Tech Class	Technology		Technology Description	Development Status	Targeted Contaminant	Applicability	Treatment Train	Time to Treat	Availability
			Describe the technology and it's use.	What is the maturity of the technology (emerging, in development, or proven)?	What contaminates does the technology effectively treat for?	In what conditions is this technology applicable (up to 10ft below surface, soil pH above)?	Is this technology typically used as part of a suite of treatment technologies? If so identify the treatment train.	How long does it take to treat a typical site?	From how many vendors is this technology available?
Biological - In-situ	Bioremediation - Microorganism	Anaerobic digester technology	utilizes a symbiotic consortium of anaerobic bacteria retained as an attached biofilm on a non-clogging vertical spindle array of geo-textile panels		aromatic and aliphatic hydrocarbons (chlorinated hydrocarbons, organo-phosphates, toluenes, dioxanes, phenols, cyanides, diesel and hydraulic oil)	In-situ; soils			
		Bioaugmentation	The use of microorganism metabolism to remove contaminants from soils, water and other materials. Introduction of non-natural species to the contaminated soil.	emerging in development	Petroleum hydrocarbons, nonchlorinated solvents, some pesticides, wood preservatives; PAHs, non-halogenated SVOCs (not including PAHs), BTEX, Metals, Radionuclides	Soil, sediment; Vadose zone (unsaturated media); Organics (full-scale); Inorganics (experimental) Most applicable In-Situ in bioreactors	Nutrients, oxygen, or other amendments are used to enhance bioremediation and contaminant desorption from subsurface materials.	Any	Available
		Biomining	Extraction of specific metals from their ores through biological means, usually bacteria	emerging in development	Metals in rock/ore	Applicable in regions with low permeability and would not be suitable for bioventing or biostimulation	CO2 source, and oxygen	Any	Available
		Biostimulation-CO2 Source	Stimulation of natural micoorganisms by injection of a CO2 source in subsurface. Bacteria can then proliferate and degrade contaminants	emerging in development	Uranium, heavy metals	Subsurface, for lowly contaminated areas	CO2 source, and oxygen	Any	Available
		Bioventing	Stimulation of natural in situ biodegradation of any aerobically degradable contaminants in soil by providing oxygen to existing soil microorganisms	emerging in development	Petroleum hydrocarbons, nonchlorinated solvents, some pesticides, wood preservatives	Soil, sediment; Vadose zone (unsaturated media); Organics (full-scale); Inorganics (experimental)	CO2 source, and oxygen	Any	Available
	Phytoremediation	Phytoaccumulator+Chelator	The use of Chelators such as EDTA to improve the phytoaccumulation abilities of certain plants	Emerging in development (due to environmental concerns/making contaminants soluble and contaminating groundwater)	Heavy Metals, Dioxane, Hydrocarbons, Radionuclides, PCBs, PAHs, Explosives	Applicable to regions within approximately 4 ft of root zone. Depending on roots this could extend to groundwater.	Nutrients and water are provided throughout growth period, Chelator is applied ~2-3 weeks before harvest, plants are harvested, dried and incinerated	Plants would most likely do best in Spring and Summer seasons. However, some may be perennial (trees).	Highly available
		Phytoaccumulator +Chlorocomplexes	The use of salinity and Cl forming metal complexes such as CdCl as a means improve the phytoaccumulation abilities of certain plants	Emerging in development (due to environmental concerns/making contaminants soluble and contaminating groundwater)	Heavy Metals, Dioxane, Hydrocarbons, Radionuclides, PCBs, PAHs, Explosives	Applicable to regions within approximately 4 ft of root zone. Depending on roots this could extend to groundwater.	Nutrients and water are provided, a Cl source is added for complexation, plants are harvested and incinerated	Plants would most likely do best in Spring and Summer seasons. However, some may be perennial (trees).	Highly available
		Phytoextraction, Hyperaccumulation	process by which plants hyperaccumulate contaminants through their roots and store them in the tissues of plant. Contaminants are not necessarily degraded but are removed from the environment when the plants are harvested. In some cases, the metals/contaminants can be harvested for reuse by incinerating the plants (phytomining)	Proven	Heavy Metals, Dioxane, Hydrocarbons, Radionuclides, PCBs, PAHs, Explosives	Applicable to regions within approximately 4 ft of root zone. Depending on roots this could extend to groundwater.	Nutrients and water are added, plants are harvested, dried and incinerated	Plants would most likely do best in Spring and Summer seasons. However, some may be perennial (trees).	Highly available
		Phytometabolization	Contaminants are taken up into the plant tissues where they are metabolized, or biotransformed. Where the transformation takes place depends on the type of plant, and can occur in roots, stem or leaves	Emerging in development (due to plant death due to toxicity)	Heavy Metals, Dioxane, Hydrocarbons, Radionuclides, PCBs, PAHs, Explosives	Applicable to regions within approximately 4 ft of root zone. Depending on roots this could extend to groundwater.	Nutrients and water are added, plants are maintained and continuously degrade contaminants	Plants would most likely do best in Spring and Summer seasons. However, some may be perennial (trees).	Highly available
		Phytovolatilization	process where plants intake volatile compounds through their roots, and transpire the same compound or its metabolite(s) into the atmosphere through the leaves	Emerging in development (due to regulation of emissions)	Heavy Metals, Dioxane, Hydrocarbons, Radionuclides, PCBs, PAHs, Explosives	Applicable to regions within approximately 4 ft of root zone. Depending on roots this could extend to groundwater.	Nutrients and water are added, plants are maintained and continuously volitilize contaminants	Plants would most likely do best in Spring and Summer seasons. However, some may be perennial (trees).	Highly available
		Rhizodegredation	process by which plant exudates stimulate rhizosphere bacteria to enhance biodegredation of soil contaminants (happens in the soil directly surrounding the plant roots)	Proven	Heavy Metals, Dioxane, Hydrocarbons, Radionuclides, PCBs, PAHs, Explosives	Applicable to regions within approximately 4 ft of root zone. Depending on roots this could extend to groundwater.	Nutrients and water are added, plants are maintained and continuously degrade contaminants	Plants would most likely do best in Spring and Summer seasons. However, some may be perennial (trees).	Highly available
		Rhizodegredation/ Phytoextraction	process by which plant exudates stimulate rhizosphere bacteria to enhance biodegredation of soil contaminants (happens in the soil directly surrounding the plant roots), and also increases the solubility of the metals so that they are more bioavailable to the plant.	Proven	Heavy Metals, Dioxane, Hydrocarbons, Radionuclides, PCBs, PAHs, Explosives	Applicable to regions within approximately 4 ft of root zone. Depending on roots this could extend to groundwater.	Nutrients and water are added, plants are maintained and continuously degrade contaminants. Plants can be harvested as desired and then incinerated	Plants would most likely do best in Spring and Summer seasons. However, some may be perennial (trees).	Highly available

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	Stress Induced Phytoremediation	The use of plant stressors such as a micronutrient deficiency or acidic contitions to instigate phytoaccumulation in plants.	Emerging in development (due to environmental concerns/making contaminants soluble and contaminating groundwater)	Heavy Metals, Dioxane, Hydrocarbons, Radionuclides, PCBs, PAHs, Explosives	Applicable to regions within approximately 4 ft of root zone. Depending on roots this could extend to groundwater.	Nutrients and water are added, plants are harvested, dried and incinerated	Plants would most likely do best in Spring and Summer seasons. However, some may be perennial (trees).	Highly available
Biological - Ex-situ	Biopiles (Heap pile bioremediation; Bioheaps; Biomounds; Static-pile composting)	Excavated soils are mixed with soil amendments and placed on a treatment area that includes leachate collection systems and some form of aeration		Nonhalogenated VOCs and halogenated VOCs, SVOCs, fuel hydrocarbons, and pesticides	Organics ; Soil, sediment; Vadose zone (unsaturated media);			
	Composting	Controlled biological process by which organic contaminants (e.g., PAHs) are converted by microorganisms (under aerobic and anaerobic conditions) to innocuous, stabilized byproducts		Organics (explosives (TNT, RDX, and HMX), ammonium picrate (or yellow-D))	Organics ; Soil, sediment; Vadose zone (unsaturated media);			
	Fluidized Bed Reactors	Fixed-film bioreactors that rely on immobilization on a hydraulically fluidized bed of media particles, and can facilitate conditions required to promote degradation of energetic compounds	Bench- and pilot-scale	Perchlorate	Groundwater and soils			
	Landfarming	Incorporates liners and other methods to control leaching of contaminants, which requires excavation and placement of contaminated soils, sediments, or sludges. Contaminated media is applied into lined beds and periodically turned over or tilled to aerate the waste.		Petroleum hydrocarbons	Organics ; Soil, sediment; Vadose zone (unsaturated media);			
	Slurry phase (slurry biodegradation)	Controlled treatment of excavated soil in a bioreactor. Soil is mixed with water to a predetermined concentration dependent upon the concentration of the contaminants, the rate of biodegradation, and the physical nature of the soils.		SVOCs, VOCs, PCBs (Explosives, petroleum hydrocarbons, petrochemicals, solvents, pesticides, wood preservatives)	Organics ; Soil, sediment; Vadose zone (unsaturated media);			
	Air Sparging	In-situ groundwater and soil remediation technology that involves the injection of a gas under pressure into a well in saturated zone.	Air sparging extends the applicability of soil vapor extraction to saturated soils and groundwater through physical removal of volatilized groundwater contaminants and enhanced biodegradation in the saturated and unsaturated zones.	dissolved and non-aqueous volatile organic compounds (VOCs)	Air sparging is applicable at sites where groundwater and/or saturated soils are contaminated with volatile, semivolatile, and/or nonvolatile aerobically biodegradable organic contaminants. Air sparging can be applied to situations in which dewatering (to allow the application of vapor extraction to residually contaminated soils) is not feasible. Examples of such situations include sites with high yield aquifers and thick smear zones. When dense non-aqueous phase liquids (DNAPLs) are present, deep penetration of non-aqueous contamination may require a level of dewatering that would not be practical.	Off-gas treatment may be required for extracted vapors (Soil Vapor Extraction, SVE), depending on site conditions and system design, although adjusting injection/extraction rates can significantly reduce, and in some cases eliminate, the need for surface vapor treatment. The presence of non-biodegradable volatile contaminants generally mandates off-gas treatment		
	Directional wells				Organics			
	Electrokinetic separation (syn: Electromigration; electroremediation)	A dc electric field is applied across electrode pairs placed in the ground. The contaminants in the liquid phase in are moved under the action of the field, by electromigration and/or electroosmosis, to wells where they are then pumped out	Pilot- and full-scale	Chromium	Low permeability soils; most effective in clays; primarily used to remove metals and radionuclides. may be used for organic compounds, including VOCs and pesticides			

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Physical/Chemical - In-situ	In-Well Vapor Stripping (In situ vapor/air stripping)	In-well vapor stripping technology involves the creation of a ground-water circulation pattern and simultaneous aeration within the stripping well to volatilize VOCs from the circulating ground water. Air-lift pumping is used to lift ground water and strip it of contaminants. Contaminated vapors may be drawn off for aboveground treatment or released to the vadose zone for biodegradation. Partially treated ground water is forced out of the well into the vadose zone where it reinfiltrates to the water table. Untreated ground water enters the well at its base, replacing the water lifted through pumping. Eventually, the partially treated water is cycled back through the well through this process until contaminant concentration goals are met.	Usually conducted on pilot-scale	VOCs (e.g., TCE, TPH, BTEX)	Site soil conditions seem to be less of a limitation for in-well stripping than air sparging, since air movement through aquifer material is not required for contaminant removal. In-well vapor stripping has been applied to a wide range of soil types ranging from silty clay to sandy gravel. Reported advantages of in-well stripping include lower capital and operating costs due to use of a single well for extraction of vapors and remediation of ground-water and lack of need to pump, handle, and treat ground-water at the surface. Additional advantages cited involve its easy integration with other remediation techniques such as bioremediation and soil vapor extraction and its simple design with limited maintenance requirements. Limitations reported for this technology include limited effectiveness in shallow aquifers, possible clogging of the well due to precipitation, and the potential to spread the contaminant plume if the system is not properly designed or constructed.			
	Lasagna	Layered configuration that combines eletrokinetics with in-situ bioremediation technologies	Full-scale	TCE	Low permeability soils			
	Multi/Dual-phase extraction (syn: Bioslurping)	This technology uses a high vacuum system to remove various combinations of contaminated ground water, separate-phase petroleum product, and hydrocarbon vapor from the subsurface. Extracted liquids and vapor are treated and collected for disposal, or re-injected to the subsurface (where permissible under applicable state laws).===Synonyms: Dual-Phase Extraction, Vacuum-enhanced extraction, bioslurping, free product recovery, liquid-liquid extraction.		Long-chained hydrocarbons, VOCs, fuels,	Multi-phase vacuum extraction is more effective than SVE for heterogeneous clays and fine sands. However, it is not recommended for lower permeability formations due to the potential to leave isolated lenses of undissolved product in the formation.	bioremediation, air sparging, or bioventing, pump-and-treat		
	Oxidation (peroxide; permanganate)	In situ chemical oxidation involves the introduction of strong oxidants in the subsurface where they can in situ destroy the contaminants of concern.		organic contaminants		Excavation, Soil Vapor Extraction, Flushing prior to In Situ Oxidation		
	Passive/reactive treatment walls (syn. Permeable Reactive Barriers, PRB's)	A permeable reaction wall is installed across the flow path of a contaminant plume, allowing passage of water while prohibiting the movement of contaminants by employing such agents as zero-valent metals, chelators (ligands selected for their specificity for a given metal), sorbents, microbes, and others.	Full-scale	TCE; Cr(VI) to Cr(III); organic-catalyzed conversion of nitrate and sulfate.	Organics (dehalogenate hydrocarbons, VOCs, SVOCs); Inorganics;			
	Soil flushing (syn: cosolvent, surfactant enhancement)	Injection or infiltration of an aqueous solution into a zone of contaminated soil/groundwater, followed by downgradient extraction of groundwater and elutriate and aboveground treatment and discharge or re-injection.	successful implementation is highly site-specific.	Non-aqueous phase liquid (NAPL), VOCs, semi-VOCs, PCBs, halogenated pesticides, dioxin/furans, cyanides, corrosives.	Depth is a limiting factor primarily due to the economics involved with injection and extraction. Permeability is a key physical parameter in determination of the feasibility of in situ flushing.			
	Soil vapor extraction (syn: soil venting, volatilization)				Soil, sediment; Vadose zone (unsaturated media); Organics			
	Soil Washing	Soil washing "scrubs" soil to remove and separate the portion of the soil that is most polluted. This reduces the amount of soil needing further cleanup. Soil washing alone may not be enough to clean polluted soil. Therefore, most often it is used with other methods that finish the cleanup.					The time it takes to clean up a site using soil washing depends onseveral factors: • amount of silt, clay, and debris in the soil • type and amount of pollution in the soil • size of scrubbing unit (The largest units can clean up to 100 cubic yards of soil per day.) Cleanup usually takes weeks to months, depending on the site.	

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	Ultraviolet oxidation	Use of an oxygen based oxidant (ozone or hydrogen peroxide) in conjunction with UV light to oxidize contaminants						
Thermal - In-situ	Hot Air/Steam Injection generally with soil vapor extraction (SVE)	Hot air or steam is injected into the contaminated underground formation or zone to enhance release of contaminants from the formation. Technology is used to enhance SVE by increasing volitilization of contaminants.	thermally enhanced SVE proven	Organics, PCBs, VOC, SVOC, pesticides	vadose vone only, dependent on soil saturation, well spacing, porosity, contamanant thermal properties soil matrix properties.	SVE, zero valent Fe		multiple
Thermal - In-situ	Radiofrequency or microwave heating	RF is used to heat a target area. Generally heats soil to less than 100C. Is geenrally used to increase effectiveness of SVE.	bench and pilot scale	SVOC, VOCs, PAH	Dependent on soil properties, requires H20 or other polar components to generate heat	SVE, zero valent Fe		few
Thermal - In-situ	Thermal Blanket (ISTD) in-situ thermal desorption	Thermal blanket heats soil to temperatures above 200C to desorb or destroy organics. A negative pressure offgas system is used to capture and treat vapors (afterburner, condensor, carbon, etc).	Full Scale proven	Organics, PCBs, VOC, SVOC, pesticides	Treats surface contamination to a depth of 15cm. Depth dependent on soil conditions and blanket specifications. Test to verify 200C is reached to target depth.	SVE	Treated area of blanlket approx 24 hrs, dependent on soil and blacket specifications	few
Thermal - In-situ	Vertical Thermal Well, Resistivity heating/high temperature thermal conduction/insitu thermal desorption and desctruction (ISTD)	Soil is heated by resistive electrical heating elements in a closely-spaced well network. Wells under vaccuum to move containinents, organics are oxidized/pyrolysized in the well, remaining contaminents are treated at the surface. Soil temperture can reach 700C.	thermally enhanced SVE proven	orgainics, SVOC, VOCs, PCBs, pesticides, PAH	vadose vone only, dependent on soil saturation, well spacing, temperature.	SVE, surface oxidation of off-gas, zero valent Fe		few
Thermal - In-situ	Vitrification	Media is subjected to tepmeratures in excess of 1200C to form stable glass or glass crystaline materials. Organics are desctroyed and radionuclides are bound in a less soluble and leachable form. An off-gas hood is used to collect gasses, particilate or HEPA filters.	Demonstratoin	Organics, VOC, SVOC distruction. radionuclides, metals/heavy metals, inorganics fixed in matrix.	Destroys organics and reduces mobility of radionuclides. Soil must have sufficient amounts of conductive cations and glass-forming metal oxides to allow soil melting and stable monolith formation. 3x3m min to 9x9m max area, 9m max depth, 188 to 1000 ton melt max.	Offgas system, SVE possible	4-6 tons/hr	few
Incineration	**Incineration**	Combution of waste	Mature, most common treatment technique, used international. Public concerns has reduced its use for hazardous and radioactive waste treatment in US.	Organics, (PCB, dioxinx possible), heavy metals and/or radionuclides captured, treated or bound to soils (reduced leachability via H2O)	ex situ, can accommodate soils, sediments liquids and sludges however mostly used on high energy content wastes. Size reduction may be necessary. Not appropriate for certain radionuclides, mercury, explosives or reactive waste. Heating soil above 1000C has ability to reduce H2) radionulcde leachability for certain radioisotopes and soils.	solidification (ash and slag)	up to 400kg/hr solids and 450 l/hr liquids	mulitiple
Incineration	Circulating Bed Combustor (CBC) a type of Fluidized Bed Combustors	This is a thermal destruction system that uses high velocity air to entrain a bed of solid matierials in a circulating and highly turbulent reaction chamber heated between 1400 and 1800C.. Waste is injected into the circulating bed and combusted. An offgas system is used to treat byproducts. Addative can be used to react with acids and sulfur in the reaction chamber.	Proven	Organics, (PCB, dioxinx possible), heavy metal captured or treated	ex situ	Offgas treatment/contaminant capture		multiple
Incineration	Fluidizer Bed (calcine)	Vertical cylindrical system refractory lined with a bed of inert material on a preforated plate. A burmner heats the bed from above to approx 900C. Waste is injected on the bed with air blown upwards through the bed. Uses high temperature oxidation to destroy organics in liquid, gas, and solid wastes, most often sludges. Particulates are blown out of the system through an afterburner and offgas system.	Proven	Organics, (PCB, dioxinx possible), heavy metal captured or treated	ex situ, solids, liquids, gasses and sludges. Sludges perferred. Size reduction may be necessary. Possible secondary treatment needed.	Offgas treatment/contaminant capture		multiple
Incineration	Hot Gas Decontamination	The process decontaminates equipment or other matierials by heating them to approximately 260C. An offgas system is necessary and may include an afterburner. The process is intended to be used to drive off the conatminent allowing the treated materials to be resused or recycled.	Proven	Organics, hazardous materials, explosives.	Generally used to treat contaminated wquipment or materials intended to be recycled. May be used to decontaminate building materials, mas	Offgas treatment/contaminant capture		few
Incineration	Infared Thermal Destruction	Infared is used in a chamber furnace to incinerate waste. Chamber is heated by infared heating elements (silicon carbide) from 500 to 1000C. Secondary chamber (hydrocarbon fired) can be used to complete gas-phase combustion reactions. Offgas treatment necessary. Solid bydroducts may need treatment.		Organics, (PCB, dioxinx possible), heavy metal captured or treated	ex situ	Offgas treatment/contaminant capture		few

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Thermal - Ex-situ		Open Burn/Detonation	Open burn and open detonation are used to destroy munitions and explosive. Open buring of munitions generally by self-sustaning combustion. May require external source for initial burn. Explosive waste may be detonated by separate initiating explosive. Burns and detonations are performed in the open environment under controlled conditions.	Proven	Explosives, energetic materials and munitions. Pyrophoric materials possible.	Since waste is treated in the open atmosphere, only waste with no or low hazardous emmisions can be treated.		miliseconds…	multiple
		Rotory Hearth Furnace	Rotory Hearth Furnace is similar to the rotary kiln design except the furnace uses a rotating table that allows input and output of materials . System uses multiple chanbers for combution of offgas products and offgas treatment.	Proven	Organics, (PCB, dioxinx possible), heavy metal captured or treated	ex situ soils, high and low BTU matierials	Offgas treatment/contaminant capture		multiple
		Rotory Kiln	Most common type- rotary kiln with afterburner. Waste is combusted with air at temps near 1500C in an inclined cylindrical rotating refractory lined shell. Offgas teatment necessary to remove particulates, NOx, SOc, acidic gasses an volitile metals.	Proven - example 99.9999 for PCB	Organics, (PCB, dioxinx possible), heavy metal captured or treated	ex situ, soils, sediments and sludges. Size reduction may be necessary	Offgas treatment/contaminant capture	2-5 tons/hr (solids) modile Ensco unit	Multiple, more than 20
	Pyrolysis	**Pyroloysis**	General: High temperature is used in a semi-closed system in the absence of O2. N2 is usually used to sweep the by-products out of the system through an off-gas system. The waste is not cumbusted such that the resulting by-products do not have CO, NOx.	various	Organics, PCBs dioxin, radionuclides, heavy metals	ex situ; Solids, liquids and gasses of orgainic wastes (carbon, hydrogen oxygen) Problematic for waste containing nitrogen, sulfur silicon, sodium, bromide, iodine, potassium and phosphorous. Alkali metals form low melting salts the make fluidided beds less efffective.	Resulting products may require further treatment. Radionuclides would be included in output stream wich may be further treated by solidification or vitrification.		
		Advanced Electric Reactor	A type of pyrolysis system. Electrically heated carbon electrodes are used for radiant heating of a porous reactor core. NO2 is pumped through the porous core isolating it from the waste in the reactor chamber. An off gas system is used to capture and treat the resultant byproducts.	Trials run on test materials. No information past 1989.	Organics, PCBs dioxin	Treats only single phase materials. Solids must be processed through a fine mesh.			few
		Electric Arc Pyrolysis	Consumable electrodes produc an arc that is used to heat waste in a reaction chamber. Temps at 1450-1800C. Off gas treatment necessary for vaporized metals and other byproducts		Organics, PCBs dioxin	soils, solids, sludges	Resulting products may require further treatment.		multiple
		Molten Salt Reactor	A heated liquified salt is injected with waste (pyrolysis), a secondary reactor may be used to combust generated gasses or an off gas system can be used to capture byproducts. Specific salts can be used in the process that will react with the decomposision products, effectively trapping these elements in the salt. The salt requires replacement or treatment to remove ash and reacted salts (melt removal).	pilot scale. Tested at ETEC for use in Oak Ridge Intermediate waste.	Organics, PCBs dioxin; heavy metals, radionuclides, other inorgaincs are reatined in salt that can be further porcessed or disposed.	ex situ orgainics. Not generally acceptable for soils since the generated salt waste would include the soil. No technical post treatment processes to separate the soil from the resulting salt waste were found.	Resulting products may require further treatment. Radionuclides would be included in output stream wich may be further treated by solidification or vitrification.	500 lbs/hr	few
		Plasma Arc Pyrolysis	A plasma arc (torch) is used in a low pressure, low O2 chanmber to decomose waste at temperature approaching 10,000C. Liquid is sprayed through the arch and into the furnace chamber (1000C reactor/mixing zone). Off gas system removes byproducts.	proven - applications for syngas from waste and possible power generation systems. Meltran in Korea, PEAT in US, Japan and Swiss	Organics, PCBs dioxin	ex situ; Generally applicable to high energy content waste and liquids. Proposed for insitu vitrification using boreholes and plasma torches.	Resulting products may require further treatment. Radionuclides would be included in output stream wich may be further treated by solidification or vitrification.		multiple
		Steam Reformers	Reduction of porganics with steam produces combutible gasses that are further combusted or captured. Pyrolysis with lower oxidation and reduction that other processes. Less offgas.	Pilot scale (various DOE initiative), industrial scale (Studvik Processinf Facility Tennesse, USA).	Orgainics, metals, soils and radionuclides	ex situ soils, organics. Not generally applicable for chlorides, alkali metals and sodium waste.		1-12 kg/hr	few
		Supercritical Water Oxidation	Water and waste are processed at a temperature and pressure above the critical point of water. At this point, water is soluble to many origainc allowing these componds to oxidize. Salts also precipitate and can be separated. Process temperature are betwen 400 and 650C.	U.S. Pilot scale, Commercial applications in S. Korea, Japan and Ireland (Sweden. ??)	Organics, PCBs dioxin	ex situ organics		3 m3/hr.	few
		Wet Oxidation - Catalytic Aqueous Process	Wet Ocidation process with FeCL3 ans HCl usinf 200C and up to 200 psig	not fully demonstrated - bench scale	Organics, PCB, radionuclides	ex situ			few

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	Thermal Desorption	**Thermal Desorption**	Treatment heats waste to drive off moister and orgainic compounds which can be condensed or captured (carbon beds) or burned in an afterburner. A carrier gas may be used besides air to avaoid combustion. A vacuum can be used instead of a carrier gas to desorb volitile and SVO. Temperature can be rased to the point were organics are pyrolyzed (high temp thermal desorbtion) or to avoid pyrolization (low temperature desorbtion).	Proven	VOC, SVOC, petroleum hydrocarbons, halogenated and non-halogenated solvents	ex situ soils, organics. Not generally applicable for chlorides, alkali metals and sodium waste.			multiple
		General Thermal Treatment Issues:	Thermal treatment is used to treat organics, for size reduction amd convert waste into a more homogeneous material. This technique can be used to remove, capture, oxidize/reduce volitive and semi-volitive organic and oxidize/reduce non-volitile organics. Metals may be melted						
		High Temperature Thermal Desorption	Thermal desorption as describved above using a temperature that facilitates pyrolysis of the non-volitile organics or all organics (750C). Can use carrier gas or vacuum. Off gas/particulate system necessary.	Proven.	VOC, SVOC, petroleum hydrocarbons, halogenated and non-halogenated solvents, mercury and other low temperture volitive metals, certain radionuclides	ex situ,			various vendors
		Low Temperature Thermal Desorption (LTTD) and Low Temperature Thermal Stripping	Soil remeadiation technicques that removews low temp volitiles (hydrocarbons) by heating in a closed system to between 90 and 320 C. May use afterburner of condenser.	proven	Organics and VOCs at specific temps, pertoleum hydrocarbons and solvents	ex situ soils, organics. Not generally applicable for chlorides, alkali metals and sodium waste. May require soil pretreatment based on soil type.			few
		Low Temperature Thermal Treatment (LT3@)	Treatment technology volitilizes the contaminents from the soil (400F), volitiles are generally condensed. System uses low flow, low O2 closed system such that the contaminents are removed from the soils without combustion or decomposition. Results in treated soil, fabric filter dust, treated condensate and treated stack gas.	Proven	VOC, SVOC, petroleum hydrocarbons, halogenated and non-halogenated solvents,	ex situ soils, organics. Not generally applicable for chlorides, alkali metals and sodium waste. May require soil pretreatment based on soil type.			few
		Radionuclide Fixation in Soil	By thermally treating soil, radionuclide mobility is reduced compared to untreated soild. Radionuclide solubility in groundwater is reduced. Treating soil (quarts, feldspar, calcite) to 1000C in contact with sorbed radionuclides reduces mobilization (Sr90, Co57, Cs134, U)	R&D	Radionuclides	Fixation of radionuclides to sand - type soils	Can be a byrpoducet of other thermal treatment techniques.		unknown

Technology	Technology Description	Development Status	Targeted Contaminant	Applicability	Treatment Train	Time to Treat	Availability	Health and Safety Concerns	Vendor Information	References	Prerequisites
XYZ	Describe the technology and it's use.	What is the maturity of the technology (emerging, in development, or proven)?	What contaminates does the technology effectively treat for?	In what conditions is this technology applicable (up to 10ft below surface, soil pH above)?	Is this technology typically used as part of a suite of treatment technologies? If so identify the treatment train.	How long does it take to treat a typical site?	From how many vendors is this technology available?	Identify potential health and safety concerns (permits required, bi-products /residuals produced).	Provide contact information for vendors.	Identify information sources. Include links if available.	
Air Sparging	In-situ groundwater and soil remediation technology that involves the injection of a gas under pressure into a well in saturated zone.	Air sparging extends the applicability of soil vapor extraction to saturated soils and groundwater through physical removal of volatilized groundwater contaminants and enhanced biodegradation in the saturated and unsaturated zones.	dissolved and non-aqueous volatile organic compounds (VOCs)	Air sparging is applicable at sites where groundwater and/or saturated soils are contaminated with volatile, semivolatile, and/or nonvolatile aerobically biodegradable organic contaminants. Air sparging can be applied to situations in which dewatering (to allow the application of vapor extraction to residually contaminated soils) is not feasible. Examples of such situations include sites with high yield aquifers and thick smear zones. When dense non-aqueous phase liquids (DNAPLs) are present, deep penetration of non-aqueous contamination may require a level of dewatering that would not be practical.	Off-gas treatment may be required for extracted vapors (Soil Vapor Extraction, SVE), depending on site conditions and system design, although adjusting injection/extraction rates can significantly reduce, and in some cases eliminate, the need for surface vapor treatment. The presence of non-biodegradable volatile contaminants generally mandates off-gas treatment			Vapor migration and release to the surface and/or accumulation in buildings, utility trenches, etc.; Groundwater mounding (due to displacement of water by injected air) causing migration of the groundwater plume; Increased mixing (due to air injection) and so increased mass transfer of contaminants to groundwater and vapor phases.		Air Sparging, Technology Overview Report, TO-96-04, Ralinda R. Miller, P.G., October 1996, GWRTAC (AirSparging_01.pdf)	* Site conditions that favor the successful application of air sparging technology include relatively coarse-grained (moderate to high permeability) homogeneous overburden materials that foster "effective contact" between air and media being treated. * Relatively large saturated thicknesses and depths to groundwater greater than 5 feet may also be required for successful application of this technology.E8
Air Sparging	Air sparging is an in situ technology in which air is injected through a contaminated aquifer. Injected air traverses horizontally and vertically in channels through the soil column, creating an underground stripper that removes contaminants by volatilization. This injected air helps to flush (bubble) the contaminants up into the unsaturated zone where a vapor extraction system is usually implemented in conjunction with air sparging to remove the generated vapor phase contamination. This technology is designed to operate at high flow rates to maintain increased contact between ground water and soil and strip more ground water by sparging. Oxygen added to contaminated ground water and vadose zone soils can also enhance biodegradation of contaminants below and above the water table.	Air sparging extends the applicability of soil vapor extraction to saturated soils and groundwater through physical removal of volatilized groundwater contaminants and enhanced biodegradation in the saturated and unsaturated zones.	The target contaminant groups for air sparging are VOCs and fuels. Only limited information is available on the process. Methane can be used as an amendment to the sparged air to enhance cometabolism of chlorinated organics.	Factors that may limit the applicability and effectiveness of the process include: *Air flow through the saturated zone may not be uniform, which implies that there can be uncontrolled movement of potentially dangerous vapors. *Depth of contaminants and specific site geology must be considered. *Air injection wells must be designed for site-specific conditions. *Soil heterogeneity may cause some zones to be relatively unaffected.		Air sparging has a medium to long duration which may last, generally, up to a few years.				http://www.frtr.gov/matrix2/section4/4-34.html	Characteristics that should be determined include vadose zone gas permeability, depth to water, ground water flow rate, radial influence of the sparging well, aquifer permeability and heterogeneities, presence of low permeability layers, presence of DNAPLs, depth of contamination, and contaminant volatility and solubility. Additionally, it is often useful to collect air-saturation data, in the saturated zone, during an air sparging test, using a neutron probe.
Electrokinetics	A low-intensity direct current (mA/cm^2) through soil between ceramic electrodes mobilizes charged species toward the individual electrodes[1]	in development[2]	Heavy metals[1], organic contaminants[1], chromium[2]	Applicable in low permeability soils1. Electrokinetics is most effective in clays because clay particles have a negative surface charge3. Electrokinetics is primarily used to remove metals and radionuclides in low permeability soils. It may also be used for organic compounds, including VOCs and pesticides, although as noted above (electrode clogging), there have been some problems with this application3.					DuPont R&D ($85/$m^3$), Electrokinetics, Inc. ($25-130/$m^3$), Geokinetics International ($80-300/$m^3$)	[1]http://www.clu-in.org/download/remed/elctro_o.pdf (Electrokinetics01.pdf), 2http://costperformance.org/profile.cfm?ID=246&CaseID=246, 3http://www.cpeo.org/techtree/ttdescript/elctro.htm	Tests (electrical conductivity, pH, chemical analysis of pore water/soil) are required to determine if the site is amenable to the technology[1]
In Situ Flushing	Injection or infiltration of an aqueous solution into a zone of contaminated soil/groundwater, followed by downgradient extraction of groundwater and elutriate and aboveground treatment and discharge or re-injection.	successful implementation is highly site-specific.	Non-aqueous phase liquid (NAPL), VOCs, semi-VOCs, PCBs, halogenated pesticides, dioxin/furans, cyanides, corrosives.	Depth is a limiting factor primarily due to the economics involved with injection and extraction. Permeability is a key physical parameter in determination of the feasibility of in situ flushing.						In Situ Flushing, Technology Overview Report, TO-97-02, by Diane S. Roote, June 1997, GWRTAC (InSituFlushing_01.pdf)	concentration and distribution of contaminant, adsorption to specific size fractions of soil, solubility, partition coefficient, vapor pressure, estimate of hydraulic conductivity, soil structure and texture, porosity, moisture content, Total Organic Carbon (TOC), Cation Exchange Capacity (CEC), pH, and buffering capacity

Technology	Technology Description	Development Status	Targeted Contaminant	Applicability	Treatment Train	Time to Treat	Availability	Health and Safety Concerns	Vendor Information	References	Prerequisites
In Situ Oxidation	In situ chemical oxidation involves the introduction of strong oxidants in the subsurface where they can in situ destroy the contaminants of concern.		organic contaminants		Excavation, Soil Vapor Extraction, Flushing prior to In Situ Oxidation					In situ Chemical Oxidation - State of the Art, by Aikaterini Tsitonaki and Poul L. Bjerg, October 2008. (InSituOxidation_01.pdf)	
In-Well Vapor Stripping (In situ vapor/air stripping)	In-well vapor stripping technology involves the creation of a ground-water circulation pattern and simultaneous aeration within the stripping well to volatilize VOCs from the circulating ground water. Air-lift pumping is used to lift ground water and strip it of contaminants. Contaminated vapors may be drawn off for aboveground treatment or released to the vadose zone for biodegradation. Partially treated ground water is forced out of the well into the vadose zone where it reinfiltrates to the water table. Untreated ground water enters the well at its base, replacing the water lifted through pumping. Eventually, the partially treated water is cycled back through the well through this process until contaminant concentration goals are met.	Usually conducted on pilot-scale	VOCs (e.g., TCE, TPH, BTEX)	Site soil conditions seem to be less of a limitation for in-well stripping than air sparging, since air movement through aquifer material is not required for contaminant removal. In-well vapor stripping has been applied to a wide range of soil types ranging from silty clay to sandy gravel. Advantages of in-well stripping include lower capital and operating costs due to use of a single well for extraction of vapors and remediation of ground-water and lack of need to pump, handle, and treat ground-water at the surface. Additional advantages: easy integration with other remediation techniques such as bioremediation and soil vapor extraction; simple design with limited maintenance requirements. Limitations reported include limited effectiveness in shallow aquifers, possible clogging of the well due to precipitation, and the potential to spread the contaminant plume if the system is not properly designed or constructed.						In-well Vapor Stripping, Technology Overview Report, TO-97-01, by Ralinda R. Miller and Diane S. Roote, February 1997, GWRTAC (InWellStripping_01.pdf)	
Multi-Phase Extraction	This technology uses a high vacuum system to remove various combinations of contaminated ground water, separate-phase petroleum product, and hydrocarbon vapor from the subsurface. Extracted liquids and vapor are treated and collected for disposal, or re-injected to the subsurface (where permissible under applicable state laws).===Synonyms: Dual-Phase Extraction, Vacuum-enhanced extraction, bioslurping, free product recovery, liquid-liquid extraction.		Long-chained hydrocarbons, VOCs, fuels,	Multi-phase vacuum extraction is more effective than SVE for heterogeneous clays and fine sands. However, it is not recommended for lower permeability formations due to the potential to leave isolated lenses of undissolved product in the formation.	bioremediation, air sparging, or bioventing, pump-and-treat				http://www.frtr.gov/matrix2/appd_a/vendor.html#water_ex_chem	http://www.frtr.gov/matrix2/section4/4-37.html	Data needs include physical and chemical properties of the product released (e.g., viscosity, density, composition, depth, and solubility in water); soil properties (e.g., capillary forces, effective porosity, moisture content, organic content, hydraulic conductivity, and texture); nature of the release (e.g., initial date of occurrence, duration, volume, and rate); geology (e.g., stratigraphy that promotes trapped pockets of free product); hydrogeologic regime (e.g., permeability, depth to water table, ground water flow direction, and gradient); and anticipated product recharge rate.
Multi-Phase Extraction	Bioslurping involves the simultaneous application of vacuum enhanced extraction/recovery, vapor extraction, and bioventing to address LNAPL contamination. Vacuum extraction/recovery is used to remove free product along with some groundwater, vapor extraction is used to remove high volatility vapors from the vadose zone, and bioventing is used to enhance aerobic biodegradation in the vadose zone and capillary fringe.		LNAPL	Use of bioslurping has occurred mostly at sites with fine to medium grained overburden materials, but has also been used successfully at sites with medium to coarse grained materials and in fractured rock.						Bioslurping, Technology Overview Report, TO-96-05, by Ralinda R. Miller, October 1996, GWRTAC (MultiPhaseExtraction_01.pdf)	* LNAPL analysis for BTEX and boiling-point distribution of hydrocarbons; * Particle-size distribution, bulk density, porosity, moisture content, BTEX, and TPH content of site soils; * Baildown tests to determine LNAPL recovery rate; * Soil gas permeability test to determine radius of influence of extraction well (conducted during bioslurping test); * In situ respiration test to determine biodegradation rates.

Technology	Technology Description	Development Status	Targeted Contaminant	Applicability	Treatment Train	Time to Treat	Availability	Health and Safety Concerns	Vendor Information	References	Prerequisites
Permeable Reactive Barrier	Reactive material is placed in the subsurface where a plume of contaminated ground water move through it as it flows, typically under its natural gradient (passive system) and treated water comes out the other side	Under development	Fe(0), as the reactive media. Reductively dehalogenate hydrocarbons, such as convertingtrichloroethene (TCE) to ethene, Cr(VI) to Cr(III), organic-catalyzed conversion of nitrate and sulfate.	50 to 70 feet bgs. Case studies on various scales available in Appendix A in the reference to the right.						Permeable reactive barrier technologies for contaminant remediation, EPA, September 1998, EPA/600/R-98/125 (PRB_02.pdf)	
Permeable Reactive Barrier	Passive groundwater treatment systems that decontaminate groundwater as it flows through a permeable treatment medium under natural gradients. Remediates soil as well.	Zero-valent iron being the most common reactive material, a variety of other adsorptive, reactive, and biodegradation-enhancing materials also being developed.	chlorinated solvents, organics, metals, inorganics, radionuclides	Gaining popularity as an alternative to pump-and-treat systems, which require higher energy consumption and aboveground structures.						Tech Data Sheet, Naval Facilities Engineering Command, NFESC TDA-2089-ENV, August 2002. (PRB_01.pdf)	
Soil Vapor Extraction	Soil vapor extraction or SVE removes harmful chemicals, in the form of vapors, from the soil above the water table. Vapors are the gases that form when chemicals evaporate. The vapors are extracted (removed) from the ground by applying a vacuum to pull the vapors out.		Solvents and fuels that evaporate easily.	Soil vapor extraction or SVE removes harmful chemicals, in the form of vapors, from the soil above the water table.		Years				A Citizen's guide to soil vapor extraction and air sparging, USEPA, EPA 542-F-01-006, April 2001, Office of Solid Waste and Emergency Response (5102G) (SoilVaporExtraction_01.pdf)	
Soil Washing	Soil washing “scrubs” soil to remove and separate the portion of the soil that is most polluted. This reduces the amount of soil needing further cleanup. Soil washing alone may not be enough to clean polluted soil. Therefore, most often it is used with other methods that finish the cleanup.					The time it takes to clean up a site using soil washing depends on several factors: • amount of silt, clay, and debris in the soil • type and amount of pollution in the soil • size of scrubbing unit (The largest units can clean up to 100 cubic yards of soil per day.) Cleanup usually takes weeks to months, depending on the site.				A Citizen's Guide to Soil Washing, USEPA, EPA 542-F-01-008, May 2001, Office of Solid Waste and Emergency Response (5102G) (SoilWashing_01.pdf)	
Soil Washing	For soil washing, contaminants sorbed onto fine soil particles are separated from bulk soil in a water-based system on the basis of particle size. The wash water may be augmented with a basic leaching agent, surfactant, or chelating agent or by adjustment of pH to help remove organics and heavy metals. Soils and wash water are mixed ex situ in a tank or other treatment unit. The wash water and various soil fractions are usually separated using gravity settling.		organics and heavy metals							http://www.clu-in.org/techfocus/default.focus/sec/Soil%5FWashing/cat/Overview/	
Solvent Extraction	Solvent extraction (also known as chemical extraction) is a cleanup method that uses solvents to extract or remove harmful chemicals from polluted materials. Chemicals like PCBs, oil, and grease do not dissolve in water. Instead, they tend to stick or sorb to soil, sediment, and sludge, making it hard to clean them up. Solvents are chemicals that can dissolve sorbed chemicals and remove them from polluted materials.		polychlorinated biphenyls (PCB), petroleum hydrocarbons, chlorinated hydrocarbons, polynuclear aromatic hydrocarbons, polychlorinated dibenzo-p-dioxins, polychlorinated dibenzo-p-furans, and metals.	Before using solvent extraction, the soil must be dug from the polluted area to be treated. The soil is sifted to remove large objects like rocks and debris. The sifted soil is then placed in a machine called an extractor where it is mixed with a solvent. The type of solvent will depend on the harmful chemicals present and the material being treated.		Solvent extraction can clean up to 125 tons of soil at a site per day. The time it takes to clean up a site depends on several factors:• amount of polluted soil • type of soil and conditions present (Is it wet or dry? Does it contain a lot of debris?) • type and amounts of harmful chemicals present. Cleanup usually takes less than a year, depending on the site.				Terra-Kleen Response Group, Inc. Solvent Extraction Technology, Innovative Technology Evaluation Report, EPA/540/R-94/521, September 1998. (SolventExtraction_01.pdf) A Citizen's Guide to Solvent Extraction, USEPA, EPA 542-F-01-009, October 2001, Office of Solid Waste and Emergency Response (5102G) (SolventExtraction_02.pdf)	

Thermal Treatments

Tech Class	Technology	Technology Description	Development Status	Targeted Contaminant	Applicability	Treatment Train	Time to Treat	Availability	Health and Safety Concerns	Vendor Information	References
	XYZ	Describe the technology and it's use.	What is the maturity of the technology (emerging, in development, or proven)?	What contaminates does the technology effectively treat for?	In what conditions is this technology applicable (up to 10ft below surface, soil pH above)?	Is this technology typically used as part of a suite of treatment technologies? If so identify the treatment train.	How long does it take to treat a typical site?	From how many vendors is this technology available?	Identify potential health and safety concerns (permits required, bi-products /residuals produced).	Provide contact information for vendors.	Identify information sources. Include links if available.
	Ex situ										
Incineration	**Incineration**	Combustion of waste	Mature, most common treatment technique, used international. Public concerns has reduced its use for hazardous and radioactive waste treatment in US.	Organics, (PCB, dioxin possible), heavy metals and/or radionuclides captured, treated or bound to soils (reduced leachability via H2O)	ex situ, can accommodate soils, sediments liquids and sludges however mostly used on high energy content wastes. Size reduction may be necessary. Not appropriate for certain radionuclides, mercury, explosives or reactive waste. Heating soil above 1000C has ability to reduce H2) radionuclide leachability for certain radioisotopes and soils.	solidification (ash and slag)	up to 400kg/hr solids and 450 l/hr liquids	multiple	Adequate off-gas treatment is necessary to reduce particulate and NOx, SOx emissions. Volatile metals must be addressed. Ash may require treatment depending on waste material properties. Permitting potential is dependent on location and regulating agency. Generally not practical in populated areas. Incineration in general is not publicly accepted. Although the technology to reduce emissions is mature and effective, past issues with incineration and down wind contamination has given the technology an unacceptable view by stakeholders. http://www.frtr.gov/matrix2/health_safety/chapter_24.html	http://www.epareachit.org/index.html (ASTEC Inc., Shaw Group)	http://www.frtr.gov/matrix2/section4/4-23.html
	Circulating Bed Combustor (CBC) a type of Fluidized Bed Combustors	This is a thermal destruction system that uses high velocity air to entrain a bed of solid materials in a circulating and highly turbulent reaction chamber heated between 1400 and 1800C.. Waste is injected into the circulating bed and combusted. An off-gas system is used to treat byproducts. Additive can be used to react with acids and sulfur in the reaction chamber.	Proven	Organics, (PCB, dioxins possible), heavy metal captured or treated	ex situ	Off-gas treatment/contaminant capture		multiple	same as incineration	Ogden Environmental Services (1991).	http://www.frtr.gov/matrix2/section4/4-23.html
	Fluidizer Bed (calcine)	Vertical cylindrical system refractory lined with a bed of inert material on a perforated plate. A burner heats the bed from above to approx 900C. Waste is injected on the bed with air blown upwards through the bed. Uses high temperature oxidation to destroy organics in liquid, gas, and solid wastes, most often sludges. Particulates are blown out of the system through an afterburner and off-gas system.	Proven	Organics, (PCB, dioxins possible), heavy metal captured or treated	ex situ, solids, liquids, gasses and sludges. Sludges preferred. Size reduction may be necessary. Possible secondary treatment needed.	Off-gas treatment/contaminant capture		multiple	Same as incineration	http://www.epareachit.org/index.html	
	Hot Gas Decontamination	The process decontaminates equipment or other materials by heating them to approximately 260C. An off-gas system is necessary and may include an afterburner. The process is intended to be used to drive off the contaminant allowing the treated materials to be reused or recycled.	Proven	Organics, hazardous materials, explosives.	Generally used to treat contaminated equipment or materials intended to be recycled. May be used to decontaminate building materials, mass	Off-gas treatment/contaminant capture		few			
	Infrared Thermal Destruction	Infrared is used in a chamber furnace to incinerate waste. Chamber is heated by infrared heating elements (silicon carbide) from 500 to 1000C. Secondary chamber (hydrocarbon fired) can be used to complete gas-phase combustion reactions. Off-gas treatment necessary. Solid byproducts may need treatment.		Organics, (PCB, dioxins possible), heavy metal captured or treated	ex situ	Off-gas treatment/contaminant capture		few			http://www.frtr.gov/matrix2/section4/4-23.html
	Open Burn/Detonation	Open burn and open detonation are used to destroy munitions and explosive. Open burning of munitions generally by self-sustaining combustion. May require external source for initial burn. Explosive waste may be detonated by separate initiating explosive. Burns and detonations are performed in the open environment under controlled conditions.	Proven	Explosives, energetic materials and munitions. Pyrophoric materials possible.	Since waste is treated in the open atmosphere, only waste with no or low hazardous emissions can be treated.		milliseconds…	multiple	http://www.frtr.gov/matrix2/health_safety/chapter_26.html	NA	

Tech Class	Technology	Technology Description	Development Status	Targeted Contaminant	Applicability	Treatment Train	Time to Treat	Availability	Health and Safety Concerns	Vendor Information	References
	Rotary Hearth Furnace	Rotary Hearth Furnace is similar to the rotary kiln design except the furnace uses a rotating table that allows input and output of materials . System uses multiple chambers for combustion of off-gas products and off-gas treatment.	Proven	Organics, (PCB, dioxins possible), heavy metal captured or treated	ex situ soils, high and low BTU materials	Off-gas treatment/contaminant capture		multiple	Same as incineration	http://www.hitemptech.com/furnhearthdual.htm	http://www.frtr.gov/matrix2/section4/4-23.html
	Rotary Kiln	Most common type- rotary kiln with afterburner. Waste is combusted with air at temps near 1500C in an inclined cylindrical rotating refractory lined shell. Off-gas treatment necessary to remove particulates, NOx, SOc, acidic gasses an volatile metals.	Proven - example 99.9999 for PCB	Organics, (PCB, dioxin possible), heavy metal captured or treated	ex situ, soils, sediments and sludges. Size reduction may be necessary	Off-gas treatment/contaminant capture	2-5 tons/hr (solids) modile Ensco unit	Multiple, more than 20	Same as incineration	http://www.frtr.gov/matrix2/section4/4-23.html http://www.ehso.com/cssepa/tsdfincin.php , http://www.tarmacinc.com/equipment.php?cat=2,45,43	http://www.frtr.gov/matrix2/section4/4-23.html
Pyrolysis	**Pyrolysis**	General: High temperature is used in a semi-closed system in the absence of O2. N2 is usually used to sweep the by-products out of the system through an off-gas system. The waste is not combusted such that the resulting by-products do not have CO, NOx.	various	Organics, PCBs dioxin, radionuclides, heavy metals	ex situ; Solids, liquids and gasses of organic wastes (carbon, hydrogen oxygen) Problematic for waste containing nitrogen, sulfur silicon, sodium, bromide, iodine, potassium and phosphorous. Alkali metals form low melting salts the make fluidided beds less effective.	Resulting products may require further treatment. Radionuclides would be included in output stream which may be further treated by solidification or vitrification.					
	Advanced Electric Reactor	A type of pyrolysis system. Electrically heated carbon electrodes are used for radiant heating of a porous reactor core. NO2 is pumped through the porous core isolating it from the waste in the reactor chamber. An off gas system is used to capture and treat the resultant byproducts.	Trials run on test materials. No information past 1989.	Organics, PCBs dioxin	Treats only single phase materials. Solids must be processed through a fine mesh.			few		patent - J.M. Huber Corp.	http://www.sciencedirect.com/science/article/pii/0304389485850032
	Electric Arc Pyrolysis	Consumable electrodes produce an arc that is used to heat waste in a reaction chamber. Temps at 1450-1800C. Off gas treatment necessary for vaporized metals and other byproducts		Organics, PCBs dioxin	soils, solids, sludges	Resulting products may require further treatment.		multiple		Electro-Pyrolysis and integrated Environmental Technologies	www-pub.iaea.org/MTCD/publications/PDF/te_1527_web.pdf
	Molten Salt Reactor	A heated liquefied salt is injected with waste (pyrolysis), a secondary reactor may be used to combust generated gasses or an off gas system can be used to capture byproducts. Specific salts can be used in the process that will react with the decomposition products, effectively trapping these elements in the salt. The salt requires replacement or treatment to remove ash and reacted salts (melt removal).	pilot scale. Tested at ETEC for use in Oak Ridge Intermediate waste.	Organics, PCBs dioxin; heavy metals, radionuclides, other inorganics are retained in salt that can be further processed or disposed.	ex situ organics. Not generally acceptable for soils since the generated salt waste would include the soil. No technical post treatment processes to separate the soil from the resulting salt waste were found.	Resulting products may require further treatment. Radionuclides would be included in output stream which may be further treated by solidification or vitrification.	500 lbs/hr	few		Rockwell, Molten Salt Oxidation Corp.	www.dtic.mil/ndia/2007global_demil/SessionIVA/0800Rivers.pdf http://www.osti.gov/bridge/purl.cover.jsp?purl=/10133119-RYQjq0/ EPA/600/2-86/096
	Plasma Arc Pyrolysis	A plasma arc (torch) is used in a low pressure, low O2 chamber to decompose waste at temperature approaching 10,000C. Liquid is sprayed through the arch and into the furnace chamber (1000C reactor/mixing zone). Off gas system removes byproducts.	proven - applications for syngas from waste and possible power generation systems. Meltran in Korea, PEAT in US, Japan and Swiss	Organics, PCBs dioxin	ex situ; Generally applicable to high energy content waste and liquids. Proposed for insitu vitrification using boreholes and plasma torches.	Resulting products may require further treatment. Radionuclides would be included in output stream which may be further treated by solidification or vitrification.		multiple		Retech, Plasma Energy Applied Technology Inc, Startech, USPlasma, Meltran, Thermal Conversion http://www.httcanada.com/ http://www.enersoltech.com/	http://www.trackg.com/R4CleanEnergy/Presentation-slides/Tuesday-tech-Ben%20Taube/Lou%20Circeo-Plasma%20Arc%20Gasification%20of%20Solid%20Waste.ppt#476,22,Commercial Plasma Waste Processing Facilities (Asia)
	Steam Reformers	Reduction of organics with steam produces combustible gasses that are further combusted or captured. Pyrolysis with lower oxidation and reduction that other processes. Less off-gas.	Pilot scale (various DOE initiative), industrial scale (Studvik Processing Facility Tennessee, USA).	Organics, metals, soils and radionuclides	ex situ soils, organics. Not generally applicable for chlorides, alkali metals and sodium waste.		1-12 kg/hr	few		GTC Duratek, Studsvik (THOR)	
	Supercritical Water Oxidation	Water and waste are processed at a temperature and pressure above the critical point of water. At this point, water is soluble to many organic allowing these compounds to oxidize. Salts also precipitate and can be separated. Process temperature are between 400 and 650C.	U.S. Pilot scale, Commercial applications in S. Korea, Japan and Ireland (Sweden. ??)	Organics, PCBs dioxin	ex situ organics		3 m3/hr.	few		General Atomics, Foster Wheeler Development Corp, Eco Waste	www-pub.iaea.org/MTCD/publications/PDF/te_1527_web.pdf
	Wet Oxidation - Catalytic Aqueous Process	Wet Oxidation process with FeCL3 and HCl using 200C and up to 200 psig	not fully demonstrated - bench scale	Organics, PCB, radionuclides	ex situ			few		Delphi Research Inc - Delphi DETOX	www-pub.iaea.org/MTCD/publications/PDF/te_1527_web.pdf

Tech Class	Technology	Technology Description	Development Status	Targeted Contaminant	Applicability	Treatment Train	Time to Treat	Availability	Health and Safety Concerns	Vendor Information	References
Thermal Desorption	**Thermal Desorption**	Treatment heats waste to drive off moister and organic compounds which can be condensed or captured (carbon beds) or burned in an afterburner. A carrier gas may be used besides air to avoid combustion. A vacuum can be used instead of a carrier gas to desorbs volatile and SVO. Temperature can be raised to the point were organics are pyrolysis (high temp thermal desorption) or to avoid pyrolization (low temperature desorption).	Proven	VOC, SVOC, petroleum hydrocarbons, halogenated and non-halogenated solvents	ex situ soils, organics. Not generally applicable for chlorides, alkali metals and sodium waste.			multiple	http://www.frtr.gov/matrix2/health_safety/chapter_23.html		
	High Temperature Thermal Desorption	Thermal desorption as described above using a temperature that facilitates pyrolysis of the non-volatile organics or all organics (750C). Can use carrier gas or vacuum. Off gas/particulate system necessary.	Proven.	VOC, SVOC, petroleum hydrocarbons, halogenated and non-halogenated solvents, mercury and other low temperature volatile metals, certain radionuclides	ex situ,			various vendors		SeparDyne, EcoLogic, Hart, IT Corp	
	Low Temperature Thermal Desorption (LTTD) and Low Temperature Thermal Stripping	Soil remediation techniques that removes low temp volatiles (hydrocarbons) by heating in a closed system to between 90 and 320 C. May use afterburner of condenser.	proven	Organics and VOCs at specific temps, petroleum hydrocarbons and solvents	ex situ soils, organics. Not generally applicable for chlorides, alkali metals and sodium waste. May require soil pretreatment based on soil type.			few		http://www.frtr.gov/matrix2/appd_a/vendor.html#soil_ex_therm	http://en.wikipedia.org/wiki/Low-temperature_thermal_desorption , http://www.frtr.gov/matrix2/section4/4-26.html
	Low Temperature Thermal Treatment (LT3@)	Treatment technology volatilizes the contaminants from the soil (400F), volatiles are generally condensed. System uses low flow, low O2 closed system such that the contaminants are removed from the soils without combustion or decomposition. Results in treated soil, fabric filter dust, treated condensate and treated stack gas.	Proven	VOC, SVOC, petroleum hydrocarbons, halogenated and non-halogenated solvents,	ex situ soils, organics. Not generally applicable for chlorides, alkali metals and sodium waste. May require soil pretreatment based on soil type.			few	May increase SVOC, dioxin and furans concentrations (formed during treatment)	Weston	EPA/540/AR-92/019
	Radionuclide Fixation in Soil	By thermally treating soil, radionuclide mobility is reduced compared to untreated solid. Radionuclide solubility in groundwater water is reduced. Treating soil (quarts, feldspar, calcite) to 1000C in contact with sorbed radionuclides reduces mobilization (Sr90, Co57, Cs134, U)	R&D	Radionuclides	Fixation of radionuclides to sand -type soils	Can be a byproduct of other thermal treatment techniques.		unknown			Env Science Technol. 2001, vol.35, 4327-4333
	SVE - Solar Detoxification	Used with SVE, condensed contaminants are mixed with water and catalyst which is activated by ultraviolet light to break down organics into non-hazardous components	R&D	organics, SVOC, VOC, solvents, pesticides	Organics, solvents, pesticides - generally a groundwater treatment but could be used for condensate or condensed off-gas.	Used with SVE or to treat condensed contaminants from off-gas systems.		unknown			
	General Thermal Treatment Issues:	Thermal treatment is used to treat organics, for size reduction and convert waste into a more homogeneous material. This technique can be used to remove, capture, oxidize/reduce volatile and semi-volatile organic and oxidize/reduce non-volatile organics. Metals may be melted and recovered or captured in an off-gas system if they are volatilized in the process. Certain radionuclides can be volatilized and may be partially captured in the off-gas system however some will certainly escape to the environment. These radionuclides include H3, C14, I129									
	In Situ										
	Hot Air/Steam Injection generally with soil vapor extraction (SVE)	Hot air or steam is injected into the contaminated underground formation or zone to enhance release of contaminants from the formation. Technology is used to enhance SVE by increasing volatilization of contaminants.	thermally enhanced SVE proven	Organics, PCBs, VOC, SVOC, pesticides	vadose zone only, dependent on soil saturation, well spacing, porosity, contaminant thermal properties soil matrix properties.	SVE, zero valent Fe		multiple			
	Radiofrequency or microwave heating	RF is used to heat a target area. Generally heats soil to less than 100C. Is generally used to increase effectiveness of SVE.	bench and pilot scale	SVOC, VOCs, PAH	Dependent on soil properties, requires H20 or other polar components to generate heat	SVE, zero valent Fe		few			Environ Sci Technol 1998, 32, 2602-2607
	Thermal Blanket (ISTD) in-situ thermal desorption	Thermal blanket heats soil to temperatures above 200C to desorbs or destroy organics. A negative pressure off-gas system is used to capture and treat vapors (afterburner, condenser, carbon, etc).	Full Scale proven	Organics, PCBs, VOC, SVOC, pesticides	Treats surface contamination to a depth of 15cm. Depth dependent on soil conditions and blanket specifications. Test to verify 200C is reached to target depth.	SVE	Treated area of blanket approx 24 hrs, dependent on soil and blanket specifications	few	incomplete destruction of contaminants may cause dioxin and furans	Therra Therm	http://pubs.acs.org/doi/abs/10.1021/es9506622

Tech Class	Technology	Technology Description	Development Status	Targeted Contaminant	Applicability	Treatment Train	Time to Treat	Availability	Health and Safety Concerns	Vendor Information	References
	Vertical Thermal Well, Resistivity heating/high temperature thermal conduction/insitu thermal desorption and destruction (ISTD)	Soil is heated by resistive electrical heating elements in a closely-spaced well network. Wells under vacuum to move contaminants, organics are oxidized/pyrolysized in the well, remaining contaminants are treated at the surface. Soil temperature can reach 700C.	thermally enhanced SVE proven	organics, SVOC, VOCs, PCBs, pesticides, PAH	vadose zone only, dependent on soil saturation, well spacing, temperature.	SVE, surface oxidation of off-gas, zero valent Fe		few		http://www.terratherm.com/ http://www.mktechsolutions.com/ISTD.htm	
	Vitrification	Media is subjected to temperatures in excess of 1200C to form stable glass or glass crystalline materials. Organics are destroyed and radionuclides are bound in a less soluble and leachable form. An off-gas hood is used to collect gasses, particulate or HEPA filters.	Demonstration	Organics, VOC, SVOC destruction. radionuclides, metals/heavy metals, inorganics fixed in matrix.	Destroys organics and reduces mobility of radionuclides. Soil must have sufficient amounts of conductive cations and glass-forming metal oxides to allow soil melting and stable monolith formation. 3x3m min to 9x9m max area, 9m max depth, 188 to 1000 ton melt max.	Off-gas system, SVE possible	4-6 tons/hr	few		Geosafe, DOE (PNNL), TVS at Oak Ridge (Envitco)	EPA/540/R-94/520

Nanotechnologies

Tech Class	Technology	Technology Description	Development Status	Targeted Contaminant	Applicability	Treatment Train	Time to Treat	Availability	References	Health and Safety Concerns	Vendor Information
	XYZ	Describe the technology and it's use.	What is the maturity of the technology (emerging, in development, or proven)?	What contaminates does the technology effectively treat for?	In what conditions is this technology applicable (up to 10ft below surface, soil pH above)?	Is this technology typically used as part of a suite of treatment technologies? If so identify the treatment train.	How long does it take to treat a typical site?	From how many vendors is this technology available?	Identify information sources. Include links if available.	Identify potential health and safety concerns (permits required, bi-products /residuals produced).	Provide contact information for vendors.
nologies (in- and ex-situ)	Bimetallic nanoscale particles (BNPs)	particles of elemental iron or other metals in conjunction with a metal catalyst, such as platinum, gold, nickel, and palladium, used for contaminant degradation	Bench-scale	Tetrachloroethene (PCE), TCE, cis-1,2-dichloroethylene (c-DCE), vinyl chloride (VC), and 1-1-1-tetrachloroethane (TCA), polychlorinated biphenyls (PCBs), halogenated aromatics, nitroaromatics, metals such as arsenic and chromium, nitrate, perchlorate, sulfate, and cyanide	Soils; Groundwater; Organics	Gravity or pressurized injection; direct-push injection; pressure pulse, atomization, and pnuematic/hydraulic fracturing			Zhang and Elliot (2006); Nutt et al. (2005); Gill (2006)	Substances considered nontoxic at the macroscale may have negative impacts on human health when nanoscale particles are inhaled, absorbed through the skin, or ingested potential to migrate to, or accumulate in, places that larger particles cannot, such as the alveoli; demonstrated ability to increase the bioavailability of certain contaminants	ARS Technologies; VeruTEK Technologies, Inc.; Hepure Technologies; OnMaterials Inc.; Polyflon Company a Crane Co. Company (makes PolyMetallix); PARS Environmental Inc.; Pneumatic fracturing inc.; Green Millennium, Inc.; Toda America maker of RNIP;
	Dendrimers	Hyper-branched, well-organized polymer molecules with three components: core, branches, and end groups. Dendrimer surfaces terminate in several functional groups that can be modified to enhance specific chemical activity.	Bench-scale	PCE, TCE	In-situ/Ex-situ; Soils; Groundwater (in PRBs); DNAPLs					Substances considered nontoxic at the macroscale may have negative impacts on human health when nanoscale particles are inhaled, absorbed through the skin, or ingested potential to migrate to, or accumulate in, places that larger particles cannot, such as the alveoli; demonstrated ability to increase the bioavailability of certain contaminants	ARS Technologies; VeruTEK Technologies, Inc.; Hepure Technologies; OnMaterials Inc.; Polyflon Company a Crane Co. Company (makes PolyMetallix); PARS Environmental Inc.; Pneumatic fracturing inc.; Green Millennium, Inc.; Toda America maker of RNIP;
	Emulsified zero-valent iron (EZVI)	Nano- or microscale ZVI surrounded by an emulsion membrane that facilitates treatment of chlorinated hydrocarbons	Bench-scale	Tetrachloroethene (PCE), TCE, cis-1,2-dichloroethylene (c-DCE), vinyl chloride (VC), and 1-1-1-tetrachloroethane (TCA), polychlorinated biphenyls (PCBs), halogenated aromatics, nitroaromatics, metals such as arsenic and chromium, nitrate, perchlorate, sulfate, and cyanide	Organics (DNAPL); Soils; Groundwater	Gravity or pressurized injection; direct-push injection; pressure pulse, atomization, and pnuematic/hydraulic fracturing			O'Hara et al. (2006); Quinn et al. (2005)	Substances considered nontoxic at the macroscale may have negative impacts on human health when nanoscale particles are inhaled, absorbed through the skin, or ingested potential to migrate to, or accumulate in, places that larger particles cannot, such as the alveoli; demonstrated ability to increase the bioavailability of certain contaminants	ARS Technologies; VeruTEK Technologies, Inc.; Hepure Technologies; OnMaterials Inc.; Polyflon Company a Crane Co. Company (makes PolyMetallix); PARS Environmental Inc.; Pneumatic fracturing inc.; Green Millennium, Inc.; Toda America maker of RNIP;
	Ferritin	an iron storage protein, have indicated that it can reduce the toxicity of contaminants such	Bench-scale	chromium and technetium	In-situ					Substances considered nontoxic at the macroscale may have negative impacts on human health when nanoscale particles are inhaled, absorbed through the skin, or ingested potential to migrate to, or accumulate in, places that larger particles cannot, such as the alveoli; demonstrated ability to increase the bioavailability of certain contaminants	ARS Technologies; VeruTEK Technologies, Inc.; Hepure Technologies; OnMaterials Inc.; Polyflon Company a Crane Co. Company (makes PolyMetallix); PARS Environmental Inc.; Pneumatic fracturing inc.; Green Millennium, Inc.; Toda America maker of RNIP;
	Metalloporphyrinogens (e.g. hemoglobin and vitamin B12)	Complexes of metals and naturally occurring, organic porphyrin molecules	R&D	TCE, PCE, and carbon tetrachloride	In-situ; Soils					Substances considered nontoxic at the macroscale may have negative impacts on human health when nanoscale particles are inhaled, absorbed through the skin, or ingested potential to migrate to, or accumulate in, places that larger particles cannot, such as the alveoli; demonstrated ability to increase the bioavailability of certain contaminants	ARS Technologies; VeruTEK Technologies, Inc.; Hepure Technologies; OnMaterials Inc.; Polyflon Company a Crane Co. Company (makes PolyMetallix); PARS Environmental Inc.; Pneumatic fracturing inc.; Green Millennium, Inc.; Toda America maker of RNIP;

Tech Class	Technology	Technology Description	Development Status	Targeted Contaminant	Applicability	Treatment Train	Time to Treat	Availability	References	Health and Safety Concerns	Vendor Information
Nanotech	Nanoscale zero-valent iron (nZVI)	Particles ranging from 10 to 100 nanometers in diameter or slightly larger. Shown to be effective for treating groundwater contaminants within PRBs but could apply to soils	Bench-, pilot- and full-scale	Tetrachloroethene (PCE), TCE, cis-1,2-dichloroethylene (c-DCE), vinyl chloride (VC), and 1-1-1-tetrachloroethane (TCA), polychlorinated biphenyls (PCBs), halogenated aromatics, nitroaromatics, metals such as arsenic and chromium, nitrate, perchlorate, sulfate, and cyanide	Soils (Vadose zone; Unsaturated media); Groundwater (saturated media)	Gravity or pressurized injection; direct-push injection; pressure pulse, atomization, and pnuematic/hydraulic fracturing			Zhang (2003); Saleh et al. (2007); Hydutsky et al. (2007); He et al. (2007); Quin et al. (2005), Tratnyek and Johnson (2006) and Phenrat et al. (2009); Cundy et al. (2008); Trues et al. (2011); Gwinn, M.R. and Vallyathan, V. (2006)	Substances considered nontoxic at the macroscale may have negative impacts on human health when nanoscale particles are inhaled, absorbed through the skin, or ingested potential to migrate to, or accumulate in, places that larger particles cannot, such as the alveoli; demonstrated ability to increase the bioavailability of certain contaminants	ARS Technologies; VeruTEK Technologies, Inc.; Hepure Technologies; OnMaterials Inc.; Polyflon Company a Crane Co. Company (makes PolyMetallix); PARS Environmental Inc.; Pneumatic fracturing inc.; Green Millennium, Inc.; Toda America maker of RNIP;
	Nanotubes	Electrically insulating, highly electronegative, and easily polymerizable engineered molecules most frequently made from carbon or TiO_2 and have demonstrated the potential for use as a photocatalytic degrader of chlorinated compounds	Bench-scale	chlorinated compounds	Ex-situ					Substances considered nontoxic at the macroscale may have negative impacts on human health when nanoscale particles are inhaled, absorbed through the skin, or ingested potential to migrate to, or accumulate in, places that larger particles cannot, such as the alveoli; demonstrated ability to increase the bioavailability of certain contaminants	ARS Technologies; VeruTEK Technologies, Inc.; Hepure Technologies; OnMaterials Inc.; Polyflon Company a Crane Co. Company (makes PolyMetallix); PARS Environmental Inc.; Pneumatic fracturing inc.; Green Millennium, Inc.; Toda America maker of RNIP;
	SAMMS™	Nanoporous ceramic substrate coated with a monolayer of functional groups tailored to preferentially bind to target contaminant	Pilot-scale	radionuclides, mercury, chromate, arsenate, pertechnetate, and selenite	Ex-situ; inorganics					Substances considered nontoxic at the macroscale may have negative impacts on human health when nanoscale particles are inhaled, absorbed through the skin, or ingested potential to migrate to, or accumulate in, places that larger particles cannot, such as the alveoli; demonstrated ability to increase the bioavailability of certain contaminants	ARS Technologies; VeruTEK Technologies, Inc.; Hepure Technologies; OnMaterials Inc.; Polyflon Company a Crane Co. Company (makes PolyMetallix); PARS Environmental Inc.; Pneumatic fracturing inc.; Green Millennium, Inc.; Toda America maker of RNIP;
	SOMS (syn: Osorb; e.g. Iron - Osorb & Palladium - Osorb)	Hydrophobic organically modified silica that swells on contact with and captures small molecule organic compounds. May capture up to eight-times its volume in organic compounds.	Bench- and pilot-scale	TCE; gasoline, natural gas, acetone, ethanol, pharmaceuticals, solvents	In-situ/Ex-situ; Soils (Vadose zone); Organics (NAPLs, Dissolved (aqueous phase), Vapors)				Kostantinou and Albanis (2003); Fryxell et al. (2007); Mattigod (2003); Tratnyek and Johnson (2006); Chen et al. (2005); Xu et al. (2005); Temple University (2006); EPA (2008); Diallo et al. (2006); Xu (2006); Dror et al. (2005); Karn et al. (2009); Gwinn and Vallyathan (2006)	Substances considered nontoxic at the macroscale may have negative impacts on human health when nanoscale particles are inhaled, absorbed through the skin, or ingested potential to migrate to, or accumulate in, places that larger particles cannot, such as the alveoli; demonstrated ability to increase the bioavailability of certain contaminants	ARS Technologies; VeruTEK Technologies, Inc.; Hepure Technologies; OnMaterials Inc.; Polyflon Company a Crane Co. Company (makes PolyMetallix); PARS Environmental Inc.; Pneumatic fracturing inc.; Green Millennium, Inc.; Toda America maker of RNIP;
Other Technologies	Hybridized Design for In-situ Enhanced Reductive Dechlorination (e.g. nZVi + Surfactant + Electrokinetics)	Remediation designs that employ multiple processes to achieve remediation targets	Conceptual; bench- and pilot-scale	All	All				Suthersan (2011)		
	MT2 ECOBOND	Chemical treatment processes for the remediation of heavy metals; achieved via MT2's process under the brand name ECOBOND®	Full-scale	Arsenic; Aluminum; Antimony; Barium; Cadmium; Chromium; Lead; Mercury; Selenium; Radionuclide; Zinc	Metals; soils; In- and ex-situ			MT2	http://www.mt2.com/ecobond.htm		MT2, LLC
	Monitored Natural Attenuation		Full-scale	Organics; In-situ	Primarily groundwater but adaptable to soils						

Tech Class	Process	Technology Description	*Species*	Targeted Contaminant	Health and Safety Concerns	Vendor information	Comments	Reference
		Describe the technology and it's use.		What contaminates does the technology effectively treat for?	Identify potential health and safety concerns (permits required, bi-products /residuals produced).	Provide contact information for vendors.		
	Bioaugmentation	The use of microorganism metabolism to remove contaminants from soils, water and other materials. Introduction of non-natural species to the contaminated soil.	*Clostridium sp./Pseudomonas fluorescens*	Uranium	Introduction of non-natural or non-native bacteria may need additional permitting as well as monitoring for environmental damage.	Multiple venders can be found to supply bacteria, implementation would need consideration	Collected soil samples from Fernald site in Ohio, RMI site in Ahstabula Ohio, and West End Treatment Fac at US DOE Oak RigdeY-12 Plant. All had uranium some technitium. Uranium was extracted with >85% efficiency using .4M Citric acid addition (Cr, Co, Mn, Ni, Sr, Th, Zn and Zr were also extracted)	FRANCIS, A.J., Dept. of Applied Science, Brookhaven National Lab, Upton, NY 11973, BNL-65782. 2009 BIOREMEDIATION OF URANIUM CONTAMINATED SOILS AND WASTES
Bioremediation	Bioaugmentation	The use of microorganism metabolism to remove contaminants from soils, water and other materials. Introduction of non-natural species to the contaminated soil.	*Acidothermophilic autotrophes*	Metals: Ag, Au, Cr, Cu, Ni, Pb and Zn but As, Bi, Cd, Co, Hg, Mo, Sn	Introduction of non-natural or non-native bacteria may need additional permitting as well as monitoring for environmental damage.	Multiple venders can be found to supply bacteria, implementation would need consideration	72 strains of acidothermophilic autotrophes are tested. (ATh-14) showed maximum adsorption of Ag 73%, followed by Pb 35%, Zn 34%, As 19%, Ni 15% and Cr 9% in chalcopyrite	Umrania, V.V., 2005. Bioremediation of toxic heavy metals using acidothermophilic autotrophes. Bioresource Technology 97 (2006) 1237–1242
	Bioaugmentation	The use of microorganism metabolism to remove contaminants from soils, water and other materials. Introduction of non-natural species to the contaminated soil.	*Shewanella sp.*	Uranium, Ni	Introduction of non-natural or non-native bacteria may need additional permitting as well as monitoring for environmental damage.	Multiple venders can be found to supply bacteria, implementation would need consideration	Assess the production of melanin production by bacteria which has redox cycling properties that increase metal reduction in-situ.Tims Branch watershed area of SRS	Turick, C.E., Kritzas, Y.G., 2004. Microbial Metabolite Production for Accelerated Metal and Radionuclide Bioremediation. Westinghouse Savannah River Company Savannah River Site. Aiken, SC 29801 Microbial Metabolite Production Report WSRC-MS-2004-00671
	Bioaugmentation	The use of microorganism metabolism to remove contaminants from soils, water and other materials. Introduction of non-natural species to the contaminated soil.	*Clostridium sp./Pseudomonas fluorescens*	Uranium	Introduction of non-natural or non-native bacteria may need additional permitting as well as monitoring for environmental damage.	Multiple venders can be found to supply bacteria, implementation would need consideration	Review of Bioremediation with bacteria. Description of process. Article focues mostly on Uranium citrate complex	Francis, A.J., 2006. Microbial Transformations of Radionuclides and Environmental Restoration Through BioremediationEvironmental Sciences Department. Brookhaven National Lab, Upton, NY 11973.
	Bioaugmentation	The use of microorganism metabolism to remove contaminants from soils, water and other materials. Introduction of non-natural species to the contaminated soil.	*ALL*	Hydrocarbons	Introduction of non-natural or non-native bacteria may need additional permitting as well as monitoring for environmental damage.	Multiple venders can be found to supply bacteria, implementation would need consideration	Paper discusses the PAHbase, which is a functional database of Polycyclic Aromatic Hydrocarbon degrading bacteria.	Surani, J.J., Akbari, V.G., Purohit, M.K., and Singh, S.P., 20011. Pahbase, a Freely Available Functional Database of Polycyclic Aromatic Hydrocarbons (Pahs) Degrading Bacteria. Journal of Bioremediation Biodegradation. 2011. 2:1
	Bioaugmentation	The use of microorganism metabolism to remove contaminants from soils, water and other materials. Introduction of non-natural species to the contaminated soil.	*various*	phenol, 2-MCP, ,2,4,6 TCP, PCP	Introduction of non-natural or non-native bacteria may need additional permitting as well as monitoring for environmental damage.	Multiple venders can be found to supply bacteria, implementation would need consideration	Discusses the implications and attributes of altering pH in order to make bacteria uptake more efficient	Antizar-Ladislao, B., Galil, N.I., 2004. Biosorption of phenol and chlorophenols by acclimated residential biomass under bioremediation conditions in a sandy aquifer. Water Research 38 (2004) 267–276
	Bioaugmentation	The use of microorganism metabolism to remove contaminants from soils, water and other materials. Introduction of non-natural species to the contaminated soil.	*Saccharomyces cerevisiae/Alcaligenes eutrophus*	Cu, Pb, Fe, Zn, Cd, Mn, Ni, Cr and Co	Introduction of non-natural or non-native bacteria may need additional permitting as well as monitoring for environmental damage.	Multiple venders can be found to supply bacteria, implementation would need consideration	Tolerance of microorganisms 250 ppm for Pb2+, 500 ppm for Cd2+. biosorption of about 67-82% of Pd2+ and 73-79 % of Cd2+ was attained within 30 days. The time taken for maximum sorption of Pb2+ and Cd2+ was 30 days for soil containing 100 and 300 ppm of Pb2+and Cd2+ respectively	Damodaran, D., Suresh, G., Mohan B, R., 2011. BIOREMEDIATION OF SOIL BY REMOVING HEAVY METALS USING Saccharomyces cerevisiae. 2011 2nd International Conference on Environmental Science and Technology IPCBEE vol.6 (2011) © (2011) IACSIT Press, Singapore
	Bioaugmentation	The use of microorganism metabolism to remove contaminants from soils, water and other materials. Introduction of non-natural species to the contaminated soil.		U, Th	Introduction of non-natural or non-native bacteria may need additional permitting as well as monitoring for environmental damage.	Multiple venders can be found to supply bacteria, implementation would need consideration	Characterization of the mechanism of binding for Uranium and thorium to Pseudomonas sp.	Kazya,S, K., D'Souzab, S.F., Sar, P., 2009. Uranium and thorium sequestration by a Pseudomonas sp.: Mechanism and chemical characterization. Journal of Hazardous Materials 163 (2009) 65–72
	Bioaugmentation	The use of microorganism metabolism to remove contaminants from soils, water and other materials. Introduction of non-natural species to the contaminated soil.	*various*	Chlorinated Solvent-trichloroethene	Introduction of non-natural or non-native bacteria may need additional permitting as well as monitoring for environmental damage.	Multiple venders can be found to supply bacteria, implementation would need consideration	A successful anaerobic bioaugmentation was carried out on trichloroethene (TCE)-contaminated site-Dover Air Force Base, DE. Microbes degrade TCE to ethene. Pilot operated 568 days. By day 509, TCE and cDCE were fully converted to ethene	Ellis, D. E., et al. 2000. Bioaugmentation for Accelerated In Situ anaerobic bioremediation. Environ. Sci. Technol. 2000, 34, 2254-22
	Bioaugmentation	The use of microorganism metabolism to remove contaminants from soils, water and other materials. Introduction of non-natural species to the contaminated soil.	*various*	all	Introduction of non-natural or non-native bacteria may need additional permitting as well as monitoring for environmental damage.	Multiple venders can be found to supply bacteria, implementation would need consideration	Good review of feasibility. Conclude that bioreactors have most success	El Fantroussi, S., and Agathos, S.N., 2005. Is bioaugmentation a feasible strategy for pollutant removal and site remediation? Current Opinion in Microbiology 2005, 8:268–275
	Bioaugmentation	The use of microorganism metabolism to remove contaminants from soils, water and other materials. Introduction of non-natural species to the contaminated soil.	*various*	Motor Oil	Introduction of non-natural or non-native bacteria may need additional permitting as well as monitoring for environmental damage.	Multiple venders can be found to supply bacteria, implementation would need consideration	Used a fixed bed bioreactor for each test. Biostimulation produced more CO2 and can be seen as a viable option.	Abdulsalam, S., Bugaje, I.M., Adefila, S.S., Ibrahim, S., 2011. Comparison of biostimulation and bioaugmentation for remediation of soil contaminated with spent motor oil. International Journal of Environment Science and Technology, Vol. 8, No. 1, 2010, pp. 187-194
	Biomining	Extraction of specific metals from their ores through biological means, usually bacteria	*Acidithiobacillus ferrooxidans/Acidithiobacillus thiooxidans/Acidithiobacillus caldus/Leptospirillum ferrooxidans/Leptospirillum ferriphilum ferriphilum*	Metals: Au, Cu, U,	Introduction of non-natural or non-native bacteria may need additional permitting as well as monitoring for environmental damage.	Multiple venders can be found to supply bacteria, implementation would need consideration	Review of Bioremediation with bacteria.	Siddiqui, M.H., Kumar, A., Kesari, K.K., and Arif, J.M., 2009. Biomining - A Useful Approach Toward Metal Extraction. American-Eurasian Journal of Agronomy 2 84-88

Tech Class	Process	Technology Description	*Species*	Targeted Contaminant	Health and Safety Concerns	Vendor information	Comments	Reference
	Biosorption	The use of microorganism metabolism to remove contaminants from soils, water and other materials. (physio-chemical binding of metals to non-viable biomass)	*Bacillus sphaericus*	As, Hg, Co, Fe and Cr	Introduction of non-natural or non-native bacteria may need additional permitting as well as monitoring for environmental damage.	Multiple venders can be found to supply bacteria, implementation would need consideration	Living vs. Dead B. sphaericus OT4b31 showed a biosorption of 25 and 44.5% of Cr respectively while B.sphaericus IV(4)10 showed a biosorption of 32 and 45%. Living cells of the twomost tolerant strains had the capacity to accumulate between 6 and 47% of Co, Hg, Fe and As. DEAD cells were better accumulators!!!!	Velásquez, L., Dussan, J., 2009. Biosorption and bioaccumulation of heavy metals on dead and living biomass of Bacillus sphaericus. Journal of Hazardous Materials 167 (2009) 713–716
	Biosorption	The use of microorganism metabolism to remove contaminants from soils, water and other materials. (physio-chemical binding of metals to non-viable biomass)	*Trichoderma sp./Agaricus sp.*	Cr	Introduction of non-natural or non-native bacteria may need additional permitting as well as monitoring for environmental damage.	Multiple venders can be found to supply bacteria, implementation would need consideration	pH 5.5 of chromium solution were 97.39% reduction by *Trichoderma* and 100% reduction by *Agaricus*	Vankar, P., Bajpai, D., Bioaccumulation and Biosorption of Chromium VI by different Fungal Species. 2007. 1st International Workshop for Advances in Cleaner Production.
	Biosorption	The use of microorganism metabolism to remove contaminants from soils, water and other materials. (physio-chemical binding of metals to non-viable biomass)	*Various*	Metals	Introduction of non-natural or non-native bacteria may need additional permitting as well as monitoring for environmental damage.	Multiple venders can be found to supply bacteria, implementation would need consideration	A really good review discussing the implications and applications of biosorption. Types and feasibility are discussed. Focuses mostly on wastewaters, however.	Wang, J., Chen, C., 2009. Biosorbents for heavy metals removal and their future. Biotechnology Advances 27 (2009) 195–226
	Biostimulation	The addition of nutrients and oxygen to increase natural bacterial growth and stimulate contaminant degredation.	*NA*	Uranium	Live bacteria stimulation may need some regulation for environmental purposes.	Multiple venders can be found to supply bacteria, implementation would need consideration	The addition of a carbon source in the subsurface of contaminated area can stimulate growth of uranium-reducing bacteria. Proposed for lightly contaminated areas.	Seyrig, G., 2010. Uranium bioremediation: current knowledge and trends. MMg 445 Biotechnology (2010) 6:19-24

Tech Class	Process	Technology Description	*Species*	Common Name	Targeted Contaminant	Health and Safety Concerns	Vendor Information	Comments	Reference
		Describe the technology and it's use.			What contaminates does the technology effectively treat for?	Identify potential health and safety concerns (permits required, bi-products /residuals produced).	Provide contact information for vendors.		Identify information sources. Include links if available.
	ALL	website describing all techniques and plants!	*ALL*		Hydrocarbons	Exposure to workers or environment during processing (This area needs further research)	Multiple venders can be found online, for Hyperaccumulation only (no amendments). Most focus on trees and long term projects.		http://phytopet.usask.ca/expfirstresult.php?group=demonstrated&experimental=View+Experimental+Data
	Phytoaccumulator	A plant that is not a hyperaccumulator however, shows accumulator properties	*Apocynum cannabinum*	Hemp Dogbane	Metals: Pb	Exposure to workers or environment during processing (This area needs further research)	Multiple venders can be found online, for Hyperaccumulation only (no amendments). Most focus on trees and long term projects.	have superior Pb accumulating properties however not to the hyperaccumulator level	Berti WR, Cunningham SD. 1993. Remediation soil Pb with green plants. Presented as the international conference Soc Environ Geochem Health. July 25-27. New Orleans, LA
	Phytoaccumulator	A plant that is not a hyperaccumulator however, shows accumulator properties	*Ambrosia atremisiifolia*	Common Ragweed	Metals: Pb	Exposure to workers or environment during processing (This area needs further research)	Multiple venders can be found online, for Hyperaccumulation only (no amendments). Most focus on trees and long term projects.	have superior Pb accumulating properties however not to the hyperaccumulator level	Berti WR, Cunningham SD. 1993. Remediation soil Pb with green plants. Presented as the international conference Soc Environ Geochem Health. July 25-27. New Orleans, LA
	Phytoaccumulator	A plant that is not a hyperaccumulator however, shows accumulator properties	*Carduus nutans*	Nodding Thistle	Metals: Pb	Exposure to workers or environment during processing (This area needs further research)	Multiple venders can be found online, for Hyperaccumulation only (no amendments). Most focus on trees and long term projects.	have superior Pb accumulating properties however not to the hyperaccumulator level	Berti WR, Cunningham SD. 1993. Remediation soil Pb with green plants. Presented as the international conference Soc Environ Geochem Health. July 25-27. New Orleans, LA
	Phytoaccumulator	A plant that is not a hyperaccumulator however, shows accumulator properties	*Aommelina communis*	Asiatic dayflower	Metals: Pb	Exposure to workers or environment during processing (This area needs further research)	Multiple venders can be found online, for Hyperaccumulation only (no amendments). Most focus on trees and long term projects.	have superior Pb accumulating properties however not to the hyperaccumulator level	Berti WR, Cunningham SD. 1993. Remediation soil Pb with green plants. Presented as the international conference Soc Environ Geochem Health. July 25-27. New Orleans, LA
	Phytoaccumulator/ Chelator	The use of Chelators such as EDTA to improve the phytoaccumulation abilities of certain plants	*Brassica juncea, Zea mays*	Indian Mustard, Corn	Metals: Au	Exposure to workers or environment during processing (This area needs further research)	Multiple venders can be found online, for Hyperaccumulation only (no amendments). Most focus on trees and long term projects.	Field validation of Gold uptake, with combined solubilizing agent NH4SCN. Compared B. juncea with Z. mays	Anderson, C., Moreno, F., and Meech, J. 2005. A field demonstration of gold phytoextraction. Min. Eng. 18, 385-392
	Phytoaccumulator/ Chelator	The use of Chelators such as EDTA to improve the phytoaccumulation abilities of certain plants	*Brassica juncea*	Indian Mustard	Metals: Pb	Exposure to workers or environment during processing (This area needs further research)	Multiple venders can be found online, for Hyperaccumulation only (no amendments). Most focus on trees and long term projects.	Use of chealators to help Pb become soluble and then be more bioavailable to the plant	Baylock MJ, Salt DE, Dushenkox S, Zakharova O, Gussman C. 1997. Enhanced accumulation of Pb in Indian mustard by soil-applied chelating agents. Environ Sci Technol 31: 860-865
	Phytoaccumulator/ Chelator	The use of Chelators such as EDTA to improve the phytoaccumulation abilities of certain plants	*Lupinus sp.*	Lupine	Metals: Cd, Zn	Exposure to workers or environment during processing (This area needs further research)	Multiple venders can be found online, for Hyperaccumulation only (no amendments). Most focus on trees and long term projects.	EDGA enhanced Cd but not Zn Highest potential was observed for lupine in combination with EDGA. EDGA exerted significant side effects on the functioning of nematodes.	Bouwman, La/A., Bloem, J., Romkens, P.F.A.M., and Japenga, J. 2005. EDGA amendment of slightly heavy metal loaded soil affects heavy metal solubility, crop growth and microbivorous nematodes but not bacteria and herbivorous nematodes. Soil Biol. Biochem. 37, 271-278
	Phytoaccumulator/ Chelator	The use of Chelators such as EDTA to improve the phytoaccumulation abilities of certain plants	*Mirabilis jalapa*	Four O'Clock Flower	Metals: Pb, Zn	Exposure to workers or environment during processing (This area needs further research)	Multiple venders can be found online, for Hyperaccumulation only (no amendments). Most focus on trees and long term projects.	found that EDDS enhanced shoot uptake of Pb and Zn by Mirabilis jalapa better than MGDA. MGDA can be biodegraded within 14 days	Cao, A., Carucci, A., Lai, T., La Colla, P., and Tamburini, E. 2007. Effect of biodegradable chelating agents on eavy metals phytoextraction with Mirabilis jalapa and on its associated bacteria. Eur. J. Soil. Biol. 43, 200-206
	Phytoaccumulator/ Chelator	The use of Chelators such as EDTA to improve the phytoaccumulation abilities of certain plants	*various*	*various*	Metals: Pb	Exposure to workers or environment during processing (This area needs further research)	Multiple venders can be found online, for Hyperaccumulation only (no amendments). Most focus on trees and long term projects.	Discusses how Phosphorus fertilizer can actually inhibit uptake of Pb due to precipitation of pyromorphite and chloro-phromorphite	Chaney RL, Brown SL, Li Y-M, Angle JS, Stuczynski TI, Daniels, WL, Henry CL, Siebelec G, Mallik M, Ryan JA, Compton H. 2000. Progress in rish assessment for soil metals, in in-situ remediation and phytoextraction of metals from hazardous contaminated soils. U.S-EPA "phytoremediation: State of Science" May 1-2 2000, Boston MA
	Phytoaccumulator/ Chelator	The use of Chelators such as EDTA to improve the phytoaccumulation abilities of certain plants	*various*	*various*	Metals: Zn Cd	Exposure to workers or environment during processing (This area needs further research)	Multiple venders can be found online, for Hyperaccumulation only (no amendments). Most focus on trees and long term projects.	Discusses the use of certain fertilizers ((NH4)2SO4) to improve the growth and acidification of the soil(which makes metals more soluble) NOTE: this may also make the metals more soluble to risk contamination of the ground water. Also discusses the option of incineration after harvest.	Chaney RL, Li YM, Angle JS, Baker AJM, Reeves RD, Brown SL, Homer FA, Malik M, Chin M. 1999. Improving metal hyperaccumulators wild plants to develop commercial phytoextraction systems: Approaches and progress. In phytoremediation of contaminated soil and waste, eds N Terry, GS Banuelos, CRC Press, Boca Raton, FL
	Phytoaccumulator/ Chelator	The use of Chelators such as EDTA to improve the phytoaccumulation abilities of certain plants	*Helianthus annuus*	Sunflower	Metals: Cd, Cr, Ni	Exposure to workers or environment during processing (This area needs further research)	Multiple venders can be found online, for Hyperaccumulation only (no amendments). Most focus on trees and long term projects.	Not as significant uptake as Pb and EDTA/HEDTA. Cd, Cr and Ni were mobilized but only Ni and Cd were significantly taken up by plant. Drastically decreased plant biomass even though shoot accumulation was observed	Chen, H. And Cutright, T. 2001. EDTA and HEDTA effects on Cd, Cr and Ni uptake by Helianthus annuus. Chemosphere 45, 21-28

Tech Class	Process	Technology Description	*Species*	Common Name	Targeted Contaminant	Health and Safety Concerns	Vendor Information	Comments	Reference
	Phytoaccumulator/ Chelator	The use of Chelators such as EDTA to improve the phytoaccumulation abilities of certain plants	*Zea mays/ Pisum sativum*	Corn/Field Pea	Metals: Pb, Cu	Exposure to workers or environment during processing (This area needs further research)	Multiple venders can be found online, for Hyperaccumulation only (no amendments). Most focus on trees and long term projects.	Heating seedlings prior to cultivation significantly increased Pb translocation. Heated EDTA solution was applied to Z.mays or P.sativum total Pb removal in shoots increased by 8-12 fold. Cu was also tested this way and increased 6-9 fold	Chen, Y.H, Mao, Y., He, S.-B., and Xu, K. 2007. Heat stress increases the efficiency of EDTA in phytoextraction of heavy metals. Chemosphere 67, 1511-1517
	Phytoaccumulator/ Chelator	The use of Chelators such as EDTA to improve the phytoaccumulation abilities of certain plants	*Elsholtzia splendens*	Elshotzia	Metals: Cu	Exposure to workers or environment during processing (This area needs further research)	Multiple venders can be found online, for Hyperaccumulation only (no amendments). Most focus on trees and long term projects.	Uptake of Cu by Elsholtzia splendens and Trifolium repens (non-accumulator) with amendments citric acid and glucose	Chen, Y.X., Wang, Y.P., Wu, W.X., Lin, Q., and Xue, S.G. 2006. Impacts of chelate-assisted pytoremediation on microbial community composition in the rizosphere of a copper accumulator and non-accumulator. Sci. Total Eviron. 356. 247-255
	Phytoaccumulator/ Chelator	The use of Chelators such as EDTA to improve the phytoaccumulation abilities of certain plants	*Chrysopogon zizanioides*	Vetiver grass	Metals: Zn, Cu	Exposure to workers or environment during processing (This area needs further research)	Multiple venders can be found online, for Hyperaccumulation only (no amendments). Most focus on trees and long term projects.	Surge in uptake of Zn, Cu and As 2-3 weeks after treatment with NTA in vetiver grass	Chiu, K.K., Ye, Z.H., and Wong, M.H. 2006. Enhanced uptake of As, Zn, and Cu by Vetiveriazizan-ioides and Zea mays using chelating agents. Chemosphere 60, 1365-1375
	Phytoaccumulator/ Chelator	The use of Chelators such as EDTA to improve the phytoaccumulation abilities of certain plants	*Zea mays*	Corn	Metals: Lead	Exposure to workers or environment during processing (This area needs further research)	Multiple venders can be found online, for Hyperaccumulation only (no amendments). Most focus on trees and long term projects.	Use of chealators to help Pb become soluble and then be more bioavailable to the plant. Compared 7 chelants for Pb (HEDTA>CDTA>DTPA>EGTA>HEIDA>EDDHA~NTA)	Cooper, E.M., Sims, J.T., Cunningham, S.D., Huang, J.E.and Berti, W.R.1999. Chelate-assisted pytoextraction of lead from contaminated soils. J. Environ. Qual. 28, 1709-1719
	Phytoaccumulator/ Chelator	The use of Chelators such as EDTA to improve the phytoaccumulation abilities of certain plants	*Zea mays/ Pisum sativum*	Corn/Field Pea	Metals: Pb	Exposure to workers or environment during processing (This area needs further research)	Multiple venders can be found online, for Hyperaccumulation only (no amendments). Most focus on trees and long term projects.	reported induced hyperaccumulation exceeding 10,0000mg kg Pb in z.mays and Pisum sativum after treatment with HEDTA and EDTA	Cunningham, S. D., and Ox, D. W. 1996. Promises and prospects of phytoremediation. Plant Physiol. 110, 715-719
	Phytoaccumulator/ Chelator	The use of Chelators such as EDTA to improve the phytoaccumulation abilities of certain plants	*various*	various	Metals:Cu, Zn, Mn, Fe	Exposure to workers or environment during processing (This area needs further research)	Multiple venders can be found online, for Hyperaccumulation only (no amendments). Most focus on trees and long term projects.	APCAs are employed in fertilizers to supply plants with trace metals. Analytical method	Deacon, M.S.M.R. and Tuinstra, L.G.M.T. 1994. Chromatographic separation of metal chelates present in commercial fertilizers. II. Development of an ion-pair chromatograpic separation and simultaveous determination of the Fe(III) chelates of EDTA, DTPA, EEDTA, EDDHA and EDDHMA and the Cu(II), Zn(II), and Mn(II) chelates of EDTA. J. Chromatograpy 659, 349-357
	Phytoaccumulator/ Chelator	The use of Chelators such as EDTA to improve the phytoaccumulation abilities of certain plants	*Brassica juncea*	Indian Mustard	Metals: Pb	Exposure to workers or environment during processing (This area needs further research)	Multiple venders can be found online, for Hyperaccumulation only (no amendments). Most focus on trees and long term projects.	Damaging root membrane integrity as a strategy to facilitate EDTA-enhanced Pb uptake by B. juncea. This strategy was good only in combination with plant growth promoting bacteria, to alleviate stress	Di Gregorio, S., Barbafieri, M., Lamis, S., Sanangelantoni, A.M., Tassi, E., and Vallini, G., 2006. Combined application of Triton X-100 and Sinorizobium so. Pb002 inoculum for the improvement of lead phytoextraction by Brassica juncea in EDTA amended soil. Chemosphere 63, 293-299
	Phytoaccumulator/ Chelator	The use of Chelators such as EDTA to improve the phytoaccumulation abilities of certain plants	*Brassica juncea*	Indian Mustard	Metals: Cd, Zn	Exposure to workers or environment during processing (This area needs further research)	Multiple venders can be found online, for Hyperaccumulation only (no amendments). Most focus on trees and long term projects.	applied organic acids on acidic multi-contaminated soil. Gallic and citric acids enhanced the net removal of Cd and Zn by B. juncea. Oxalic acid increased removal of Ni. Only synthetic chelates worked on Pb.	Do Nascimento, C.W.A., Amarasiriwardena, D., And Xing, B. 2006. Comparison of natural organic acids and synthetic chelates at enhancing pytoextraction of metals from a multi-metal contaminated soil. Environ. Poll. 140, 114-123
	Phytoaccumulator/ Chelator	The use of Chelators such as EDTA to improve the phytoaccumulation abilities of certain plants	*Paulownia tomentosa*	Paulownia tree	Metals: Cd, Cu, Pb, Zn	Exposure to workers or environment during processing (This area needs further research)	Multiple venders can be found online, for Hyperaccumulation only (no amendments). Most focus on trees and long term projects.	EDTA, Tartrate and glutamate comparison. Concentrations were taken 60days after planting and 30days after application of enhancer(ie.EDTA). Averages Cd-64mg kg, Cu 2081 mg kg, Pb 3362 mg kg, Zn 4680 mg kg	Doumett, S., Lamperi, L., Checchini, L., Azzarello, W., Mugnai, S., Mancuso, S., Petruzzelli, G., Del Bubba, M., 2008. Heavy metal distribution between contaminated soil and Paulownia tomentosa, in a pilot-scale assisted phytoremediation study: Influence of different complexing agents. Chemosphere 72 (2008) 1481-1490
	Phytoaccumulator/ Chelator	The use of Chelators such as EDTA to improve the phytoaccumulation abilities of certain plants	*Beta vulgaris*	beet	Uranium	Exposure to workers or environment during processing (This area needs further research)	Multiple venders can be found online, for Hyperaccumulation only (no amendments). Most focus on trees and long term projects.	Addition of citric acid increased Uranium uptake by Beta vulgaris.	Ebbs, S.D., Brady, D.J., and Kocian, L.V. 1998. Role of uranium speciation in the uptake and translocation of uranium by plants. J.Exp. Bot. 324, 1183-1190
	Phytoaccumulator/ Chelator	The use of Chelators such as EDTA to improve the phytoaccumulation abilities of certain plants	*H.vulgare*	Barley	Metals: Zn	Exposure to workers or environment during processing (This area needs further research)	Multiple venders can be found online, for Hyperaccumulation only (no amendments). Most focus on trees and long term projects.	Tested H. vulgare (and 15 other grasses) for phytoextraction of Zn and compared it to B. juncea with and without EDTA. H.vulgare uptake did not increase with EDTA but overall had higher uptake than B. juncea	Ebbs, S.D., Kocian, L.V. 1998. Pytoextraction of Zinc by Oat (Avena sativa), Barley (Hordeum vulgare), and Indian mustard (Brassica juncea). Environ. Sci. Technol. 32, 802-806
	Phytoaccumulator/ Chelator	The use of Chelators such as EDTA to improve the phytoaccumulation abilities of certain plants	*various*	various	NA	Exposure to workers or environment during processing (This area needs further research)	Multiple venders can be found online, for Hyperaccumulation only (no amendments). Most focus on trees and long term projects.	Half-life of NTA is ~3-7 days.	Egli, T. 2001. Biodegradation of metal-complexing aninopolycarboxylic acids. J. Bio Sci. Bioeng 92, 89-97
	Phytoaccumulator/ Chelator	The use of Chelators such as EDTA to improve the phytoaccumulation abilities of certain plants	*Brassica juncea*	Indian Mustard	Metals: Pb	Exposure to workers or environment during processing (This area needs further research)	Multiple venders can be found online, for Hyperaccumulation only (no amendments). Most focus on trees and long term projects.	Pb-EDTA complex was translocated within the plant	Epstein, A.L., Gussman, C.D., Blaylock, M.J., Yermiyahu, U., Huang, J.W., Kapulnik, Y., and Orser, C.S. 1999. EDTA and Pb-EDTA accumulation in Brassica juncea grwon in Pb-amended soil. Plant Soil 208, 87-94
	Phytoaccumulator/ Chelator	The use of Chelators such as EDTA to improve the phytoaccumulation abilities of certain plants	*Tabacum nicotiana*	Tocabbo plant	Metals: Cu, Pb	Exposure to workers or environment during processing (This area needs further research)	Multiple venders can be found online, for Hyperaccumulation only (no amendments). Most focus on trees and long term projects.	copared application of citric, oxalic and tartaric acids with EDTA for uptake of Cu, and Pb by Tabacum nicotiana. Copper increased with citric acid, not EDTA treatment. Concluded that org acids were unsuitable for phytoextraction	Evangelou, M.W.H., Ebel, M. and Schaeffer, A. 2006. Evaluation of the effect of small organic acids on phytoextraction of CU, and Pb from soil with tobacco Nicotiana tabacum. Chemosphere 63. 996-1004

Tech Class	Process	Technology Description	*Species*	Common Name	Targeted Contaminant	Health and Safety Concerns	Vendor Information	Comments	Reference
	Phytoaccumulator/ Chelator	The use of Chelators such as EDTA to improve the phytoaccumulation abilities of certain plants	*various*	various	Metals: Cu, Zn,	Exposure to workers or environment during processing (This area needs further research)	Multiple venders can be found online, for Hyperaccumulation only (no amendments). Most focus on trees and long term projects.	Nicotinanamine helps to transport Cu and Zn in Xylem and phloem of plants	Fox. T.C. and Guerinot, M.L. 1998. Molecular biology of cation transport in plants. Ann. Rev. Plant Physiol. Plant Mol. Biol. 49. 669-696
	Phytoaccumulator/ Chelator	The use of Chelators such as EDTA to improve the phytoaccumulation abilities of certain plants	*Helianthus annuus*	Sunflower	Metals: Fe, Zn, Mn, Cu, Pb	Exposure to workers or environment during processing (This area needs further research)	Multiple venders can be found online, for Hyperaccumulation only (no amendments). Most focus on trees and long term projects.	Irrigated field with 25mM-EDTA and reported increased uptake of Fe, Zn, Mn, Cu and Pb in H. annuus. No reductions in biomass were observed	Ghinhas, A., Ojeda, M. A., Alcantara, E. And Benlloch, M. 2000. Metal accumulation in sunflower plants grwon in a contaminated area from Aznalcollar (Southern Spain). Presented at the COST837 Conference, Madrid, Spain.
	Phytoaccumulator/ Chelator	The use of Chelators such as EDTA to improve the phytoaccumulation abilities of certain plants	*Brassica rapa*	Chinese Cabbage	Metals: Cd, Pb, Zn	Exposure to workers or environment during processing (This area needs further research)	Multiple venders can be found online, for Hyperaccumulation only (no amendments). Most focus on trees and long term projects.	Use of chelators could cause greater amounts of leaching into ground water. Macronutrients may also be leached out of soil. Examined B. juncea for Cd, Pb and Zn uptake with EDTA treatment. Had toxic effect on soil fungi.	Grcman, H., Velikonja-Bolta, S., Vodnik, D., Kos, B., and Lestan, D. 2001. EDTA enhanced heavy metal phytoextraction: Metal accumulation, leaching and toxicity. Plant Soil 235, 105-114
	Phytoaccumulator/ Chelator	The use of Chelators such as EDTA to improve the phytoaccumulation abilities of certain plants	*various*	various	NA	Exposure to workers or environment during processing (This area needs further research)	Multiple venders can be found online, for Hyperaccumulation only (no amendments). Most focus on trees and long term projects.	Observed 18-42% biodegredability of EDDS after 7 weeks (applied at very high doses 20mmlo kg).	Hauser. L., Tandy, S., Schulin, R., and Vowack. B. 2005. Column extraction of heavy metals from soils using the biodegradable chelating agent EDDS. Environ. Sci, Technol. 39, 6819-6824
	Phytoaccumulator/ Chelator	The use of Chelators such as EDTA to improve the phytoaccumulation abilities of certain plants	*Cynara cardunculus*	cardoon plants	Metals: Pb	Exposure to workers or environment during processing (This area needs further research)	Multiple venders can be found online, for Hyperaccumulation only (no amendments). Most focus on trees and long term projects.	Hypothesized metal EDTA complexes taken up by non-selective apoplastic root transport. Damaging root integrity to facility Pb uptake	Hernandez-Allica, J., Garbisu, C., Barrutia, O., and Becerril, J.M. 2006. EDTA-induced heavy metal accumulation and phytotoxicity in cardoon plants. Environ. Exp. Bot. 60, 26-32
	Phytoaccumulator/ Chelator	The use of Chelators such as EDTA to improve the phytoaccumulation abilities of certain plants	*Brassica juncea*	Indian Mustard	Metals: Ni, Cr	Exposure to workers or environment during processing (This area needs further research)	Multiple venders can be found online, for Hyperaccumulation only (no amendments). Most focus on trees and long term projects.	EDTA improved removal of Ni and Cr however the Low molecular wt org acids better enhanced the tolerance of B. juncea toxicity	Hsiao, K.-H., Kai, P.H., and Hseu, Z.-Y. 2007. Effects of chelators on chromium and nickel uptake by Brassica juncea on serpentine mine-tailings for phytoextraction. J. Hazard. Mat. 148, 366-376
	Phytoaccumulator/ Chelator	The use of Chelators such as EDTA to improve the phytoaccumulation abilities of certain plants	*Zea mays/Brassica juncea*	maize/ Indian Mustard	Metals: Pb	Exposure to workers or environment during processing (This area needs further research)	Multiple venders can be found online, for Hyperaccumulation only (no amendments). Most focus on trees and long term projects.	Use of chealators to help Pb become soluble and then be more bioavailable to the plant.HEDTA increased Pb accumulation in shoots of Indian Mustard, from 40ppm to 10,600ppm	Huang JW, Cunningham SD. 1996 Lead phytoextraction: species variation in lead uptake and translocation. New Phytol 134: 75-84
	Phytoaccumulator/ Chelator	The use of Chelators such as EDTA to improve the phytoaccumulation abilities of certain plants	*Brassica juncea*	Indian Mustard	Uranium	Exposure to workers or environment during processing (This area needs further research)	Multiple venders can be found online, for Hyperaccumulation only (no amendments). Most focus on trees and long term projects.	Use of chelators to extract uranium. Citric acid was used for desorption of U. 200-fold increase if U was observed after citric acid addition. HNO3 didn't work. Worked in various species…B.juncea accumulated more than 5000mg kg U, achieved within 24 Hours!	Huang, J.W., Blaylock, M.J, Kaulmik, Y., and Ensley, B.D. 1998. Pytoremediation of uranium-contaminated soils: Role of organic acids in triggering uranium hyperaccumulation in plants. Environ. Sci. Teccnol. 32, 2004-2008
	Phytoaccumulator/ Chelator	The use of Chelators such as EDTA to improve the phytoaccumulation abilities of certain plants	*Zea mays/ Pisum sativum*	Corn/Field Pea	Metals: Lead	Exposure to workers or environment during processing (This area needs further research)	Multiple venders can be found online, for Hyperaccumulation only (no amendments). Most focus on trees and long term projects.	Use of chealators to help Pb become soluble and then be more bioavailable to the plant. Effectiveness (EDTA>HEDTA>DTPA>EGTA>EDDHA). Increased root to shoot translocation in Z.mays in 24 hours.	Huang, J.W., Chen, J., Berti, W.R., and Cunnigham, S. D. 1997. Pytoremediation of lead-contaminated soils: Role of synthetic chelates in lead pytoextraction. Environ. Sci. Tecnol. 31, 800-805
	Phytoaccumulator/ Chelator	The use of Chelators such as EDTA to improve the phytoaccumulation abilities of certain plants	*Lupinus sp./Brassica nigra*	Lupine, grass and Yellow mustard	Metals: Cd, Cu, Zn	Exposure to workers or environment during processing (This area needs further research)	Multiple venders can be found online, for Hyperaccumulation only (no amendments). Most focus on trees and long term projects.	compared Citric acid and GEDTA for enhanced uptake of Cd, Cu and Zn in Lupine, grass and yellow mustard. GEDTA worked, Citric Acid did not due to short life in soil.	Japenga J. and Romkens, P.F.A.M. 2000. Chelate-enhanced phyroremediation of soils: An integrated approach. Presented at the COST 837 Conference, Madrid, Spain Session 1
	Phytoaccumulator/ Chelator	The use of Chelators such as EDTA to improve the phytoaccumulation abilities of certain plants	*Chamaecytisus proliferus/ Proliferus var. palmensis*	Lucerne tree	Metals: Pb	Exposure to workers or environment during processing (This area needs further research)	Multiple venders can be found online, for Hyperaccumulation only (no amendments). Most focus on trees and long term projects.	Pb translocation in Chamaecytisus proliferus with EDTA and HEDTA with highest shoot accumulation with HEDTA. Lucerne tree is native to California.	Jarvis, M.D. and Leung, D.W.M. 2001. Chelated lead transport in Chamaecytisus proliferus (L.f.) link sspp. Proliferus var. palmensis (H. Christ): An ultrastructural study. Plant Sci. 161, 433-441
	Phytoaccumulator/ Chelator	The use of Chelators such as EDTA to improve the phytoaccumulation abilities of certain plants	*Brassica juncea*	Indian Mustard	Metals: Cd	Exposure to workers or environment during processing (This area needs further research)	Multiple venders can be found online, for Hyperaccumulation only (no amendments). Most focus on trees and long term projects.	EDTA added to B. juncea grown on Cd-spiked soils did not increase plant adsorption, however it increased plant translocation of Cd.	Jiang, X.J., Luo, Y.M., Zhao, Q.G., Baker, A.J.M., Christie, P., and Wong, M.H. 2003. Soil Ce availability to Indian mustard and environmental risk following EDTA addition to Ce-contaminated soil. Chemoshere 50, 813-818
	Phytoaccumulator/ Chelator	The use of Chelators such as EDTA to improve the phytoaccumulation abilities of certain plants	*various*	various	Metals: Pb, Cd	Exposure to workers or environment during processing (This area needs further research)	Multiple venders can be found online, for Hyperaccumulation only (no amendments). Most focus on trees and long term projects.	EDTA has been proposed as a soil washing mechanism in the neutral pH range. Risk of heavy metal leaching in a field test is an issue to be considered.	Kedziorek, M.A.M., and Bourg, A.C.M. 2000. Solubilisation of lead and cadmium during the percolation of EDTA through a soil polluted by smelting activities. J. Contam. Hydrol. 40. 381-392
	Phytoaccumulator/ Chelator	The use of Chelators such as EDTA to improve the phytoaccumulation abilities of certain plants	*NA*	NA	NA	Exposure to workers or environment during processing (This area needs further research)	Multiple venders can be found online, for Hyperaccumulation only (no amendments). Most focus on trees and long term projects.	Analytical Method	Krzyszowksa, A.J. Blaylock, M.J., Vance, G.G., and David, M.B. 1996. Ion-chromatographic analysis of low molecular weight organic acids in spodsol forest solutions. Soil Sci. jSoc. Amer. J. 60, 1565-1571

Tech Class	Process	Technology Description	*Species*	Common Name	Targeted Contaminant	Health and Safety Concerns	Vendor Information	Comments	Reference
	Phytoaccumulator/ Chelator	The use of Chelators such as EDTA to improve the phytoaccumulation abilities of certain plants	*Lactuca sativa*	lettuce	Metals	Exposure to workers or environment during processing (This area needs further research)	Multiple venders can be found online, for Hyperaccumulation only (no amendments). Most focus on trees and long term projects.	Use of nitrilotriacetate as a chelator in metal uptake	Kulli, B., Balmer, M. Krebs, R., Lothenbach, B., Geiger, G., and Schulin, R. 1999. The influence of nitrilotriacetate on heavy metal uptake of lettuce and ryegrass
	Phytoaccumulator/ Chelator	The use of Chelators such as EDTA to improve the phytoaccumulation abilities of certain plants	*Lolium sp.*	ryegrass	Metals	Exposure to workers or environment during processing (This area needs further research)	Multiple venders can be found online, for Hyperaccumulation only (no amendments). Most focus on trees and long term projects.	Use of nitrilotriacetate as a chelator in metal uptake	Kulli, B., Balmer, M. Krebs, R., Lothenbach, B., Geiger, G., and Schulin, R. 1999. The influence of nitrilotriacetate on heavy metal uptake of lettuce and ryegrass
	Phytoaccumulator/ Chelator	The use of Chelators such as EDTA to improve the phytoaccumulation abilities of certain plants	*Helianthus annuus*	Sunflower	Metals	Exposure to workers or environment during processing (This area needs further research)	Multiple venders can be found online, for Hyperaccumulation only (no amendments). Most focus on trees and long term projects.	citric acid degredation occurred so rapidly that metals could not be taken up. EDTA application at germination decreased biomass production	Lesage, E., Meers, E., Vervaeke, P., Lamsal, S., Hopgood, M., Tack, F.M.G., and Verloo, M.G. 2005. Enhanced phytoextraction II. Effect of EDTA and Citric acid on heavy metal uptake by Helianthus annuus from a calcareous soil. Int.J. Phytoremed. 7, 143-152
	Phytoaccumulator/ Chelator	The use of Chelators such as EDTA to improve the phytoaccumulation abilities of certain plants	*various*	various	Metals: Pb	Exposure to workers or environment during processing (This area needs further research)	Multiple venders can be found online, for Hyperaccumulation only (no amendments). Most focus on trees and long term projects.	EDDS offers potential over EDTA. Half-life of only 2.5 days in natural soils	Lestan, D. and Grcman, H. 2002. Chelate enhanced Pb phytoextraction: Plant uptake, leaching and toxicity. Proceedings of the 17th WCSS World Congressof Soil Science, Bongkok, Thailand, Symposium 42 Paper number 1701
	Phytoaccumulator/ Chelator	The use of Chelators such as EDTA to improve the phytoaccumulation abilities of certain plants	*various*	various	Metals: Pb, Zn	Exposure to workers or environment during processing (This area needs further research)	Multiple venders can be found online, for Hyperaccumulation only (no amendments). Most focus on trees and long term projects.	Ozonation (Hydrogen Peroxide) before soil washing with EDTA increased Pb removal but not Zn.	Lestan, D., Hanc, A., and Finzgar, N. 2005. Influence of ozonation on extractability of Pb and Zn from conatiminated soil. Chemosphere 61, 1012-1019
	Phytoaccumulator/ Chelator	The use of Chelators such as EDTA to improve the phytoaccumulation abilities of certain plants	*Zea mays*	Corn	Metals: Pb	Exposure to workers or environment during processing (This area needs further research)	Multiple venders can be found online, for Hyperaccumulation only (no amendments). Most focus on trees and long term projects.	Proposed the use of coated granules for slow release of mobilizing agents. Total accumulation of Pb by Z.mays was similar between EDTA added as solution or EDTA added in slow-release form.	Li, H., Wang, Q.., Cui, Y., Dong, Y., Christi, P. 2005. Slow release chelate enhancement of lead phytoextraction by corn (Zea mays L.) from contaminated soil- A preliminary study. Sci. Total Environ. 339, 179-187
	Phytoaccumulator/ Chelator	The use of Chelators such as EDTA to improve the phytoaccumulation abilities of certain plants	*Zea mays/ Thalaspi caerulescens*	Corn/Alpine Pennycress	Metals: Cd, Zn	Exposure to workers or environment during processing (This area needs further research)	Multiple venders can be found online, for Hyperaccumulation only (no amendments). Most focus on trees and long term projects.	EDTA amended Z.mays compared with unamended "natural" hyperaccumulator T. caerulescens for Cd and Zn accumulation. Natural exhibited higher accumulation however also higher sensitivity to toxicity.	Lombi, E., Zhao, F. J., Dunham, S.J., and McGrath, S.P. 2001. Phytoremediation of heavy-metal contaminated soils: Natural hyperaccumulation versus chemically enhanced phytoextraction. J. Environ. Qual. 30, 1919-1926
	Phytoaccumulator/ Chelator	The use of Chelators such as EDTA to improve the phytoaccumulation abilities of certain plants	*Zea mays*	Corn	Metals: Pb	Exposure to workers or environment during processing (This area needs further research)	Multiple venders can be found online, for Hyperaccumulation only (no amendments). Most focus on trees and long term projects.	Examined combined treatment with EDDS:EDTA. Mix had similar and greater results for Pb uptake in Z.mays	Lou, C. Shen, Z, Li, X., and Baker, A.J.M. 2006b. Enhanced phytoextraction of Pb and other metals from atrificially contaminated soils through the combined application of EDTA and EDDS. Chemosphere 63, 1773-1784
	Phytoaccumulator/ Chelator	The use of Chelators such as EDTA to improve the phytoaccumulation abilities of certain plants	*Zea mays*	Corn	Metals: Cu, Zn,	Exposure to workers or environment during processing (This area needs further research)	Multiple venders can be found online, for Hyperaccumulation only (no amendments). Most focus on trees and long term projects.	EDDS enhances Cu and Zn uptake by Z. mays and P. vulgaris is better than EDTA. While for Cd and Pb EDTA was better.	Lou, C., Shen, Z., and Li, X. 2005. Enhanced phytoexteaction of Cu, Pb, Zn and Cd with EDTa dn EDDs. Chemosphere 59, 1-11
	Phytoaccumulator/ Chelator	The use of Chelators such as EDTA to improve the phytoaccumulation abilities of certain plants	*Zea mays/ Chrysanthemum coronarium*	Corn/Chrysanthemum	Metals: Zn, Cd	Exposure to workers or environment during processing (This area needs further research)	Multiple venders can be found online, for Hyperaccumulation only (no amendments). Most focus on trees and long term projects.	Reported residual phytotoxic effect of EDTA after 6 months after chelant treatment. Observed increased Zn and Cd in Z.mays and Chrysanthemum coronarium in soils treated with EDDS	Lou, C., Shen, Z., Lou, L., and Li, X. 2006a. EDDS and EDTA-enhanced phytoextraction of metals from artificially contaminated soil and residual effects of chelant compounds. Environ. Poll. 144, 862-871
	Phytoaccumulator/ Chelator	The use of Chelators such as EDTA to improve the phytoaccumulation abilities of certain plants	*Thlaspi caerulescens*	Alpine Pennycress	Metals: Cd, Zn	Exposure to workers or environment during processing (This area needs further research)	Multiple venders can be found online, for Hyperaccumulation only (no amendments). Most focus on trees and long term projects.	Developed a multi-user predictive model for the phytoextraction of Cd and Zn by Thlaspi caerulescens	Maxted, A.P., Black, C. R., West, H.M., Crout, N.J.M., McGrath, S.P., and Young, S.D. 2007. Phytoexteaction of cadmium and zinc from arable soils amended with seware sludge using Thlaspi caerulescens: Development of a predictive tool. Environ. Pollut. 150, 363-372
	Phytoaccumulator/ Chelator	The use of Chelators such as EDTA to improve the phytoaccumulation abilities of certain plants	*NA*	NA	NA	Exposure to workers or environment during processing (This area needs further research)	Multiple venders can be found online, for Hyperaccumulation only (no amendments). Most focus on trees and long term projects.	Report a half-life of EDTA of 6 months	Means, J. L. Kucak, T., and Crear, A. 1980. Relative degradation rates of NTA, EDTA and DTPA and environmental applications Environ. Pollut. B. 1 45-60
	Phytoaccumulator/ Chelator	The use of Chelators such as EDTA to improve the phytoaccumulation abilities of certain plants	*various*	various	Metals: Cd, Cu, Pb, Zn	Exposure to workers or environment during processing (This area needs further research)	Multiple venders can be found online, for Hyperaccumulation only (no amendments). Most focus on trees and long term projects.	Low-molecular wt org acids are mineralized within weeks. This means effects of or acids are not prolonged after removal of vegetative cover, suppressing risks of leaching. Mobilizing effects on Cd, Cu, Pb and Zn were reduced to initial situation after 1 week for citric acid	Meers, E., Lesage, E., Lamsal, S., Hopgood, M., Vervaeke, P., Tack,. F.M.G., and Verloo, M.G. 2005c. Enhanced phytoexteaction. I. Effect of EDTA and citric acid on heavy metal mobility in a calcaresous soil. Int. J. Phytoremed. 7, 129-142
	Phytoaccumulator/ Chelator	The use of Chelators such as EDTA to improve the phytoaccumulation abilities of certain plants	*various*	various	Metals	Exposure to workers or environment during processing (This area needs further research)	Multiple venders can be found online, for Hyperaccumulation only (no amendments). Most focus on trees and long term projects.	EDDS half-life was between 3.8 and 7.5 days	Meers, E., Ruttens, A., Samson, D., Hopgeed, M. and Tack, F.M.G. 2005a. Comparison of EDTA and EDDS as potential soil amendments for enhanced phytoextraction of heavy metals. Chemosphere 58, 1011-1022

Tech Class	Process	Technology Description	*Species*	Common Name	Targeted Contaminant	Health and Safety Concerns	Vendor Information	Comments	Reference
	Phytoaccumulator/ Chelator	The use of Chelators such as EDTA to improve the phytoaccumulation abilities of certain plants	*various*	various	Metals	Exposure to workers or environment during processing (This area needs further research)	Multiple venders can be found online, for Hyperaccumulation only (no amendments). Most focus on trees and long term projects.	Degredation patterns of EDDS vary between soils. However EDDS was fully degraded within 54 days in all soils.	Meers, E., Tack, F.M.G., and Verloo, M.G. 2007a. Degradability of ethylenediaminedisuccinic acid (EDDS) in metal contaminated soils: Implications for its use soil remediation. Chemosphere, 70, 358-363
	Phytoaccumulator/ Chelator	The use of Chelators such as EDTA to improve the phytoaccumulation abilities of certain plants	*Salix sp.*	Willow tree	Metals: Cu, Ni	Exposure to workers or environment during processing (This area needs further research)	Multiple venders can be found online, for Hyperaccumulation only (no amendments). Most focus on trees and long term projects.	Observed the effects of uptake of EDDS by Salix. Spp. For Cu and Ni	Meers, E., Vandecasteele, B., Ruttens, A., Vangronsveld, J., and Tack, F.M.G., 2007b. Potential of five willow species (Salix spp.) for phytoextraction of heavy metals. J.Exp. Environ. Bot. 120, 243-267
	Phytoaccumulator/ Chelator	The use of Chelators such as EDTA to improve the phytoaccumulation abilities of certain plants	*Helianthus annuus/Brassica rapa/Cannabis sativa/Zea mays*		Metals: Cd, Cu, Ni, Pb, Zn	Exposure to workers or environment during processing (This area needs further research)	Multiple venders can be found online, for Hyperaccumulation only (no amendments). Most focus on trees and long term projects.	H.annuus, uptake of Cd, Cu, Ni, Pb, and Zn was increased when EDTA was applied shortly before harvest, No depression in biomass	Meers. E. Ruttens, A. Hopgood, M., Lesage, E. and Tack. F.M.G., 2005b. Potential of Brassica rapa, Cannabis sativa, Helianthus annuus and Zea Mays for phytoextraction of heavy metals from calcareous dredged sediment derived soils. Chemosphere 61, 561-572
	Phytoaccumulator/ Chelator	The use of Chelators such as EDTA to improve the phytoaccumulation abilities of certain plants	*Lycopersicum esculentum*	tomato	Metals:Cu	Exposure to workers or environment during processing (This area needs further research)	Multiple venders can be found online, for Hyperaccumulation only (no amendments). Most focus on trees and long term projects.	demonstrated increased Cu translocation in nicotianamine-less Lycopersicum esculentum plant upon foliar and root application	Pich, A., Scholz, G., and Stephan, U.W. 1996. Iron-dependant changes of heavy metals, nicotianamine, and citrate in different plant organs and in the xylem exudates of two tomato genotypes. Nicotianamine as possible copper translocatoer. Plant Soil 165, 189-196
	Phytoaccumulator/ Chelator	The use of Chelators such as EDTA to improve the phytoaccumulation abilities of certain plants	*Brassica carinata*	Ethopian mustard	Metals: Cu, Zn, As, Cd	Exposure to workers or environment during processing (This area needs further research)	Multiple venders can be found online, for Hyperaccumulation only (no amendments). Most focus on trees and long term projects.	Compared the effect of EDDS and NTA on plant accumulation of Cu, Zn, Pb, As, and Cd by Brassica carinata. EDDS is better.	Quartacci, M. G. Irtelli, B., Baker, A.J.m. and Navari-Isso, F. 2007. the use of NTA and EDDS for enhanced phytoextraction of metals from a multiply contaminated soil by Brassica carinata Chemosphere 68, 1920-1928
	Phytoaccumulator/ Chelator	The use of Chelators such as EDTA to improve the phytoaccumulation abilities of certain plants	*Brassica juncea*	Indian Mustard	Metals: Cd, Cu, Pb, Zn	Exposure to workers or environment during processing (This area needs further research)	Multiple venders can be found online, for Hyperaccumulation only (no amendments). Most focus on trees and long term projects.	Compared NTA and Citric acid on uptake of Cd, Cu, Pb, and Zn by Brassica juncea and found a 2-3 fold increase in NTA treated plants	Quartacci, M.F., Argilla, A., Baker A.J.M., and Navari-Izzo, F. 2006. Phytoextraction of metals from a multiply contaminated soil by Indian mustard. Chemosphere 63, 918-925
	Phytoaccumulator/ Chelator	The use of Chelators such as EDTA to improve the phytoaccumulation abilities of certain plants	*Brassica juncea*	Indian Mustard	Metals: Cd	Exposure to workers or environment during processing (This area needs further research)	Multiple venders can be found online, for Hyperaccumulation only (no amendments). Most focus on trees and long term projects.	Found that 10 mg kg NTA resulted in a 2 fold increase in Cd uptake by B. juncea	Quartacci, M.F., Irtelli, B., Baker, A.J.M. and Narari-Izzo, F. 2005. Nitrilotriacetate- and citric acid-assisted phytoextraction of cadmium by Indian mustard (Brassica juncea) Chemosphere. 68, 1920-1928
	Phytoaccumulator/ Chelator	The use of Chelators such as EDTA to improve the phytoaccumulation abilities of certain plants	*Populus sp./ Salix sp.*	Poplar trees/Willow trees	Metals: Cd	Exposure to workers or environment during processing (This area needs further research)	Multiple venders can be found online, for Hyperaccumulation only (no amendments). Most focus on trees and long term projects.	Observed growth depression for poplars cultivated on NTA-amended contaminated soils	Robinson, B.H., Millis, T.M., Petit, D., Fung, L.E., Green, S. R. and Clothier, B.E. 2000. natural and induced cadmium accumulation in poplar and willow: implications for phytoremediation. Plant Soil 227, 301-306
	Phytoaccumulator/ Chelator	The use of Chelators such as EDTA to improve the phytoaccumulation abilities of certain plants	*Hemidesmus indicus*	Indian sarasaparilla	Metals: Pb	Exposure to workers or environment during processing (This area needs further research)	Multiple venders can be found online, for Hyperaccumulation only (no amendments). Most focus on trees and long term projects.	Enhanced Pb accumulation by Hemidesmus indicus in the order EDTA>HEDTA>DTPA>CDTA	Sekhar, C.K. Kamala, C. T., Chary, N.S., Balaram, V., and Garcia, G. 2005. Potential of Hemidesmus indicus for phytoextraction of lead from industrially contaminated soil. Chemosphere 58, 507-514
	Phytoaccumulator/ Chelator	The use of Chelators such as EDTA to improve the phytoaccumulation abilities of certain plants	*NA*	NA	NA	Exposure to workers or environment during processing (This area needs further research)	Multiple venders can be found online, for Hyperaccumulation only (no amendments). Most focus on trees and long term projects.	Method for analysis of organic acids on IC	Shen, Y., Srom, L., Jonsson, J.A., and Tyler, G. 1996. Low-molecular organic-acids in the rhizophere soil solution of beech forest (Fagus sylvatica) cambisols determined by ion chromatography using supported liquid membrane enrichment technique. Soil Biol. Biochem. 28, 1163-1169
	Phytoaccumulator/ Chelator	The use of Chelators such as EDTA to improve the phytoaccumulation abilities of certain plants	*Brassica rapa*	Field mustard	Metals: Pb	Exposure to workers or environment during processing (This area needs further research)	Multiple venders can be found online, for Hyperaccumulation only (no amendments). Most focus on trees and long term projects.	comparative screening of citric acid and various synthetic chelants. Citric acid was least effective in Pb mobilization and uptake by B. rapa, EDTA was most effective. Effectiveness for Pb uptake(EDTA>HEDTA>DTPA>NTA>citric Acid) elevated within days after application (Applications of EDTA was most effective over multiple doses)	Shen, Z.-G., Li, X.-D, Wang, C.-C., Chen, H.-M., and Chua, -H., 2002. Lead phytoextractio nfrom a contaminated soil with high-biomass plant species. J. Environ. Qual. 31, 1893-1900
	Phytoaccumulator/ Chelator	The use of Chelators such as EDTA to improve the phytoaccumulation abilities of certain plants	*Alyssum lesbiacum*	Alyssum	Metals: Ni	Exposure to workers or environment during processing (This area needs further research)	Multiple venders can be found online, for Hyperaccumulation only (no amendments). Most focus on trees and long term projects.		Singer, A. C., Bell, T., Heywood, C.A. Smith, J.A.C., and Thompson, I.P. 2007. Phytoremediation of mixed-contaminated soil using the hyperaccumulator plant Alyssum lesbiacum: Evidence of histidine as a measure of phytoextractable nickel. Environ. Pollut. 147, 74-82
	Phytoaccumulator/ Chelator	The use of Chelators such as EDTA to improve the phytoaccumulation abilities of certain plants	*Nicotiana tabacum*	Tobacco plant	Metals: Pb	Exposure to workers or environment during processing (This area needs further research)	Multiple venders can be found online, for Hyperaccumulation only (no amendments). Most focus on trees and long term projects.	Saw increases in Pb concentration in Nicotiana tabacum shoots. With EDDS application.	Sudova, R., Pavlikova, D., Macek, T., and vosatka, M. 2007. The effect of EDDs chelate and inoculation with arbuscular mycorrhizal fungus Glomus intraradices on the efficacy of lead phytoextraction by two tobacco clones. Appl. Soil. Ecol. 35, 163-173
	Phytoaccumulator/ Chelator	The use of Chelators such as EDTA to improve the phytoaccumulation abilities of certain plants	*Helianthus annuus*	Sunflower	Metals: cu, Zn, Pb	Exposure to workers or environment during processing (This area needs further research)	Multiple venders can be found online, for Hyperaccumulation only (no amendments). Most focus on trees and long term projects.	Studied Cu, Zn and Pb uptake in presence of EDDS. All metals were taken up by non-selective apoplastic pathways in absence of EDDS metals were taken up by symplastic pathway	Tandy, S., Schulin, R., And Nowack, B. 2006. The influence of EDDS on the uptake of heavy metals in hydroponically grown sunflowers. Chemosphere 62, 1454-1463

Tech Class	Process	Technology Description	*Species*	Common Name	Targeted Contaminant	Health and Safety Concerns	Vendor Information	Comments	Reference
Phytoremediation	Phytoaccumulator/ Chelator	The use of Chelators such as EDTA to improve the phytoaccumulation abilities of certain plants	*Brassica juncea*	Indian Mustard	Metals: Pb	Exposure to workers or environment during processing (This area needs further research)	Multiple venders can be found online, for Hyperaccumulation only (no amendments). Most focus on trees and long term projects.	Discusses how Indian Mustard was able to accumulate more than 1% Pb in dry shoots with the application of EDTA	Vassil A, Kapulnik Y, Raskin I, Salt DE. 1998. The role of EDTA in lead transport and acculation by Indian Mustard. Plant Physiol 117:447-453
	Phytoaccumulator/ Chelator	The use of Chelators such as EDTA to improve the phytoaccumulation abilities of certain plants	*various*	various	Metals: Cd	Exposure to workers or environment during processing (This area needs further research)	Multiple venders can be found online, for Hyperaccumulation only (no amendments). Most focus on trees and long term projects.	Fast preliminary lab tests to characterize site and design phytoremediation plan and select soil amendments.	Wu, Q.-T., Deng, J.-C., Long, X.-X., Morel, J.-L., and Schwartz, C. 2006. Selection of appropriate organic additives for enhancing Zn and Cd phytoextraction by hyperccumulators. J.Environ.Sci 18,1113-1118
	Phytoaccumulator/ Chelator	The use of Chelators such as EDTA to improve the phytoaccumulation abilities of certain plants	*Zea mays*	Corn	Metals: Pb	Exposure to workers or environment during processing (This area needs further research)	Multiple venders can be found online, for Hyperaccumulation only (no amendments). Most focus on trees and long term projects.	Comparison of EDTA and HBED. EDTA was better at increasing water soluble Pb concentrations. Z.mays	Wu, Q.-T., Hsu, F.C., and Cunningham, S.D. 1999. Chelate-assisted Pb phytoextraction: Pb availability, uptake and translocation constraints. Environ. Sci. Technol. 33, 1898-1904
	Phytoaccumulator/ Chelator	The use of Chelators such as EDTA to improve the phytoaccumulation abilities of certain plants	*various*	various	Metals: Cu	Exposure to workers or environment during processing (This area needs further research)	Multiple venders can be found online, for Hyperaccumulation only (no amendments). Most focus on trees and long term projects.	studied the effect of oxalate and citrate on Cu2+.	Zhang, G. , Li, H., Li, Y., Wei, J., and Li, X. 2002. Effects of organic ligands on Cu2+ sorption in permanent and variable charge soils. 17th WCSS World Congress of Soil Science, Bangkok, Thailand, Symposium 8, Paper no 1088
	Phytoaccumulator/ Chlorocomplexes	The use of salinity and Cl forming metal complexes such as CdCl as a means improve the phytoaccumulation abilities of certain plants	*various*	various	Metals: Cd	Exposure to workers or environment during processing (This area needs further research)	Multiple venders can be found online, for Hyperaccumulation only (no amendments). Most focus on trees and long term projects.	Increased uptake of Cd with increased soil salinity	Gambrell, R. P., Wiesepape, J.B. Patrick, W. Hand Duff, M.C. 1991. The effects of pH, redox and salinity on metal release from a contaminated sediment. Water, Air Soil Pollut. 57-58, 359-367
	Phytoaccumulator/ Chlorocomplexes	The use of salinity and Cl forming metal complexes such as CdCl as a means improve the phytoaccumulation abilities of certain plants	*NA*	NA	Metals: Hg, Cd, Zn, Pb	Exposure to workers or environment during processing (This area needs further research)	Multiple venders can be found online, for Hyperaccumulation only (no amendments). Most focus on trees and long term projects.	Find that especially Cd, Hg, Pb and Zn form soluble chlorocomplexes that aid in phytoremediation	Hahne, H.C.H. and Krootje, W. 1973. Significance of pH and chloride concentration on behaviour of heavy metal pollutants: Mercury(II), cadmium (II), Zinc (II), and lead (II). J. Environ. Qual. 2, 444-450
	Phytoaccumulator/ Chlorocomplexes	The use of salinity and Cl forming metal complexes such as CdCl as a means improve the phytoaccumulation abilities of certain plants	*Solanum tuberosum*	potato	Metals: Cd	Exposure to workers or environment during processing (This area needs further research)	Multiple venders can be found online, for Hyperaccumulation only (no amendments). Most focus on trees and long term projects.	Increased uptake of Cd by tubers with increased presence of chlorides. Explained by complex CdCl+.	McLaughlin, M.J., Palmer, L.T., and Tiller, K.G. et.al. 1994. Increased soil salinity causes elevated cadmium concentrastions in field-grwon potato tubers. J.Environ. Qual. 23, 1013-1018
	Phytoaccumulator/ Chlorocomplexes	The use of salinity and Cl forming metal complexes such as CdCl as a means improve the phytoaccumulation abilities of certain plants	*Salix sp.*	Willow tree	Metals: Hg	Exposure to workers or environment during processing (This area needs further research)	Multiple venders can be found online, for Hyperaccumulation only (no amendments). Most focus on trees and long term projects.	Willow trees accumulated 5, 3, and 8 times more Hg with addition of 1mM KI. KI did work, but not enough for practical use.	Wang, Y. and Gregar, M. 2006. Use of iodide to enhance the phytoextraction of mercury-contaminated soil. Sci. Total Environ. 368, 30-39
	Phytodegradation	Contaminants are taken up into the plant tissues where they are metabolized, or biotransformed. Where the transformation takes place depends on the type of plant, and can occur in roots, stem or leaves	*Populus spp.*	Poplar tree	Explosives	Exposure to workers or environment during processing (This area needs further research)	Multiple venders can be found online, for Hyperaccumulation only (no amendments). Most focus on trees and long term projects.	Transpiration of Poplar trees was reduced when exposed to TNT contaminant at certain concentrations.	Thompson, P.L., Ramer, L.A., Schooer, J.L., 1998. Decreased transpiration in poplar trees exposed to 2,4,6,-trinitrotoluene. Environ. Toxicol. Chem. 17, 902-906
	Phytodegradation	Contaminants are taken up into the plant tissues where they are metabolized, or biotransformed. Where the transformation takes place depends on the type of plant, and can occur in roots, stem or leaves	*Populus spp.*	Poplar tree	Explosives	Exposure to workers or environment during processing (This area needs further research)	Multiple venders can be found online, for Hyperaccumulation only (no amendments). Most focus on trees and long term projects.	Use of poplars to remediate 2,4,6-trinitrotoluene. Most of TNT remained in roots with very little transportation to the shoots. However, TNT was transformed into new compounds.	Thompson, P.L., Ramer, L.A., Schooer, J.L., 1998. Uptake and transformation of TNT by hybrid poplar trees. Environmental Science and Technology 32, 975-980
	Phytoextraction, Hyperaccumulation, Phytoaccumulation	process by which plants hyperaccumulate contaminants through their roots and store them in the tissues of plant. Contaminants are not necessarily degraded but are removed from the environment when the plants are harvested. In some cases, the metals/contaminants can be harvested for reuse by incinerating the plants (phytomining)	*Thlaspi caerulescens*	Alpine pennycress	Metals	Exposure to workers or environment during processing (This area needs further research)	Multiple venders can be found online, for Hyperaccumulation only (no amendments). Most focus on trees and long term projects.	Cadmium, Zinc, Nickel. Accumulate Zn:Cd at 39,000:1,800 ppm (leaf content)	Baker Ajm, Walker PL. 1990 Ecophysiology of metal uptake by tolerant plants. In Heaavy metal tolerance in plants:Evolutionary aspects, ed AJ Shaw pp155-177 CRC Press Boca Raton, FL
	Phytoextraction, Hyperaccumulation, Phytoaccumulation	process by which plants hyperaccumulate contaminants through their roots and store them in the tissues of plant. Contaminants are not necessarily degraded but are removed from the environment when the plants are harvested. In some cases, the metals/contaminants can be harvested for reuse by incinerating the plants (phytomining)	*Ipomea alpina*	Ipomoea	Metals: Cu	Exposure to workers or environment during processing (This area needs further research)	Multiple venders can be found online, for Hyperaccumulation only (no amendments). Most focus on trees and long term projects.	Accumulates Cu at 12,300 ppm (leaf content)	Baker Ajm, Walker PL. 1990 Ecophysiology of metal uptake by tolerant plants. In Heaavy metal tolerance in plants:Evolutionary aspects, ed AJ Shaw pp155-177 CRC Press Boca Raton, FL

Tech Class	Process	Technology Description	Species	Common Name	Targeted Contaminant	Health and Safety Concerns	Vendor Information	Comments	Reference
	Phytoextraction, Hyperaccumulation, Phytoaccumulation	process by which plants hyperaccumulate contaminants through their roots and store them in the tissues of plant. Contaminants are not necessarily degraded but are removed from the environment when the plants are harvested. In some cases, the metals/contaminants can be harvested for reuse by incinerating the plants (phytomining)	*Astragalus racemosus*	Cream milkvetch	Metals: Se	Exposure to workers or environment during processing (This area needs further research)	Multiple venders can be found online, for Hyperaccumulation only (no amendments). Most focus on trees and long term projects.	Accumulated Se at 14,900 ppm	Beath OA, Eppsom HF, Gilbert CS 1937. Selenium distrubution in and seasonal variation of vegetation type occurring on seleniferous soils. J American Pharm Assoc 26:394-405
	Phytoextraction, Hyperaccumulation, Phytoaccumulation	process by which plants hyperaccumulate contaminants through their roots and store them in the tissues of plant. Contaminants are not necessarily degraded but are removed from the environment when the plants are harvested. In some cases, the metals/contaminants can be harvested for reuse by incinerating the plants (phytomining)	*NA*	NA	Metals: Nickel	Exposure to workers or environment during processing (This area needs further research)	Multiple venders can be found online, for Hyperaccumulation only (no amendments). Most focus on trees and long term projects.	Propose a technique for collection of accumulated metals (Furnace application)	Boominathan, R., Saha-Chaudhury, N.M., Sahajwalla, V., 2004. Production of Nickel Bio-Ore from hyperaccumulator plant biomass: Applications in Phytomining. Wiley InterScience (www.interscience.wiley.com) DOI: 10.1002/bit.10795
	Phytoextraction, Hyperaccumulation, Phytoaccumulation	process by which plants hyperaccumulate contaminants through their roots and store them in the tissues of plant. Contaminants are not necessarily degraded but are removed from the environment when the plants are harvested. In some cases, the metals/contaminants can be harvested for reuse by incinerating the plants (phytomining)	*Haumaniastrum robertii*	Copper Flower	Metals Co, Cu	Exposure to workers or environment during processing (This area needs further research)	Multiple venders can be found online, for Hyperaccumulation only (no amendments). Most focus on trees and long term projects.	Accumulated CO at 10,200 ppm	Brooks RR. 1977. Copper and Cobalt uptake by Haumaniastrum species. Plant Soil 48:541-544
	Phytoextraction, Hyperaccumulation, Phytoaccumulation	process by which plants hyperaccumulate contaminants through their roots and store them in the tissues of plant. Contaminants are not necessarily degraded but are removed from the environment when the plants are harvested. In some cases, the metals/contaminants can be harvested for reuse by incinerating the plants (phytomining)	*Vetiveria zizanioides/ V. nemoralis*	Vetiver grass	Metals: Pb	Exposure to workers or environment during processing (This area needs further research)	Multiple venders can be found online, for Hyperaccumulation only (no amendments). Most focus on trees and long term projects.	Biomass was decreased with high concentrations of lead. (9-11 g/L)	Chantachon, S., Kruatrachue, M., Pokethitiyook, P., Upatham, S., Tantanasarit, S., and Soonthornsarathool, V., 2003. Phytoextraction and accumulation of lead from contaminated sol by vetiver grass: laboratory and simulated field study. Water, Air, and Soil Pollution 00: 1-20
	Phytoextraction, Hyperaccumulation, Phytoaccumulation	process by which plants hyperaccumulate contaminants through their roots and store them in the tissues of plant. Contaminants are not necessarily degraded but are removed from the environment when the plants are harvested. In some cases, the metals/contaminants can be harvested for reuse by incinerating the plants (phytomining)	*Populus sp.*	Poplar Tree	TCE	Exposure to workers or environment during processing (This area needs further research)	Multiple venders can be found online, for Hyperaccumulation only (no amendments). Most focus on trees and long term projects.	Discusses Cost analysis, List of phyto companies, Case Studies etc. for 1997	Chappell, J., 1997. Phytoremediation of TCE using Populus. Status report prepared for U.S. EPA Technology Innovation Office
	Phytoextraction, Hyperaccumulation, Phytoaccumulation	process by which plants hyperaccumulate contaminants through their roots and store them in the tissues of plant. Contaminants are not necessarily degraded but are removed from the environment when the plants are harvested. In some cases, the metals/contaminants can be harvested for reuse by incinerating the plants (phytomining)	*Andropogon sp./Schizachyrium scoparium*	Big Bluestem/ Splitbeard Bluestem/Broom Sedge/ Little Blue Stem	Uranium	Exposure to workers or environment during processing (This area needs further research)	Multiple venders can be found online, for Hyperaccumulation only (no amendments). Most focus on trees and long term projects.	US DOE site Weldon Sprint Site, Uranium refinery. An assessment of cover and establishment of the prairie and the plant variety after burning.	Franson, R. L., Scholes, C.M., (2011). Quantification of prairie resotration for phytostability at a remediated defense plant. Int Jor of Phytoremediation 13 sup1, 140-153
	Phytoextraction, Hyperaccumulation, Phytoaccumulation	process by which plants hyperaccumulate contaminants through their roots and store them in the tissues of plant. Contaminants are not necessarily degraded but are removed from the environment when the plants are harvested. In some cases, the metals/contaminants can be harvested for reuse by incinerating the plants (phytomining)	*D.chinensis/ Tagetes patula/Ixora chinensis Lam/Helianthus annuus/Kalanchoe blossfeldiana/Canna gereralis spp./Verbena hybrida*	Rainbow pink, French marigold, Chinese ixora, Sunflower, Kalanchoe, Garden Canna, Garden verbena	Metals: Cr, Cu, Ni, Zn	Exposure to workers or environment during processing (This area needs further research)	Multiple venders can be found online, for Hyperaccumulation only (no amendments). Most focus on trees and long term projects.	Tested 12 plants in Taiwan contaminated area (contaminated with As, Pb, Cr, Cu, Ni and Zn). Most significant accumulations (Garden canna and Garden verbena (45-60 mg Cr kg), Chinese ixora and Kalanchoe (30 mg/Cu kg) Rainbow pink and sunflower (30 mg Ni kg), French marigold and sunflower 300-470mg Zn kg). done by natural means no chelators. Values above were accumulated in 31days!	Hung-Yu, L., Kai-Wei, J., Chen, Z-S., 2010. Large-area experiment on uptake of metals by twelve plants growing in soils contaminated with multiple metals

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	Phytoextraction, Hyperaccumulation, Phytoaccumulation	process by which plants hyperaccumulate contaminants through their roots and store them in the tissues of plant. Contaminants are not necessarily degraded but are removed from the environment when the plants are harvested. In some cases, the metals/contaminants can be harvested for reuse by incinerating the plants (phytomining)	*Sebertia acuminata*	NA	Metals: Ni	Exposure to workers or environment during processing (This area needs further research)	Multiple venders can be found online, for Hyperaccumulation only (no amendments). Most focus on trees and long term projects.	Accumulated 25% dry wt dried sap	Jaffre T, Brooks RR, Lee J. Reeves RD. 1976. Sebertia acuminata: a nickel-accumulating plant from new Caledonia. Science 193:579-580
	Phytoextraction, Hyperaccumulation, Phytoaccumulation	process by which plants hyperaccumulate contaminants through their roots and store them in the tissues of plant. Contaminants are not necessarily degraded but are removed from the environment when the plants are harvested. In some cases, the metals/contaminants can be harvested for reuse by incinerating the plants (phytomining)	*Paulownia elongata S.Y.Hu/Pualownia fortunei Hemsl*	Paulownia tree	Metals: Pb, Ni, Fe, Zn, Mn	Exposure to workers or environment during processing (This area needs further research)	Multiple venders can be found online, for Hyperaccumulation only (no amendments). Most focus on trees and long term projects.	P. elongata hyperaccumulator of Mn, Zn/ P.fortunei is a hyperaccumulator of Fe and Ni. Average concentration of Ni 6.63ug/g, Zn-23ug/g-91.88ug/g, Fe 236ug/g and 105 ug/g, Mn, 31ug/g and 42 ug/g, Pb 3.16 ug/g. Content was measured in Leaves.	Knezevic, M., Stankovic, D., Krstic, B., Nikolic, M.S, Vilotic, D., 2009. Concentrations of heavy metals in soil and leaves of plant species Paulownia elongata S.Y.Hu and Paulownia fortunei Hemsl. African Journal of Biotechnology Vol. 8 (20) pp. 5422-5429. October 19, 2009.
	Phytoextraction, Hyperaccumulation, Phytoaccumulation	process by which plants hyperaccumulate contaminants through their roots and store them ion the tissues of plant. Contaminants are not necessarily degraded but are removed from the environment when the plants are harvested. In some cases, the metals/contaminants can be harvested for reuse by incinerating the plants (phytomining)	*Thlaspi goesingense*	Tiny Wild Mustard	Metals: Ni	Exposure to workers or environment during processing (This area needs further research)	Multiple venders can be found online, for Hyperaccumulation only (no amendments). Most focus on trees and long term projects.	Discusses Ni accumulation and Histidine complexation with Ni which makes Ni inactive	Kramer U, Cotter-Howells JD, Charnock JM, Baker AJM, Smith AC. 1996. Free histidine as a metal chelator in plants that accumulate nickel. Nature 379-635-638
	Phytoextraction, Hyperaccumulation, Phytoaccumulation	process by which plants hyperaccumulate contaminants through their roots and store them in the tissues of plant. Contaminants are not necessarily degraded but are removed from the environment when the plants are harvested. In some cases, the metals/contaminants can be harvested for reuse by incinerating the plants (phytomining)	*Thlaspi goesingense*	Tiny Wild Mustard	Metals: Ni	Exposure to workers or environment during processing (This area needs further research)	Multiple venders can be found online, for Hyperaccumulation only (no amendments). Most focus on trees and long term projects.	Discusses Ni accumulation and Histidine complexation with Ni which makes Ni inactive	Kramer U, Smith RD, Wenzel, W, Raskin I, Salt DE 1997. The role of metal transport and tolerance in Nickel hyperaccumulation by Thlaspi goesingense Halacsy. Plant Physiol 115:1641-1650
	Phytoextraction, Hyperaccumulation, Phytoaccumulation	process by which plants hyperaccumulate contaminants through their roots and store them ion the tissues of plant. Contaminants are not necessarily degraded but are removed from the environment when the plants are harvested. In some cases, the metals/contaminants can be harvested for reuse by incinerating the plants (phytomining)	*Biscutella laevigata/Iberis intermedia*	Buckler Mustard/Candytuft	Metals: Thallium	Exposure to workers or environment during processing (This area needs further research)	Multiple venders can be found online, for Hyperaccumulation only (no amendments). Most focus on trees and long term projects.	Naturally accumulated high concentrations of Thallium, B.laevigata and I. intermedia respectively (1.94 and .4% dry wt).	LaCoste, C., Robinson, B., Brooks, R., Anderson, C., Alessandro, C., and Leblanc, M., 1999. The phytoremediation potential of Thallium-contaminated soils using Iberis and Biscutella species.
	Phytoextraction, Hyperaccumulation, Phytoaccumulation	process by which plants hyperaccumulate contaminants through their roots and store them ion the tissues of plant. Contaminants are not necessarily degraded but are removed from the environment when the plants are harvested. In some cases, the metals/contaminants can be harvested for reuse by incinerating the plants (phytomining)	*Pteris vitata*	Brake fern	Metals: As	Exposure to workers or environment during processing (This area needs further research)	Multiple venders can be found online, for Hyperaccumulation only (no amendments). Most focus on trees and long term projects.	Has been shown to hyperaccumulate As at 23,000ug g. with high resistance to toxicity.	Ma, L.Q., Komar, K.m., Tu, c., Zhang, W.H., Cai, Y., Kennelley, E.D., 2001. A fern that hyperaccumulates arsenic, nature, v. 409 p. 579, 2001
	Phytoextraction, Hyperaccumulation, Phytoaccumulation	process by which plants hyperaccumulate contaminants through their roots and store them ion the tissues of plant. Contaminants are not necessarily degraded but are removed from the environment when the plants are harvested. In some cases, the metals/contaminants can be harvested for reuse by incinerating the plants (phytomining)	*transgenic plants*	transgenic plants (tomato, tobacco, indian mustard, rice, cottonwood, poplar)	Metals	Exposure to workers or environment during processing (This area needs further research)	Multiple venders can be found online, for Hyperaccumulation only (no amendments). Most focus on trees and long term projects.	A proposal to the use of transgenic plants for phytoextraction.	Maestri, E., Marmiroli, N., 2011. Transgenic plants for phytoremediation. Int. Jor. Of Phytoremediation. 13: sup1, 264-279

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	Phytoextraction, Hyperaccumulation, Phytoaccumulation	process by which plants hyperaccumulate contaminants through their roots and store them ion the tissues of plant. Contaminants are not necessarily degraded but are removed from the environment when the plants are harvested. In some cases, the metals/contaminants can be harvested for reuse by incinerating the plants (phytomining)	*Solidago hispida*	Hairy golden rod	Metals	Exposure to workers or environment during processing (This area needs further research)	Multiple venders can be found online, for Hyperaccumulation only (no amendments). Most focus on trees and long term projects.	Al, metabolizing TCE	McCutcheon, S.C., and Schnoor, J.L. 2003. Phytoremediation: Transformation and control of contaminants. Hoboken, New Jersey: Wiley-Interscience, Inc.
	Phytoextraction, Hyperaccumulation, Phytoaccumulation	process by which plants hyperaccumulate contaminants through their roots and store them in the tissues of plant. Contaminants are not necessarily degraded but are removed from the environment when the plants are harvested. In some cases, the metals/contaminants can be harvested for reuse by incinerating the plants (phytomining)	*Acer rubrum*	Red Maple	Leachate	Exposure to workers or environment during processing (This area needs further research)	Multiple venders can be found online, for Hyperaccumulation only (no amendments). Most focus on trees and long term projects.		McCutcheon, S.C., and Schnoor, J.L. 2003. Phytoremediation: Transformation and control of contaminants. Hoboken, New Jersey: Wiley-Interscience, Inc.
	Phytoextraction, Hyperaccumulation, Phytoaccumulation	process by which plants hyperaccumulate contaminants through their roots and store them ion the tissues of plant. Contaminants are not necessarily degraded but are removed from the environment when the plants are harvested. In some cases, the metals/contaminants can be harvested for reuse by incinerating the plants (phytomining)	*Thlaspi caerulescens*	Alpine pennycress	Metals	Exposure to workers or environment during processing (This area needs further research)	Multiple venders can be found online, for Hyperaccumulation only (no amendments). Most focus on trees and long term projects.	Cadmium, Zinc, Nickel. Accumulate Zn:Cd at 39,000:1,800	Reeves RD, Baker AJM. 1983. European species of Thlaspi L. (Cruciferae) as indicatior of nickel and zinc. J Geochem Explor 18:275-283
	Phytoextraction, Hyperaccumulation, Phytoaccumulation	process by which plants hyperaccumulate contaminants through their roots and store them ion the tissues of plant. Contaminants are not necessarily degraded but are removed from the environment when the plants are harvested. In some cases, the metals/contaminants can be harvested for reuse by incinerating the plants (phytomining)	*Cornus stolonifera/Salix lutea/Picea glauca/ Pinus banksiana/ Larix laricina*	Dogweed, Yellow Willow, White Spruce, Jack Pine, Tamarack	Metals: Cu	Exposure to workers or environment during processing (This area needs further research)	Multiple venders can be found online, for Hyperaccumulation only (no amendments). Most focus on trees and long term projects.	Found high accumulation of Cu in natural growth of tamarack, dogwood, Jack pine and White spruce	Renault, S., Szczerski, C., Sailerova, E., Fedikow, M.A.F., 2004. Phytoremediation and revegetation of mine tailings and bio-ore production: progress report on plant growth in amended tailings and metal accumulation in seedlings planted at Central Manitoba (Au) minesite (NTS 52L13); in Report of Activities 2004, Manitoba Industry, Economic Development and Mines, Manitoba Geoligical Survey p. 257-261
	Phytoextraction, Hyperaccumulation, Phytoaccumulation (possible Phytodegredation)	process by which plants hyperaccumulate contaminants through their roots and store them ion the tissues of plant. Contaminants are not necessarily degraded but are removed from the environment when the plants are harvested. In some cases, the metals/contaminants can be harvested for reuse by incinerating the plants (phytomining)	*Populus deltoides*	Eastern Cottonwood	Explosives	Exposure to workers or environment during processing (This area needs further research)	Multiple venders can be found online, for Hyperaccumulation only (no amendments). Most focus on trees and long term projects.	Plants were harvested after 11 days, grown in hydroponic solution. TNT was rapidly removed (within 48hours). RDX was slower but also removed (120g/kg) and HMX was not removed.	Sealock, G.A. 2002. Phytoremediation of explosives using Populus deltoides. MS Thesis. Athens, Univ. of Georgia, 70pp.
	Phytoextraction, Hyperaccumulation, Phytoaccumulation	process by which plants hyperaccumulate contaminants through their roots and store them ion the tissues of plant. Contaminants are not necessarily degraded but are removed from the environment when the plants are harvested. In some cases, the metals/contaminants can be harvested for reuse by incinerating the plants (phytomining)	*Fagopyrum esculentum*	Common Buckwheat	Metals: Pb	Exposure to workers or environment during processing (This area needs further research)	Multiple venders can be found online, for Hyperaccumulation only (no amendments). Most focus on trees and long term projects.	only known Natural Pb hyperaccumulator. Shown to accumulate in shoots at 4,200 ug g. Introduction of MGDA resulted in 5-fold increase of this.	Tamura, H., Honda, M., Sato, T., Kamachi, H., 2005. Pb hyperaccumulation and tolerance in common buckwheat (Fagopyrum esculentum Moench) Journal of Plant Research v. 118, P. 355-359, 2005
	Phytoextraction, Hyperaccumulation, Phytoaccumulation	process by which plants hyperaccumulate contaminants through their roots and store them ion the tissues of plant. Contaminants are not necessarily degraded but are removed from the environment when the plants are harvested. In some cases, the metals/contaminants can be harvested for reuse by incinerating the plants (phytomining)	*Paulownia fortunei*	Paulownia tree	Metals: Pb, Zn, Cu, Cd	Exposure to workers or environment during processing (This area needs further research)	Multiple venders can be found online, for Hyperaccumulation only (no amendments). Most focus on trees and long term projects.	Study on the inhibitory response of metals on young seedlings in mine tailings with contaminants (Pb, Zn, Cu and Cd)	Wang, J., Li, W., Zhang, C., Ke, S., 2010. Physiological responsees and detoxific mechanisms to Pb, Zn, Cu and Cd, in young seedlings of Paulownia fortunei. Journal of Environmental Sciences 2010, 22 (12) 1916-1922

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	Phytoextraction, Hyperaccumulation, Phytoaccumulation	process by which plants hyperaccumulate contaminants through their roots and store them ion the tissues of plant. Contaminants are not necessarily degraded but are removed from the environment when the plants are harvested. In some cases, the metals/contaminants can be harvested for reuse by incinerating the plants (phytomining)	*Populus spp./Salix sp.*	Poplar and Willow tree	Landfill contaminants	Exposure to workers or environment during processing (This area needs further research)	Multiple venders can be found online, for Hyperaccumulation only (no amendments). Most focus on trees and long term projects.	A guide and experiment utilizing Poplars and willows to extract contaminates from soil.	Zalesny, R.S., and Bauer, E.O., 2007. Selecting and utilizing Populus and Salix for landfull covers: implications for leachate irrigation
	Phytovolatilization	process where plants intake volatile compounds through their roots, and transpire the same compound or its metabolite(s) into the atmosphere through the leaves	*Populus deltoides X nigra*	poplar tree, hybrid	1,4 Dioxane	Volitilization of contaminants could occur during plant growth. Emissions may need to be monitored for toxicity.Exposure to workers or environment during processing (This area needs further research)	Multiple venders can be found online, for Hyperaccumulation only (no amendments). Most focus on trees and long term projects.	Lab Study, Dioxane half-life in air (7-10 Hours)	Aitchison, E.W., Kelley, S.L., Schnoor, J.L. 2000. Phytoremediation of 1,4 dioxane by hybrid poplar tree. Water Environment Research 72, 313-321
	Phytovolatilization	process where plants intake volatile compounds through their roots, and transpire the same compound or its metabolite(s) into the atmosphere through the leaves	*Populus spp.*	Poplar tree	1,4 Dioxane	Volitilization of contaminants could occur during plant growth. Emissions may need to be monitored for toxicity.Exposure to workers or environment during processing (This area needs further research)	Multiple venders can be found online, for Hyperaccumulation only (no amendments). Most focus on trees and long term projects.	Remediation of 1-4-dioxane form contaminated sandy soil by poplar trees. 30% removed within 7 days	Ouyang, Y., 2002. Phytoremediation: modleing plant uptake and contaminant transport in the soil-plant-atmosphere continuum. Journal of Hydrology. 266 66-82
	Rhizodegredation	process by which plant exudates stimulate rhizosphere bacteria to enhance biodegradation of soil contaminants (happens in the soil directly surrounding the plant roots)	*Agropyron smithii*	Western Wheat Grass	Hydrocarbons	Exposure to workers or environment during processing (This area needs further research)	Multiple venders can be found online, for Hyperaccumulation only (no amendments). Most focus on trees and long term projects.	Enhance degredation of TPH and PAH in soils	McCutcheon, S.C., and Schnoor, J.L. 2003. Phytoremediation: Transformation and control of contaminants. Hoboken, New Jersey: Wiley-Interscience, Inc.
	Rhizodegredation	process by which plant exudates stimulate rhizosphere bacteria to enhance biodegradation of soil contaminants (happens in the soil directly surrounding the plant roots)	*Bouteloua gracilis*	Blue gamma grass	Hydrocarbons	Exposure to workers or environment during processing (This area needs further research)	Multiple venders can be found online, for Hyperaccumulation only (no amendments). Most focus on trees and long term projects.	PAHs in soil	McCutcheon, S.C., and Schnoor, J.L. 2003. Phytoremediation: Transformation and control of contaminants. Hoboken, New Jersey: Wiley-Interscience, Inc.
	Rhizodegredation	process by which plant exudates stimulate rhizosphere bacteria to enhance biodegradation of soil contaminants (happens in the soil directly surrounding the plant roots)	*Festuca rubra*	Red fescue	Hydrocarbons	Exposure to workers or environment during processing (This area needs further research)	Multiple venders can be found online, for Hyperaccumulation only (no amendments). Most focus on trees and long term projects.	TPH and PAHs in soil	McCutcheon, S.C., and Schnoor, J.L. 2003. Phytoremediation: Transformation and control of contaminants. Hoboken, New Jersey: Wiley-Interscience, Inc.
	Rhizodegredation	process by which plant exudates stimulate rhizosphere bacteria to enhance biodegradation of soil contaminants (happens in the soil directly surrounding the plant roots)	*Melilotus officinalis*	Yellow sweet clover	Hydrocarbons	Exposure to workers or environment during processing (This area needs further research)	Multiple venders can be found online, for Hyperaccumulation only (no amendments). Most focus on trees and long term projects.	Degrade TPH	McCutcheon, S.C., and Schnoor, J.L. 2003. Phytoremediation: Transformation and control of contaminants. Hoboken, New Jersey: Wiley-Interscience, Inc.
	Rhizodegredation	process by which plant exudates stimulate rhizosphere bacteria to enhance biodegradation of soil contaminants (happens in the soil directly surrounding the plant roots)	*Maclura pomifera*	Osage orange	PCBs	Exposure to workers or environment during processing (This area needs further research)	Multiple venders can be found online, for Hyperaccumulation only (no amendments). Most focus on trees and long term projects.	hearty, stimulate PCB degrading bacteria in soil	McCutcheon, S.C., and Schnoor, J.L. 2003. Phytoremediation: Transformation and control of contaminants. Hoboken, New Jersey: Wiley-Interscience, Inc.
	Rhizodegredation	process by which plant exudates stimulate rhizosphere bacteria to enhance biodegradation of soil contaminants (happens in the soil directly surrounding the plant roots)	*Morus rubra*	Mulberry	PAHs, PCBs	Exposure to workers or environment during processing (This area needs further research)	Multiple venders can be found online, for Hyperaccumulation only (no amendments). Most focus on trees and long term projects.	produces phenolic compounds stimulating PCB-degrading bacteria	McCutcheon, S.C., and Schnoor, J.L. 2003. Phytoremediation: Transformation and control of contaminants. Hoboken, New Jersey: Wiley-Interscience, Inc.
	Rhizodegredation/ Phytoextraction	process by which plant exudates stimulate rhizosphere bacteria to enhance biodegradation of soil contaminants (happens in the soil directly surrounding the plant roots), and also increases the solubility of the metals so that they are more bioavailable to the plant.	*various*	various	Metals: Cr, Hg, Pb, Cd	Exposure to workers or environment during processing (This area needs further research)	Multiple venders can be found online, for Hyperaccumulation only (no amendments). Most focus on trees and long term projects.	Soil microorganisms may be able to influence metal solubility by altering their chemical properties	Blake RC, Choate DM, Bardhan S, Revis N, Barton LL, Zocco TG 1993. Chemical transformation of toxic metals by a Pseudomonas strain from a toxic waste site. Environ Toxic and Chem 12: 1365-1376
	Rhizodegredation/ Phytoextraction	process by which plant exudates stimulate rhizosphere bacteria to enhance biodegradation of soil contaminants (happens in the soil directly surrounding the plant roots), and also increases the solubility of the metals so that they are more bioavailable to the plant.	*various*	various	Metals	Exposure to workers or environment during processing (This area needs further research)	Multiple venders can be found online, for Hyperaccumulation only (no amendments). Most focus on trees and long term projects.	APCAs can form stable soluble complexes with di and trivalent cations. Half-life of NTA is ~3-7 days	Bucheli-Witschel, M. and Egli, T. 2001. Environmental fate and microbial degradation of aminopoly-carboxylic acids. FEMS Microbiol. Rev. 25, 69-106

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	Rhizodegredation/ Phytoextraction	process by which plant exudates stimulate rhizosphere bacteria to enhance biodegredation of soil contaminants (happens in the soil directly surrounding the plant roots), and also increases the solubility of the metals so that they are more bioavailable to the plant.	*various*	various	Metals: Fe	Exposure to workers or environment during processing (This area needs further research)	Multiple venders can be found online, for Hyperaccumulation only (no amendments). Most focus on trees and long term projects.	Discusses how microorganisms can produce organic compounds which facilitate adsorption of metals	Crowley DE, Wang YC, Reid CPP, Szansiszlo PJ. 1991. Mechanism of iron acquisiton from siderophores by microorganisms and plants. Plant and Soil 130:179-198
	Rhizodegredation/ Phytoextraction	process by which plant exudates stimulate rhizosphere bacteria to enhance biodegredation of soil contaminants (happens in the soil directly surrounding the plant roots), and also increases the solubility of the metals so that they are more bioavailable to the plant.	*Zea mays*	Corn	Metals	Exposure to workers or environment during processing (This area needs further research)	Multiple venders can be found online, for Hyperaccumulation only (no amendments). Most focus on trees and long term projects.	Observed growth depressions in Z.mays after treatment with elemental sulfur	Cui, Y., Dong, Y., Li, H., and Wang, Q., 2004. Effect of elemental sulphur on solubility of soil heavy metals and their uptake by maize. Environ. Int. 30, 323-328
	Rhizodegredation/ Phytoextraction	process by which plant exudates stimulate rhizosphere bacteria to enhance biodegredation of soil contaminants (happens in the soil directly surrounding the plant roots), and also increases the solubility of the metals so that they are more bioavailable to the plant.	*Helianthus annuus/ Salix viminalis*	Sunflower/Willow	Metals: Zn	Exposure to workers or environment during processing (This area needs further research)	Multiple venders can be found online, for Hyperaccumulation only (no amendments). Most focus on trees and long term projects.	Studied the effects of soil acidification induced by elemental sulfur uptake by H.annuus and Salix viminalis. Zn uptake in Salix increased from 930mg kg in untreated to 4300mg kg in amended soils. H. annuus control 1101mg kg and 3812 mg kg in amended soil (effects were validated in Z.mays and N. tabacum)	Kayser, A., Wenger K., Keller, A., Attinger, W. Felix, H.R., Gupta, S.K., and Schulin, R. 2000. Enhancement of phytoextraction of Zn, Cd and Cu from calcareous soil: The use of NTA and sulfur amendments. Environ. Sci Technol 34, 1778-1783
	Rhizodegredation/ Phytoextraction	process by which plant exudates stimulate rhizosphere bacteria to enhance biodegredation of soil contaminants (happens in the soil directly surrounding the plant roots), and also increases the solubility of the metals so that they are more bioavailable to the plant.	*various*	various	Metals: Fe, Mn, Zn and Cu	Exposure to workers or environment during processing (This area needs further research)	Multiple venders can be found online, for Hyperaccumulation only (no amendments). Most focus on trees and long term projects.	In P-deficient conditions plants exude malic acid, citric acid and acid phosphates. Phytosiderophores are released in Zn and Fe deficient conditions, increasing Fe, Mn, Zn, and Cu in the rhizosphere	Khan,Ag.G., Kuek, C., Chaudry, T.M., Khoo, C.S., and Hayes, W.J. 2000. Role of plants, mycorrhizae and phytochelators in heavy metal contaminated land remediation. Chemosphere 41, 197-207
	Rhizodegredation/ Phytoextraction	process by which plant exudates stimulate rhizosphere bacteria to enhance biodegredation of soil contaminants (happens in the soil directly surrounding the plant roots), and also increases the solubility of the metals so that they are more bioavailable to the plant.	*various*	various	Metals	Exposure to workers or environment during processing (This area needs further research)	Multiple venders can be found online, for Hyperaccumulation only (no amendments). Most focus on trees and long term projects.	use of bacteria in phytoremediation.	Lodewyckx, C. 2001. A potential role for bacterial endophytes in phytoremediation of heavy metals contaminated soils. PhD thesis, Limburg University (LUC), Limburg, Belgium, 157pp.
	Rhizodegredation/ Phytoextraction	process by which plant exudates stimulate rhizosphere bacteria to enhance biodegredation of soil contaminants (happens in the soil directly surrounding the plant roots), and also increases the solubility of the metals so that they are more bioavailable to the plant.	*various*	various	Metals: Zn	Exposure to workers or environment during processing (This area needs further research)	Multiple venders can be found online, for Hyperaccumulation only (no amendments). Most focus on trees and long term projects.	Plants and rhizophere microorganisms are known to release low molecular organic acids that increase solubility uptake by plants. Examined Zn, complexation by citric acid	Lombnaes, Chang, and Singh, 2002. Zinc complexation with citric acid in soils as affected by pH and ionic stength. Presented at the COST837 Action Workshop, 25-27 April, Bordeaux, France
	Rhizodegredation/ Phytoextraction	process by which plant exudates stimulate rhizosphere bacteria to enhance biodegredation of soil contaminants (happens in the soil directly surrounding the plant roots), and also increases the solubility of the metals so that they are more bioavailable to the plant.	*various*	various	Metals: Cr, Hg, Pb, Cd	Exposure to workers or environment during processing (This area needs further research)	Multiple venders can be found online, for Hyperaccumulation only (no amendments). Most focus on trees and long term projects.	Soil microorganisms may be able to influence metal solubility by altering their chemical properties	Park CH, Keyhan M, Matin A. 1999. Purification and characterization of chromate reductase in Pseudomonas putida. Abs Gen Meet American Soc Microbiol. 99: 536
	Rhizodegredation/ Phytoextraction	process by which plant exudates stimulate rhizosphere bacteria to enhance biodegredation of soil contaminants (happens in the soil directly surrounding the plant roots), and also increases the solubility of the metals so that they are more bioavailable to the plant.	*Salix sp.*	Willow tree	Metals: Cd, Zn	Exposure to workers or environment during processing (This area needs further research)	Multiple venders can be found online, for Hyperaccumulation only (no amendments). Most focus on trees and long term projects.	Study the use of ectomycorrhizal fungi (Hebeloma crustuliniforme) and ectomycorrhiza associated bacteria (Micrococcus luteus and Sphingomonas sp.), Bacteria/fungi combination helped plant growth and also increased Cd, Zn concentrations by 53 and62%	Zimmer, D., Baum, C., Leinweber, P., Hrynkiewicz, K., Meissner, R., 2009. Associated bacteria increase the phytoextraction of cadmium and zinc from a metal-contaminated soil by mycorrhizal willows, International Journal of Phytoremediation, 11:2, 200-213
	Rhizodegredation/ Accumulation	process by which plant exudates stimulate rhizosphere bacteria to enhance biodegredation of soil contaminants (happens in the soil directly surrounding the plant roots)	*Buchloe dactyloides*	Buffalo grass	Hydrocarbons	Exposure to workers or environment during processing (This area needs further research)	Multiple venders can be found online, for Hyperaccumulation only (no amendments). Most focus on trees and long term projects.	TPH and PAHs in soil	McCutcheon, S.C., and Schnoor, J.L. 2003. Phytoremediation: Transformation and control of contaminants. Hoboken, New Jersey: Wiley-Interscience, Inc.
	Rhizodegredation/ Accumulation	process by which plant exudates stimulate rhizosphere bacteria to enhance biodegredation of soil contaminants (happens in the soil directly surrounding the plant roots)	*Cynodon dactylon*	Bermuda grass	Hydrocarbons	Exposure to workers or environment during processing (This area needs further research)	Multiple venders can be found online, for Hyperaccumulation only (no amendments). Most focus on trees and long term projects.	TPH and PAHs in soil	McCutcheon, S.C., and Schnoor, J.L. 2003. Phytoremediation: Transformation and control of contaminants. Hoboken, New Jersey: Wiley-Interscience, Inc.

Tech Class	Process	Technology Description	*Species*	Common Name	Targeted Contaminant	Health and Safety Concerns	Vendor Information	Comments	Reference
	Rhizodegredation/ Accumulation	process by which plant exudates stimulate rhizosphere bacteria to enhance biodegradation of soil contaminants (happens in the soil directly surrounding the plant roots)	*Elymus Canadensis*	Canadian wild rye	Hydrocarbons	Exposure to workers or environment during processing (This area needs further research)	Multiple venders can be found online, for Hyperaccumulation only (no amendments). Most focus on trees and long term projects.	PAHs in soils	McCutcheon, S.C., and Schnoor, J.L. 2003. Phytoremediation: Transformation and control of contaminants. Hoboken, New Jersey: Wiley-Interscience, Inc.
	Stress Induced Phytoaccumulation	The use of plant stressors such as a micronutrient deficiency or acidic conditions to instigate phytoaccumulation in plants.	*various*	various	Metals: Cd	Exposure to workers or environment during processing (This area needs further research)	Multiple venders can be found online, for Hyperaccumulation only (no amendments). Most focus on trees and long term projects.	Fe deficiency stimulates uptake of Cd	Cohen, C.K., Fox, T.C., Garvin, D.F., and Kochian, L.V. 1998. The role of iron-defficiency stress responses in stimulating heavy-metal transport in plants. Plant Pysiol. 116, 1063-1072
	Stress Induced Phytoaccumulation	The use of plant stressors such as a micronutrient deficiency or acidic conditions to instigate phytoaccumulation in plants.	*various*	various		Exposure to workers or environment during processing (This area needs further research)	Multiple venders can be found online, for Hyperaccumulation only (no amendments). Most focus on trees and long term projects.	Observed increases in P concentration after citric and malic acid treatment, focused on nutrient-mobilization in a rotationl crop schedule	Hens, M. and Hocking, P. 2002. Phosphorus mobilisation by organic-acid exudation: Processes governing benefits in rotational cropping. Proceedings of the 17th WCWSS World Congress of Soil Science, Bangkok, Thailand, Symposium 6, Paper no. 1092
	Stress Induced Phytoaccumulation	The use of plant stressors such as a micronutrient deficiency or acidic conditions to instigate phytoaccumulation in plants.	*Hordeum vulgare*	Barley	Metals: Cd	Exposure to workers or environment during processing (This area needs further research)	Multiple venders can be found online, for Hyperaccumulation only (no amendments). Most focus on trees and long term projects.	assessed ascorbic acid effect on Cd in Hordeum vulgare. Ascorbic acid increased Cd in shoot 13-18%	Wu, F. and Zhang, G. 2002. Alleviation of cadmium-toxicity by application of zinc and ascorbic acid in barley. J. Plant Nutrit. 25, 2745-2761
	Bacteria Assisted Phytoaccumulation	Process by which plant growth-promoting bacteria are used to protect plants from toxicity of contaminants	*various*	various	Metals	Exposure to workers or environment during processing (This area needs further research)	Multiple venders can be found online, for Hyperaccumulation only (no amendments). Most focus on trees and long term projects.	Look at chart on pg 8 of paper. List of plants and bacteria combinations that have proven to be beneficial. Bacteria protect the plant from the metals toxicity by producing ACC deaminase activity and therefore reduce plant ethylene levels	Glick, B. R., Stearns, J.C., 2011. Making phytoremediation work better: Maximizing a plant's growth potential in the midst of adversity. Int Jor of Phytoremediation. 13 (SI): 4-16
	Phytochelatins	Process by which plants produce Phytochelatins which is an enzymatically synthesized Cys-rich peptides to protect the plant from heavy metal toxicity.	*Capsicum annuum*	Pepper	Metals: Cd	Exposure to workers or environment during processing (This area needs further research)	Multiple venders can be found online, for Hyperaccumulation only (no amendments). Most focus on trees and long term projects.	Capsicum annuum was able to sustain elevated shoot concentrations of Cd due to PCs accumulation	Jemal, F., Diedierjean, L., Ghirr, R., Ghorbal, M.H., and Burkard, G. 1998. characterization of cadmium binding peptides from pepper (Capsicum annuum). Plant Sci. 137, 143-154
	Phytochelatins	Process by which plants produce Phytochelatins which is an enzymatically synthesized Cys-rich peptides to protect the plant from heavy metal toxicity.	*various*	various	NA	Exposure to workers or environment during processing (This area needs further research)	Multiple venders can be found online, for Hyperaccumulation only (no amendments). Most focus on trees and long term projects.	PCs can detoxify heavy metals for plants. Plants can tolerate 10-1000 fold higher with PC, free PCs restore metal poisoned enzymes	Kneer, R. and Zenk, M. H. 2002. Phytochelatins protect plant enzymes from heavy metal poisoning. Phytochem. 31, 2663-2667
	Phytochelatins	Process by which plants produce Phytochelatins which is an enzymatically synthesized Cys-rich peptides to protect the plant from heavy metal toxicity.	*various*	various	Metals	Exposure to workers or environment during processing (This area needs further research)	Multiple venders can be found online, for Hyperaccumulation only (no amendments). Most focus on trees and long term projects.	Higher plants respond to potentially toxic metals by synthesizing phytochelatins (PCs) and related cysteine-rich polypeptides	Zenk, M. H. 1996. Heavy metal detoxidication In higher plants - A review. Gene. 176, 21-30.