH contaminated soil are incineration and in-situ thermal desorption. While these methods are highly effective, they require a high energy and resource input. Chemical methods, like solvent extraction/soil washing, are often used when the PAHs are resistant to physical methods of removal.[23] Various tree species, including green ash, have been proven to support microbial communities that break down PAHs in the rhizosphere.[24]

References

1) "Lead Poisoning." Mayo Clinic. Accessed July 31, 2023. https://www.mayoclinic.org/diseases-conditions/lead-poisoning/symptoms-causes/syc-20354717.

2) "Learn About Lead." EPA. Accessed July 31, 2023. https://www.epa.gov/lead/learn-about-lead.

3) Li, Muyang, et al. "Dynamic Substance Flow Analysis of Lead in the Fossil Fuel System of China from 1980 to 2018." Journal of Cleaner Production, June 14, 2021. https://www.sciencedirect.com/science/article/abs/pii/S0959652621021363#:~:text=Lead%20is%20a%20common%20impurity,and%20consumer%20of%20fossil%20fuels.

4) "Lead (PB) Toxicity: What Are U.S. Standards for Lead Levels?" Centers for Disease Control and Prevention, May 24, 2023. https://www.atsdr.cdc.gov/csem/leadtoxicity/safety_standards.html#:~:text=EPA%20has%20established%20400%20ppm,systems%20is%2015%20%C2%B5g%2FL.

5) "Lead Remediation." Earth Repair, December 2, 2018. https://earthrepair.ca/resources/scenarios/lead-remediation/#:~:text=A%20common%20conventional%20remediation%20way,capped%2C%20using%20grass%20or%20concrete.

6) Laidlaw, Mark, et al. "Seasonality and Children's Blood Lead Levels: Developing a Predictive Model Using Climatic Variables and Blood Lead Data from Indianapolis, Indiana, Syracuse, New York, and New Orleans, Louisiana (USA)." Environmental health perspectives, June 2005. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC1257609/#:~:text=The%20half%2Dlife%20of%20Pb,many%20generations%20(Semlali%20et%20al.

7) "Zinc." Centers for Disease Control and Prevention, March 18, 2014. https://wwwn.cdc.gov/TSP/PHS/PHS.aspx?phsid=300&toxid=54#:~:text=Most%20of%20the%20zinc%20in%20soil%20is%20bound%20to%20the,or%20drinking%20water%20containing%20zinc.

8) Li, Muyang, et al. "Dynamic Substance Flow Analysis of Lead in the Fossil Fuel System of China from 1980 to 2018." Journal of Cleaner Production, June 14, 2021. https://www.sciencedirect.com/science/article/abs/pii/S0959652621021363#:~:text=Lead%20is%20a%20common%20impurity,and%20consumer%20of%20fossil%20fuels.

9) Balafrej, Habiba, et al. "Zinc Hyperaccumulation in Plants: A Review." Plants (Basel, Switzerland), April 29, 2020. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7284839/.

10) "Arsenic Factsheet." Centers for Disease Control and Prevention, April 7, 2017. https://www.cdc.gov/biomonitoring/Arsenic_FactSheet.html.

11) "Arsenic and Drinking Water Active." Arsenic and Drinking Water | U.S. Geological Survey, March 1, 2019. https://www.usgs.gov/mission-areas/water-resources/science/arsenic-and-drinking-water#:~:text=Arsenic%20also%20can%20be%20released,and%20is%20a%20known%20carcinogen.

12) "U.S. Environmental Protection Agency | US EPA." EPA.gov, September 2002. https://www.epa.gov/sites/default/files/2015-04/documents/arsenic_report.pdf.

13) Srivastava, Sudhakar, et al. “Arsenic Remediation through Sustainable Phytoremediation Approaches.” MDPI, August 28, 2021. https://www.mdpi.com/2075-163X/11/9/936.

14) “Louisiana Office of Public Health’s Heavy Metal Surveillance Data.” Louisiana.gov, August 2017. https://ldh.la.gov/assets/oph/Center-EH/envepi/Heavy_Metal/Documents/Annual_Heavy_Metal_Surveillance_Report_2014.pdf.

15) “Cadmium Overview.” Occupational Safety and Health Administration. Accessed August 6, 2023. https://www.osha.gov/cadmium.

16) Tang, Xin, and Yuqin Ni. “Review of Remediation Technologies for Cadmium in Soil.” E3S Web of Conferences, 2020. https://www.e3s-conferences.org/articles/e3sconf/pdf/2021/09/e3sconf_iaecst20_01037.pdf.

17) “Consumer Factsheet on: Copper - Archives | US EPA.” EPA.gov. Accessed August 6, 2023. https://archive.epa.gov/water/archive/web/pdf/archived-consumer-fact-sheet-on-copper.pdf.

18) Obeng, Samuel Yaw. “Remediation Technology for Copper Contaminated Soil: A Review.” Research Gate, January 2018. https://www.researchgate.net/publication/328927651_Remediation_Technology_for_Copper_Contaminated_Soil_A_Review.

19) “Learn About Dioxins.” EPA. Accessed August 6, 2023. https://www.epa.gov/dioxin/learn-about-dioxin#tab-3.

20) “Houston Health Department Detects Cancer-Causing Dioxin in Soil Sampling around Contaminated Union Pacific Rail Yard: Houston Health Department.” Houston Health Department detects cancer-causing dioxin in soil sampling around contaminated Union Pacific rail yard | Houston Health Department, September 23, 2022. https://www.houstonhealth.org/news/news-releases/houston-health-department-detects-cancer-causing-dioxin.

21) Nhung, Nguyen Thi Hong, Xuan-Tung Tan Nguyen, Vo Dinh Long, Yuezou Wei, and Toyohisa Fujita. “A Review of Soil Contaminated with Dioxins and Biodegradation Technologies: Current Status and Future Prospects.” Toxics, May 24, 2022. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC9227754/.

22) “Polycyclic Aromatic Hydrocarbons (Pahs) Fact Sheet - U.S. Environmental ...” CDC Environmental Health, November 2009. https://www.epa.gov/sites/default/files/2014-03/documents/pahs_factsheet_cdc_2013.pdf.

23) Kuppusamy, Saranya, Palanisami Thavamani, Kadiyala Venkateswarlu, Yong Bok Lee, Ravi Naidu, and Mallavarapu Megharaj. 2017. “Remediation Approaches for Polycyclic Aromatic Hydrocarbons (PAHs) Contaminated Soils: Technological Constraints, Emerging Trends and Future Directions.” Chemosphere 168: 944–68. https://doi.org/10.1016/j.chemosphere.2016.10.115.

24) Spriggs, Thomas, M. Katherine Banks, and Paul Schwab. 2005. “Phytoremediation of Polycyclic Aromatic Hydrocarbons in Manufactured Gas Plant-Impacted Soil.” Journal of Environmental Quality 34 (5): 1755–62. https://doi.org/10.2134/jeq2004.0399.