Use of Field-Scale Phytotechnology for Chlorinated Solvents, Metals, Explosives and Propellants, and Pesticides

STATUS REPORT

Introduction

Phytotechnology is an emerging technology that has the potential to treat a wide range of contaminants for a lower cost than traditional technologies. This technology uses various types of plants to degrade, extract, contain, or immobilize contaminants in soil and water. Phytotechnology has been used for remediation of chlorinated solvents, metals, explosives and propellants, pesticides, polycyclic aromatic hydrocarbons, radionuclides, and petroleum hydrocarbon compounds (EPA 2000).

Since the 1980s, phytotechnology has been used by federal, state, and private sector organizations to treat contaminated soil and groundwater. Although information is available about the types of mechanisms that are considered to be components of phytotechnology, only limited information is available about project performance and time frames for project completion. Where project information is available, there is a wide variation in how performance is measured, making it difficult for decision-makers to interpret project results.

Purpose

For this status report, the U.S. Environmental Protection Agency (EPA) has collected information about 79 field-scale phytotechnology projects conducted throughout the United States and Canada that involved treatment of soil and groundwater contaminated with chlorinated solvents, metals, explosives and propellants, and pesticides. The purpose of this report is to inform readers of the status of these projects. This document can be used as a networking tool for federal, state, and industrial employees to share lessons learned from and practical experiences with field-scale applications of phytotechnology. Appendix A identifies the specific project sites, provides a reference for each site, and summarizes the types of information compiled for this status report.

For Additional Information About Phytotechnology, visit *http://www.clu-in.org/techfocus.*
Topics covered include the following:

- Overview
- Guidance
- Application
- Training
- Additional Resources

Solid Waste and Emergency Response (5102G)

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Methodology

EPA prepared summaries of available phytotechnology data and contacted project managers and researchers to confirm and update the information. The information was obtained from technology providers; technical literature; and Web sites such as the Remediation Technologies Development Forum (*www.rtdf.org*), the Federal Remediation Technology Roundtable (FRTR) (*www.frtr.gov*), Superfund Innovative Technology Evaluation Reports (*www.epa.gov/ORD/SITE*), and the Annual Status Report (*www.clu-in.org/asr*).

This phytotechnology status report includes data about projects performed at Superfund sites; federal and military sites; and other sites in the United States and Canada that are being addressed under state, local, or voluntary cleanup programs. EPA attempted to compile information that was readily available and current for each project as of summer and fall 2004 (EPA 2004c). However, EPA was unable to verify the available information for all projects. In addition, for many of the projects, there were gaps in the types of information available (for example, for some sites, performance data were not available). Some of the projects were successful in remediating contamination, while others were not. Furthermore, the set of projects may not include all the field-scale phytotechnology projects that are ongoing or have been completed at this time. Based on the time and resources available, EPA limited this effort to phytotechnology projects that were reported in the information resources identified above and that were conducted at the field scale. Projects using constructed wetlands or alternative landfill covers (such as evapotranspiration caps) were not considered (see the text box for further information about the phytotechnology projects included in this report).

The rest of this status report summarizes information for the 79 field-scale phytotechnology projects, including the types of contaminants treated; vegetation used; phytotechnology mechanisms; planting date; and project size, location, cost, and performance.

About the phytotechnology projects in this report:

- Full- and pilot-scale field projects only (no projects conducted only at a laboratory research level)
- Sites contaminated with chlorinated solvents, metals, explosives and propellants, and pesticides only (no sites with organic, petroleum, or radiation contamination are included)
- Projects in the United States and Canada only
- No projects that used constructed wetlands
- No projects that used alternative landfill covers (such as evapotranspiration caps) – for information about these types of projects, visit *http://clu-in.org/products/altcovers/*

Types of information collected for each phytotechnology project include:

- Site name and location
- Site characterization
- Planting date and description
- Media treated
- Vegetation types
- Contaminants treated
- Phytomechanisms used
- Project size, scale, and status
- Operation and maintenance
- Technology cost and performance
- Lessons learned
- Point(s) of contact

Superfund Sites

Some of the phytotechnology projects addressed in this report have been performed at Superfund sites. Table 1 summarizes selected federal Superfund sites where phytotechnology has been used or is expected to be used.

Project Locations

The 79 phytotechnology projects have been performed at sites in 31 states throughout the United States, as shown in Figure 1. The following four states have had five or more phytotechnology projects: Idaho, Illinois, Texas, and Wisconsin. As shown in Figure 1, phytotechnology projects have been performed in states with both warmer and colder climates as well as in states with both relatively little precipitation and extensive precipitation.

Contaminants

For all 79 projects, information was available about the types of contaminants treated using phytotechnology. The types of contaminants covered in this report are chlorinated solvents, metals, explosives and propellants, and pesticides.

Chlorinated solvents are manmade organic compounds that are typically manufactured using naturally occurring hydrocarbon constituents and chlorine. These solvents include tetrachloroethene (PCE); trichloroethene (TCE); 1,1,1-trichloroethane (TCA); vinyl chloride (VC); and other chlorinated methanes, ethanes, ethenes, and benzenes. The solvents have many applications, including uses as degreasers in dry cleaning operations and manufacturing. As a result of their widespread historical use, chlorinated solvents are frequently found in soil and groundwater at remediation sites. For example, TCE, TCA, and VC have been identified as 3 of the 12 contaminants most commonly found at Superfund sites (EPA 2004a).

Metal contamination is the result of anthropogenic actions such as fossil fuel combustion, mining and smelting operations, and sewage and municipal waste discharges. These activities can cause metals to be found at elevated concentrations in soil and groundwater. Metals such as arsenic, cadmium, chromium, lead, and mercury are often identified as contaminants of concern at remediation sites. The sites where metal contaminants have been found include artillery and small arms impact areas, burn pits, electroplating and metal finishing shops, landfills and burial pits, and vehicle maintenance areas (FRTR 2004).

Explosives are manmade organic substances that undergo rapid chemical transformations and produce gases and pressures that can cause damage to their surroundings (see *http://web.em.doe.gov/idb97/tab85.html*). Some common explosives include 2,4,6-trinitrotoluene (TNT); dinitrotoluene (DNT); and octohydro-1,3,5,7-tetranitro-1,3,5,7-tetrazine (HMX). Common uses of explosives include military applications and pyrotechnic displays.

Propellants are inorganic ions such as perchlorate that have been widely used in the manufacture of solid propellants and explosives, including rocket motors, fireworks, and flares. Contamination of soil by propellants is typically the result of the manufacture, storage, testing, and disposal of these chemicals (FRTR 2004).

Pesticides are defined by EPA as any substances or mixtures of substances that are intended to prevent, destroy, repel, or mitigate any pest. This definition applies to herbicides, fungicides, and various other substances used to control pests. Pesticides are ubiquitous in the environment because of their worldwide use. Organochlorine pesticides, including aldrin, chlordane, DDT, and dieldrin, tend to persist in soil and groundwater for extended periods of time (EPA 2004b).

Figure 2 shows a breakdown of the phytotechnology projects by type of contaminant. Among the 79 projects, chlorinated solvents were treated most frequently (44%), followed by metals (37%), pesticides (15%), and explosives and propellants (4%).

For phytotechnology projects involving chlorinated solvents, TCE (71%), PCE (49%), VC (26%), and dichloroethane (DCA) (23%) were the contaminants most commonly treated. Exhibit 1 provides an example of a phytotechnology field demonstration project involving treatment of chlorinated solvents in groundwater. The metals that were most frequently treated using phytotechnology were lead (40%), arsenic (33%), cadmium (24%), zinc (15%), and copper (15%). The most commonly treated pesticides were atrazine (36%), alachlor (21%), and dieldrin (14%). For explosives and propellants, DNT (66%), TNT(33%), and perchlorate (33%) were treated using phytotechnology.

Table 1. Phytotechnology Use at Superfund Sites for Chlorinated Solvents, Metals, Explosives and Propellants, and Pesticides*

Site Name	Site Location	ROD Date	Contaminants	Phytotechnology Status
Aberdeen Pesticides Dumps	NC	06/04/99	Dieldrin, Hexachlorobenzene, Hexachlorahexane	Ongoing (1999 -)
Aberdeen Proving Ground	MD	09/27/01	1,1,2,2-Tetrachlorothane; 1,1,2-Trichloroethane; 1,1-DCE; 1,2-Dichloroethane; 1,2-DCE; PCE; TCE; VC	Ongoing (1996 -)
Argonne National Laboratory West 1	ID	09/29/98	Cesium-137, Silver, Mercury, Chromium	Completed (1999 - 2002)
AT & SF Albuquerque	NM	06/27/02	2-Methylnaphthalene, Benzo(a)anthracene, Benzo(b)fluoranthene, Benzo(k)fluoranthene, Dibenzo(a,h)anthracene, Dibenzofuran, Ideno(1,2,3-cd)pyrene, Naphthalene, Zinc	Predesign
Atlas Tack Corporation	MA	03/10/00	Benzene, Chromium, Copper, Cyanide, Mercury, Nickel, Zinc	Design (2003 -)
Boarhead Farm	PA	11/18/98	Benzene, Cadmium, Nickel, TCE	Designed/Not Installed (2003)
Bofors-Nobel Inc.	MI	ROD Amendment: 07/16/99	3,3-Dichlorobenzidine; Acetone; Arsenic; VC; PCE; Aniline; Benzene; Toluene; Xylene; Zinc	Pilot Completed (1999 - 2002); Design Phase (2005 -)
Carswell Naval Air Station	TX	08/96	TCE, DCE	Ongoing (1996 - 2006)
Combustion, Inc.	LA	05/28/04	DCA, PCB, Benzene, Lead, Mercury, Nickel, Silver, Toluene, Toluene Diisocynate, Toluene Diamine	Ongoing (2002 -)
Del Monte Corp.	HI	09/25/03	Ethylene Dibromide; 1,2-Dibromo-3-chloropropane; 1,2-Dichloropropane; 1,2,3-Trichloropropane (Pesticides)	Ongoing (1998 -)
East Palo Alto	CA	RCRA Drop Site	Arsenic, Sodium	Ongoing (1981-)
Fort Dix	NJ	Field Demonstration	Lead	Completed (1997 - 2002)
Fort Wainwright	AK	06/27/97	Aldrin, DDD, DDT, Dieldrin	Completed (1997 - 2001)
Naval Undersea Warfare Station	WA	09/28/98	TCA, Halogenated Volatiles	Ongoing (1999 - 2009)
Sangamo Electric Dump/Crab Orchard National Wildlife Refuge	IL	ROD Amendment: Expected in 2005	1,1-DCE; PCE; VC	Planned (2006 -)
Tibbetts Road	NH	09/28/98	TCE	Ongoing (1998 - 2015)

* Includes federal Superfund sites at which phytotechnology was selected and/or used for remediation of one or more of the four types of contaminants included in this report. This table includes sites for which phytotechnology has been selected in a record of decision (ROD), has been used in a field demonstration, or is planned for use. Further site-specific information about Superfund is available at *www.epa.gov/superfund*.

Figure 1. Locations of Phytotechnology Projects in the United States

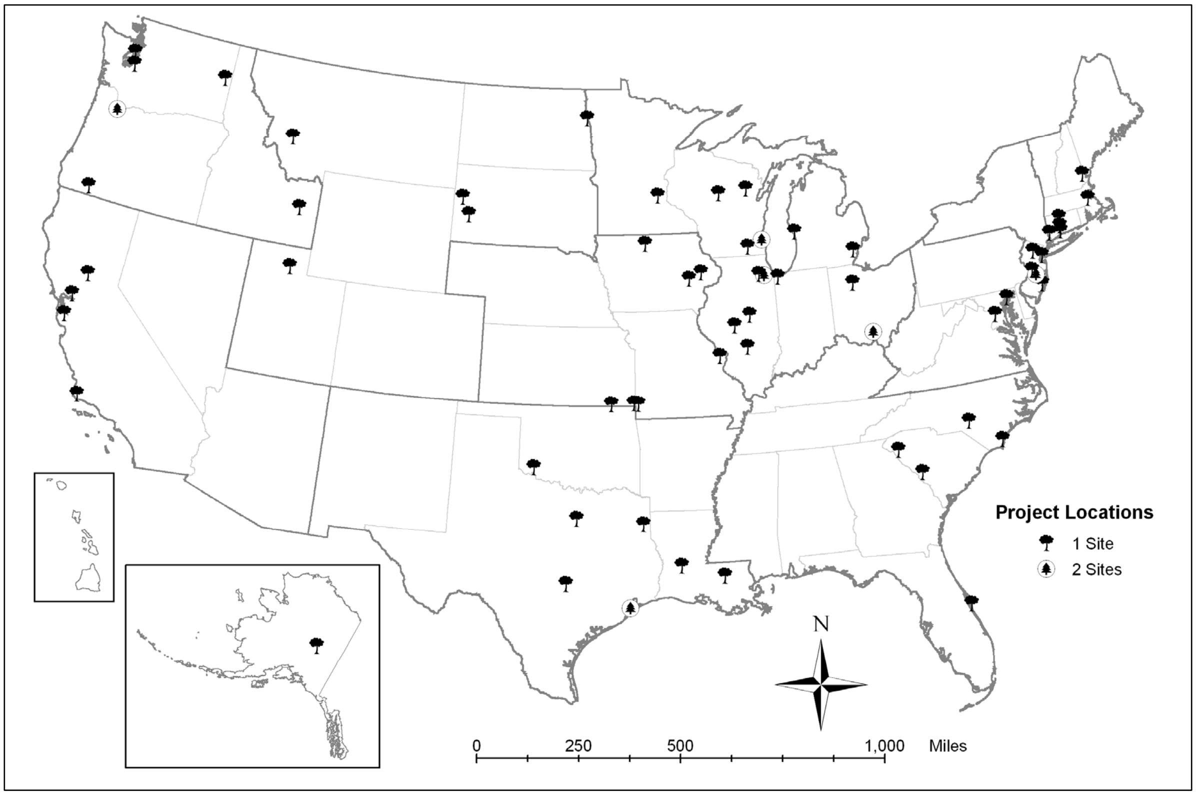
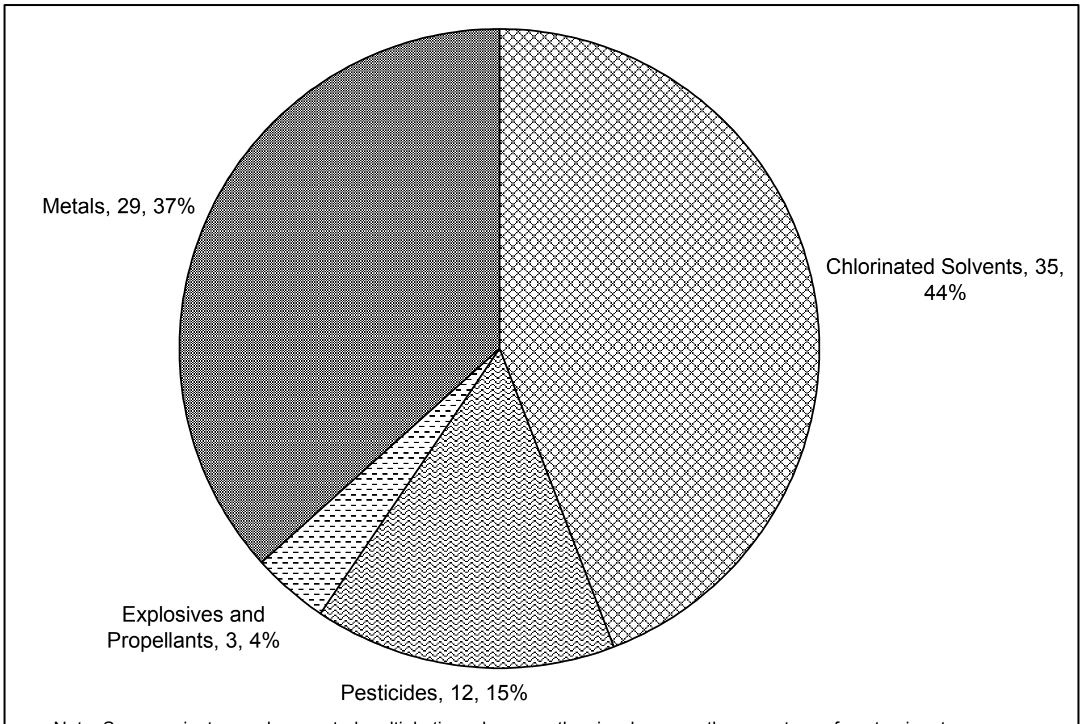


Figure 2. Distribution of Contaminants Treated in 79 Phytotechnology Projects



Note: Some projects may be counted multiple times because they involve more than one type of contaminant. Labels present the contaminant type, number of projects, and percentage of total projects.

Exhibit 1. Phytodegradation of Chlorinated Solvents in Groundwater at the Edward Sears Property, New Gretna, New Jersey

From the mid-1960s to the early 1990s, the Edward Sears property was used for repackaging and sale of paints, adhesives, paint thinners, and various military surplus materials. Groundwater at the site was contaminated with a variety of solvents, including methylene chloride, trimethylbenzene, TCE, and xylenes. Beginning in 1996, a field demonstration of phytotechnology was performed that used hybrid poplars to clean up shallow groundwater at the site. Substantial reductions in contaminant concentrations have been reported. For example, data for the period from 1995 to 2004 show that concentrations of methylene chloride were reduced from as high as 6,700 micrograms per liter (µg/L) to below detection levels; concentrations of trimethylbenzene were reduced from as high as 1,890 µg/L to 730 µg/L; and concentrations of TCE were reduced from as high as 510 µg/L to 46 µg/L. Groundwater monitoring is ongoing at the site.

Sources:

FRTR. 2002. "Cost and Performance Case Study, Phytoremediation at Edward Sears Site, New Gretna, NJ." *www.frtr.gov*.

Prince, George, EPA Emergency Response Team (ERT). 2004 Email to Ellen Rubin, EPA Office of Superfund Remediation and Technology Innovation (OSRTI) regarding Edward Sears Site Data. November 1.

Vegetation Types

Many types of vegetation have been used in phytotechnology projects, including tree species such as hybrid poplars, willows, and cottonwoods; plants such as sunflowers, Indian mustard, and ferns; and various types of grasses. Of the 79 projects, 78 have reported information about the types of vegetation used in phytotechnology. Table 2 summarizes the types of vegetation used in the 78 projects by type of contaminant treated. A total of 70 different species were used; however, Table 2 summarizes information only for the vegetation types used in two or more projects. In general, hybrid poplars (59%), various grass species (44%), and willows (19%) were the most frequently used types of vegetation.

For chlorinated solvents, the most commonly used vegetation types were hybrid poplars (used in 83% of the chlorinated solvent projects), willows (26%), various grass species (26%), and cottonwoods or native poplars (11%). Diverse stands of vegetation (that is, stands containing more than one type of vegetation) were used in 20 of the 35 solvent projects. Of the 15 projects using monocultures (single types of vegetation), 13 used hybrid poplars and/or willow species for remediation.

For pesticides, the most commonly used vegetation types were hybrid poplars (used in 83% of the pesticide projects) and various grass species (67%). Six of the 12 pesticide projects used diverse stands of vegetation. Of the six projects that used monocultures, four used hybrid poplars, one used willows, and one used squash. An example of a project that used hybrid poplars and ground-cover grasses to degrade pesticides in groundwater is provided in Exhibit 2.

For explosives and propellants, one of the projects did not provide information about the type of vegetation used for remediation. The other two projects used hybrid poplars. One project used a monoculture, and the other combined willows and bald cypress with hybrid poplars.

At sites contaminated with metals, the types of vegetation used were different than at sites with other contaminants. Only six of the 29 metal projects used hybrid poplars or willows. Most projects (62%) used one or more grass species. Other than various grass species, no vegetation type was used more than 25% of the time, and only four types – Indian mustard (24%), hybrid poplars (21%), sunflowers (14%), and willows (14%) – were used in more than 10% of the projects. Eleven of the metal projects (38%) used a monoculture.

Table 2. Vegetation Types Used in 78 Phytotechnology Projects

Type	Chlorinated Solvents	Pesticides	Explosives and Propellants	Metals	Total
Corn	1	1	0	2	4
Cottonwood	4	0	0	2	6
Eastern Gamagrass	1	0	0	2	3
Eucalyptus	1	0	0	2	3
Fescue	0	1	0	1	2
Grasses	9	8	0	18	35
Hybrid Poplar	29	11	2	5	47
Hyperaccumulating Fern	0	0	0	2	2
Indian Mustard	1	0	0	7	8
Legumes	1	1	0	0	2
Loblolly Pine	1	0	0	1	2
Magnolia	2	0	0	0	2
Mulberry	1	0	0	1	2
Silver Maple	3	0	0	0	3
Sunflower	0	1	0	4	5
Sweet Gum	3	0	0	0	3
Willow	9	1	1	4	15

Exhibit 2. Phytodegradation of Pesticides in Groundwater at Aberdeen Pesticides Dumps Site, Aberdeen, North Carolina

The Aberdeen Pesticides Dumps site (APDS) consists of five geographically separate areas, one pesticide formulation plant and four disposal areas, that operated between the mid-1930s and 1987. Soil and groundwater at the site were contaminated with pesticides such as dieldrin, benzene hexachloride (BHC) isomers, hexachlorohexane, DDT, and DDE. This site was placed on the National Priorities List (NPL) in 1989. A 1999 ROD selected phytotechnology as a remedy for the McIver Dump Area (one of the five areas that constitute APDS). This area was considered to be suitable for implementation of phytotechnology because of its shallow water table, which would allow tree roots to contact the contaminated groundwater. Hybrid poplars and ground-cover grasses were planted in the Dump Area in 1999. Quarterly groundwater sampling results from 2001 indicated that BHC isomer concentrations in all the monitoring wells had either remained unchanged or decreased. For example, in one monitoring well, the concentration of alpha-BHC decreased from 0.224 µg/L to less than 0.047 µg/L, while in another well, the beta-BHC concentration decreased from 0.243 µg/L to 0.0565 µg/L. A 2001 McIver Annual Report indicated that the remedy continued to be protective of potential human and ecological receptors. Groundwater sampling activities are ongoing at the site.

Sources:

EPA. 2004. "North Carolina NPL/NPL Caliber Cleanup Site Summaries – Aberdeen Pesticide Dumps." *http://www.epa.gov/region4/waste/npl/nplnc/aberdnnc.htm*. Web Site Accessed on November 10.

EPA. 2003. "Close-Out Report for Aberdeen Pesticide Dumps Superfund Site, Aberdeen, Moore County, North Carolina." *http://www.epa.gov/region4/waste/npl/nplnc/aberdnnc.htm*.

EPA. 1999. "Record of Decision System (RODS) – Aberdeen Pesticide Dumps (OU5)." *http://cfpub.epa.gov/superrods/srchrods.cfm*.

Mann, Thomas, URS Corporation. 2004. Email to Ellen Rubin, EPA OSRTI regarding McIver Dump Area. October 27.

Phytotechnology Mechanisms

Several mechanisms have been used in phytotechnology projects, including those that control groundwater hydraulics or degrade, extract, contain, or immobilize contaminants (EPA 2000). Of the 79 projects, 75 provided information about the type of phytotechnology mechanism that was used. The most commonly used mechanisms were phytoextraction (used in 53% of the projects) and hydraulic control (42%). This section describes each mechanism, and Table 3 summarizes the mechanisms used in the 75 projects by type of contaminant treated.

Hydraulic control (HC) refers to use of plants to remove groundwater through uptake and consumption in order to contain or control migration of contaminants. For the 75 projects, hydraulic control was used most frequently at sites with chlorinated solvent contamination. When hydraulic control is used in place of or in addition to an engineered pump-and-treat system, there are seasonal limitations on groundwater uptake. The types of contaminants that hydraulic control is used to contain are water-soluble organics or inorganics that are not phytotoxic.

Phytodegradation (PD) involves the breakdown of contaminants taken up by plants through metabolic processes within the plants. Phytodegradation is typically used to remediate chlorinated solvents such as TCE and pesticides such as atrazine. Among the 75 projects, phytodegradation was used most often for chlorinated solvents and pesticides.

Phytoextraction (PE), the most commonly used mechanism for the projects, is the uptake of contaminants by plant roots and the translocation of the contaminants within the plants. This mechanism was most often applied at sites with metal contamination. Plants used for phytoextraction, which are typically called hyperaccumulators, are found in the *Brassicaceae*, *Euphorbiaceae*, *Asteraceae*, *Lemiaceae*, and *Scrophulariaceae* families. Hyperaccumulator species include Indian mustard, ferns, tall fescue, sunflowers, and corn. The mechanism has been extensively researched in the laboratory; however, the effectiveness of its field applications has been limited.

Table 3. Number of Projects Using Phytotechnology Mechanisms

Mechanism	Chlorinated Solvents	Pesticides	Explosives and Propellants	Metals	Total
Hydraulic Control	26	4	0	3	33
Phytodegradation	14	3	1	0	18
Phytoextraction	11	6	1	23	41
Phytostabilization	0	3	0	9	12
Phytovolatilization	7	0	0	1	8
Rhizodegradation	11	8	2	0	21
Rhizofiltration	0	1	0	0	1

Phytostabilization (PS) is the immobilization of a contaminant in soil through absorption and accumulation by roots, absorption onto roots, or precipitation within the root zone of plants. The mechanism involves the use of plants and plant roots to prevent contaminant migration via wind and water erosion, leaching, and soil dispersion. The phytostabilization processes occur through changes in root zone microbiology and chemistry. This mechanism was typically used for metal-contaminated soils. The mechanism does not require extensive soil excavation; however, it does require long-term maintenance because the contamination remains in place. Plant species that have been used for phytostabilization include grasses, Indian mustard, sunflowers, tall fescue, and soybeans.

Phytovolatilization (PV) is the uptake and transpiration of a contaminant by plants and the release of the contaminant to the atmosphere. Phytovolatilization has been used for projects involving chlorinated solvents in groundwater, including TCE, TCA, and carbon tetrachloride. Poplars, willows, and cottonwoods have been used for phytovolatilization. At one site, eastern cottonwoods were used for a field demonstration to evaluate phytovolatilization of mercury from soil.

Rhizodegradation (RD) is the breakdown of an organic contaminant in soil through microbial activity that is enhanced by the presence of a root zone. In rhizodegradation, plant roots are used to create an environment that is more conducive to microbial activity by adding root exudates, increasing soil aeration, or increasing soil moisture. Rhizodegradation has been used for projects involving chlorinated solvents, pesticides, and explosives and propellants. Plant species used for rhizodegradation include poplars, willows, and grasses. Exhibit 3 provides an example of a field demonstration that examined the use of phytodegradation and rhizodegradation for perchlorate remediation.

Exhibit 3. Phytodegradation and Rhizodegradation of Perchlorate in Groundwater at Longhorn Army Ammunition Plant, Marshall, Texas

The Longhorn Army Ammunition Plant (LAAP) has groundwater that is contaminated with perchlorate. A field demonstration of phytotechnology was performed using 425 hybrid poplars; the trees were planted in March 2003 on a 0.7-acre demonstration site. In this demonstration, concentrations of perchlorate were reduced from 34 to 23 milligrams per liter (mg/L) as of October 2004. According to the site researcher, the mass of perchlorate taken up by the poplar trees and/or degraded within the rhizosphere was 0.114 kilogram per day (kg/d) ± 0.016 kg/d. Between April 2003 and September 2004, 52 kg of perchlorate was removed from the groundwater by the hybrid poplar trees and/or the microbes that grow in the root zone. However, because of a complicated hydrogeologic setting and trenching, it was difficult to obtain a water balance and mass balance for perchlorate in order to prove the effectiveness of the treatment. In addition, the site researcher reported that the trees were growing well and that the phytoremediation system was functioning well; only 5% of the trees did not survive the first growing season.

Source:

Schnoor, J.L., et al. 2004. "Demonstration Project of Phytoremediation and Rhizodegradation of Perchlorate in Groundwater at the Longhorn Army Ammunition Plant." University of Iowa, Department of Civil and Environmental Engineering.

Rhizofiltration (RF) is the adsorption or precipitation of contaminants onto plant roots or the absorption of contaminants into the roots as a result of biotic or abiotic processes. One project used rhizofiltration to treat pesticides, herbicides, and volatile organic compounds (VOC) in groundwater and soil. The vegetation types used were hybrid poplars and grasses.

Number of Phytotechnology Projects by Planting Year

Phytotechnology projects often are performed over several years while species become established and contact between plants and contaminants is increased. To provide an indication of the age of the 79 phytotechnology projects, Figure 3 shows the number of projects that were started in particular years. This information is drawn from the 73 projects that reported a planting year. Among those projects, the use of phytotechnology peaked in projects that were begun between 1996 and 2001. The use of phytotechnology for metal contamination has been relatively constant, with one to three projects started each year except for 1992, when no metal projects began. There have been no new pesticide projects begun since 1999. The earliest phytotechnology project involving chlorinated solvents began in 1996. Solvent projects reached their peak phytotechnology use in 2001, when eight projects were started. Since 2001, only one chlorinated solvent project has been started each year.

Site Size and Project Scale

Among the 61 projects that reported treatment site size information, site size ranged from less than 0.5 acre to more than 1,000 acres, as shown in Figure 4. Thirty-six sites occupied 1.5 acres or less, and five were more than 9 acres in size. The 39 pilot- and field-scale demonstration projects account for most of the sites that were 1.5 acres or smaller but include projects at several larger sites. For example, a field demonstration was performed at the Naval Undersea Warfare Station in Washington that used hybrid poplars on an 8-acre site to treat TCA and other halogenated VOCs. Project scale information was provided by 68 of the projects; of these, 29 were reported to be full-scale and 39 were reported to be pilot- or field-scale demonstrations.

Phytotechnology Cost and Performance

The cost and performance of phytotechnology are highly site-specific as they depend on factors such as the types of contaminants present, contaminant concentrations, other site characteristics (for example, the depth to groundwater and soil properties), and the type of vegetation used. Cost information was available for 40 of the 79 phytotechnology projects. Performance information was available for 52 projects, including 25 pilot- or field-scale demonstrations and 27 full-scale remedies.

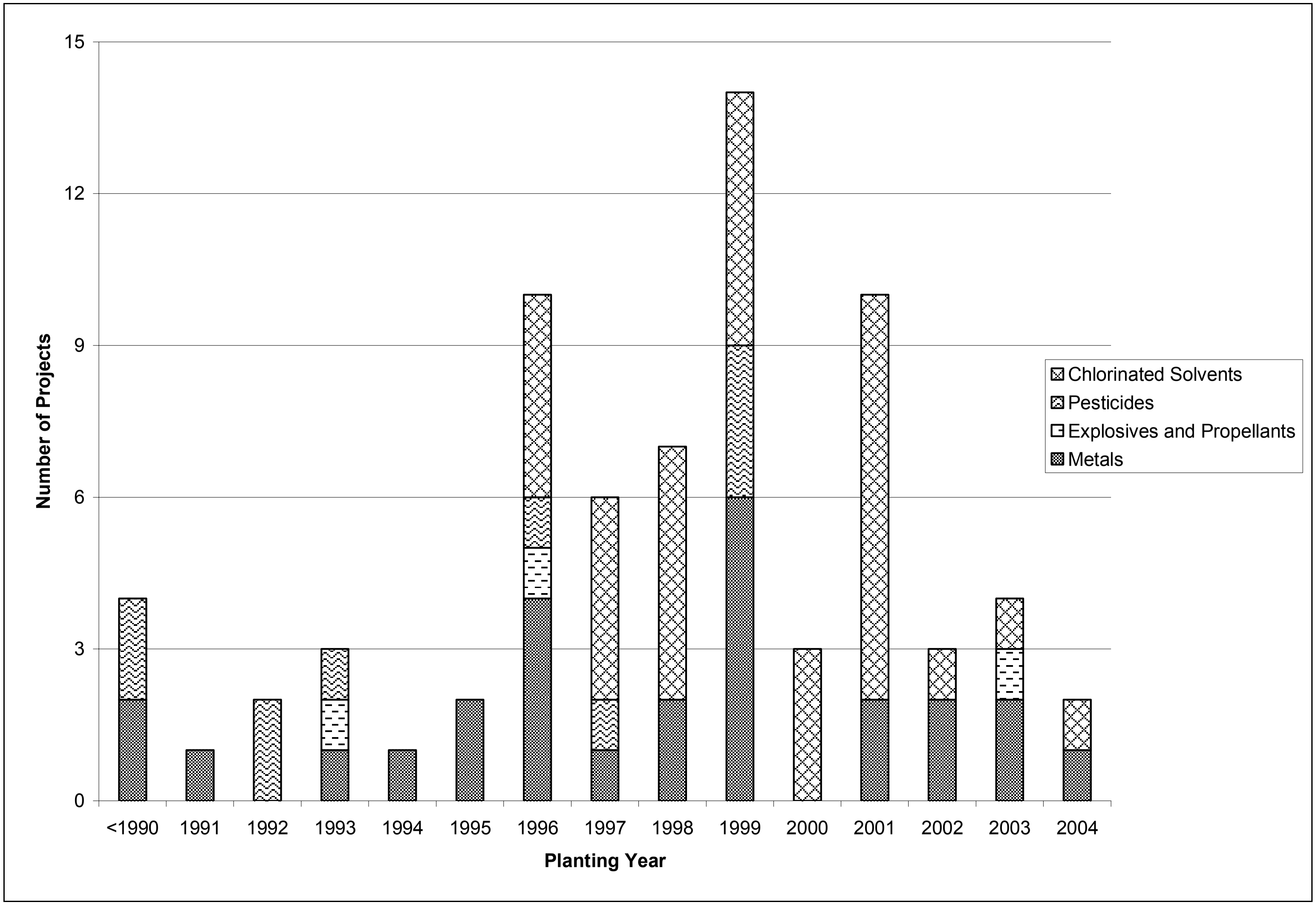
The cost information included various types of data and levels of detail. The FRTR has suggested that cost data should be itemized for each activity performed during a phytotechnology project. Specifically, data should be reported for planning and site preparation; site work; materials (such as trees or other vegetation); and operation and maintenance, including labor (FRTR 1998).

For Additional Information about the FRTR guidelines for reporting technology cost data, refer to the "Guide to Documenting and Managing Cost and Performance Information for Remediation Projects" (October 1998, EPA 542-B-98-007) located at *http://www.frtr.gov/pdf/guide.pdf/.*

Eight of the 40 projects provided cost information at the level of detail suggested by the FRTR. For those eight projects, the costs ranged from $30,000 for a 1.5-acre site where hybrid poplars were used to treat pesticides to $800,000 for a 5-acre site where TCE was treated using more than 800 trees and for which research and development activities were conducted. Collection and reporting of cost data in the manner suggested by the FRTR would improve the total body of information available for phytotechnology evaluation.

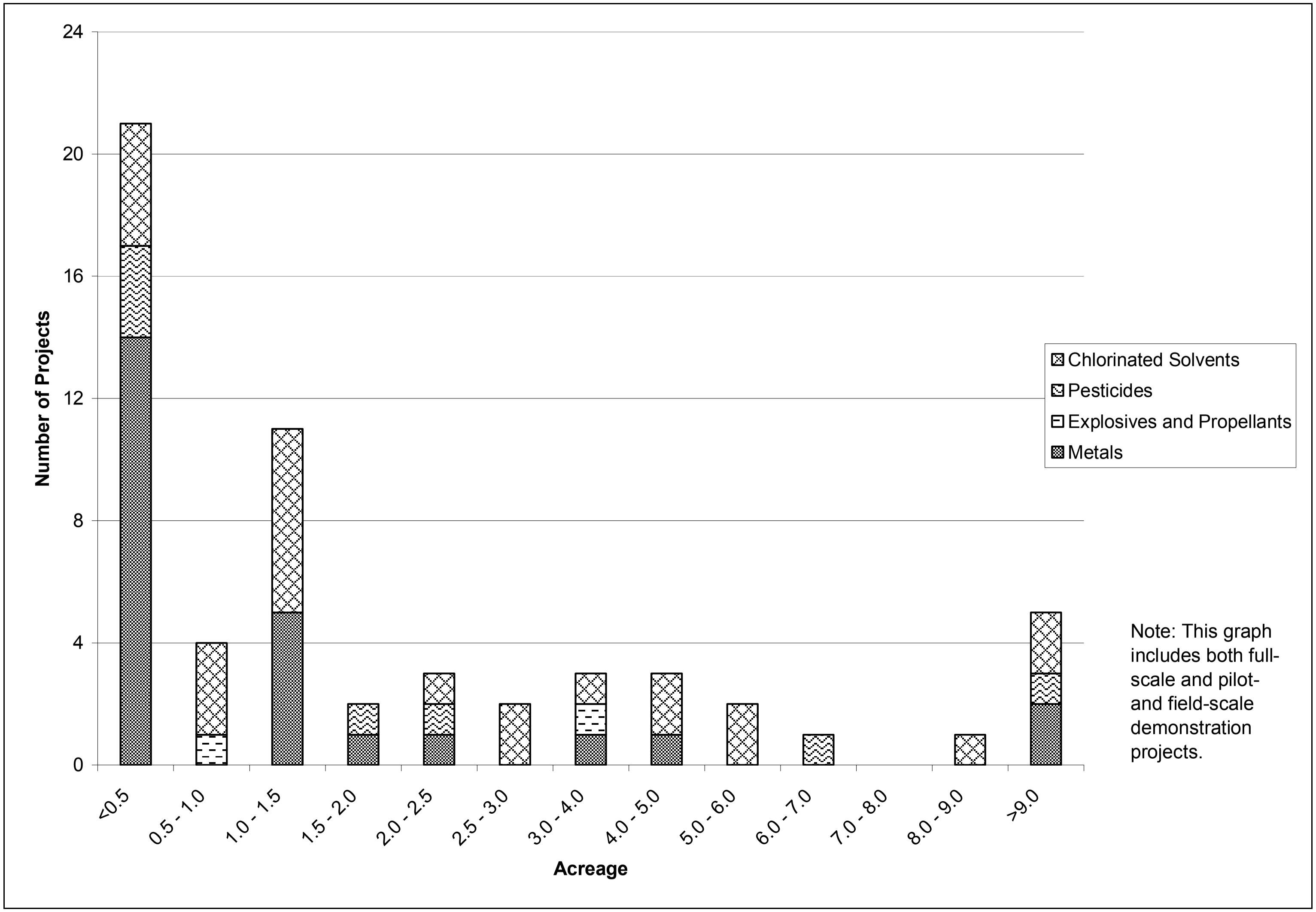
The performance information also varied in terms of the type and specificity of data reported. Project performance was described in both qualitative and quantitative terms. Examples of the qualitative information include plant growth and plant survival data. Five projects provided this type of information; in three projects the vegetation thrived, and in two projects the vegetation did not.

Figure 3. Number of Phytotechnology Projects by Planting Year – 73 Projects Total



Source: Refer to the projects listed in Appendix A.

Figure 4. Site Size Range for 61 Phytotechnology Projects



Note: This graph includes both full-scale and pilot- and field-scale demonstration projects.

Source: Refer to the projects listed in Appendix A.

The quantitative performance information that is often provided for phytotechnology projects includes contaminant concentrations in groundwater, soil, or plant tissue before and after treatment was performed as well as information about rooting depth; transpiration leaf area index; canopy height; plant and core tissue samples; tree girth; concentrations of degradation products; rates of groundwater extraction. Other indicator parameters such as soil oxygen levels, hydraulic control, and groundwater depression may also be included. A total of 31 projects provided information about changes in contaminant concentrations, with 26 reporting decreased concentrations and five indicating no change in concentration. In addition, five projects provided information about hydraulic control, with four reporting that control was achieved using phytotechnology. Information was not available to fully describe the contaminant concentrations achieved by phytotechnology for any of the contaminant types covered in this report. Additional cost and performance information for specific phytotechnology projects is provided in the references for this report.

An example of the types of performance and cost information that is available for a phytotechnology project involving treatment of metal-contaminated groundwater is provided in Exhibit 4.

Ongoing EPA Efforts Regarding Use of Phytotechnology

EPA is continuing its efforts to examine current trends in the use of phytotechnology. Areas of particular interest include measurement of technology performance, ecosystem restoration, use of phytotechnology in remedial systems, and the fate and transport of contaminants.

Exhibit 4. Phytoextraction of Metal-Contaminated Groundwater at Texas City Chemicals, C-H Area, Texas City, Texas

The Plant C site in Texas City, Texas, which is owned by BP is adjacent to the Tex Tin Superfund site, a former smelter facility that operated during World War II. The Area H portion of the Plant C site has highly saline groundwater that is contaminated with metals such as lead, copper, and cadmium that originated at the Tex Tin site. BP is performing a phytotechnology field demonstration using eucalyptus trees in Area H as a contingency to the voluntary cleanup efforts at the Tex Tin site, which include capping and barrier wall installation. In a greenhouse study, BP was able to grow trees with water having twice the salinity of seawater; however, the salinity of Area H groundwater has been measured at three times that of seawater. In field trials, BP reported that metals are being phytostabilized in the tree root zone with some minor uptake into leaves. BP also reported that saline components – sodium, calcium, and magnesium – have been found in the aboveground plant tissues. Water isotope ratio studies indicated that approximately 35% of the water taken up by trees has been contaminated groundwater. The pilot-scale project is a precursor to a potential full-scale phytoremediation project that could include as many as 1,000 additional trees should the voluntary cleanup efforts prove inadequate. The estimated cost for the full-scale project is $136,000 for installation plus $18,000 for operation and maintenance during the first 3 years of the study.

Sources:

Interstate Technology and Regulatory Cooperation Work Group (ITRC). 2004. Technologies Workshop.

Tsao, David, BP. Email to Ellen Rubin, EPA OSRTI regarding Combustion, Inc. Site Data. October 21.

http://www.bp.com/sectiongenericarticle.do?categoryId=2011066&contentId=2016238

http://www.bp.com/liveassets/bp_internet/globalbp/STAGING/global_assets/downloads/C/cs_USA_Reducing_NOx_emissions_at_Texas_City_USA_2003.pdf

Third International Phytotechnology Conference, Atlanta, Georgia
April 20 through 22, 2005

EPA is currently planning the third international conference on the use of phytotechnology, which will be conducted in Atlanta, Georgia, in April 2005. Topics of discussion for the conference include measurement technologies or techniques for assessing a project's progress; projects that decrease costs associated with existing, conventional remediation or containment; use of phytotechnology in developing economies; ecological restoration or habitat creation during remediation; fate and transport of contaminants through plants and associated ecological risk; case studies of successful phytotechnology applications; and case studies that illustrate the regulatory process for evaluating phytotechnology projects. The information collected at the conference will be made available at *www.clu-in.org/phytoconf*.

Notice

If you have comments or questions regarding this report or the Third International Phytotechnology Conference in April 2005, please contact Ellen Rubin at EPA's Office of Superfund Remediation and Technology Innovation at (703) 603-0141 or *rubin.ellen@epa.gov*.

References

EPA. 2000. "Introduction to Phytoremediation." Office of Research and Development. EPA 600/R-99/107. February.

EPA. 2001a. "Ground Water Issue – Phytoremediation of Contaminated Soil and Ground Water at Hazardous Waste Sites." Office of Research and Development. 540/S-01/500. February.

EPA. 2001b. "Brownfields Technology Primer: Selecting and Using Phytoremediation for Site Cleanup." Brownfields Technology Support Center. EPA 542-R-01-006.

EPA. 2004a. "*In Situ* Thermal Treatment of Chlorinated Solvents: Fundamentals and Field Applications." Office of Solid Waste and Emergency Response. EPA 542-R-04-010. March. *www.clu-in.org*.

EPA. 2004b. Pesticides Web Site at *www.epa.gov/pesticides/about*. Information Downloaded on October 19.

EPA. 2004c. "Phytoremediation Field Studies Database for Chlorinated Solvents, Pesticides, Explosives, and Metals." Compiled by Ana Hoffnagle and Cynthia Green (Summer Interns). *http://www.clu-in.org/studentpapers/*.

EPA. 2004d. "Treatment Technologies for Site Cleanup: Annual Status Report." Eleventh Edition. EPA 542-R-03-009.

FRTR. 1998. "Guide to Documenting and Managing Cost and Performance Information for Remediation Projects." Revised Version. EPA 542-B-98-007. October. *www.frtr.gov*.

FRTR. 2004. Remediation Technologies Screening Matrix – Version 4.0 at *http://www.frtr.gov/matrix2/top_page.html*. Information Downloaded on October 19.

ITRC. 2001. "Technical and Regulatory Guidance Document: Phytotechnology." Phytotechnologies Work Team Document No: PHYTO-2. April.

Newman, Lee A., and Charles M. Reynolds. 2004. "Phytodegradation of Organic Compounds." *Current Opinion in Biotechnology*. Volume 15. Pages 225 through 230. *www.sciencedirect.com*.

Acknowledgements

EPA would like to thank their Summer Interns Ana Hoffnagle and Cynthia Green for gathering the information used in this Status Report.

APPENDIX A

Summary of Phytotechnology Projects in the United States and Canada

APPENDIX A

SUMMARY OF PHYTOTECHNOLOGY PROJECTS IN THE UNITED STATES AND CANADA

Site Name	State	Planting Date	End Date	Medium	Vegetation Type	Contaminants Treated	Phytomechanisms							Site Size and Project Scale		
							HC	PD	PE	PS	PV	RD	RF	Acreage	Full-Scale	Pilot/Field Scale
Chlorinated Solvents																
Aberdeen Proving Ground	MD	1996	NA	GW, Soil	Hybrid Poplar, Sweet Gum, Silver Maple, Magnolia	PCA, TCA, PCE, TCE, DCE, DCA, VC	x	x						1	x	
http://web.ead.anl.gov/jfield/phyto/index.cfm																
Altus Air Force Base	OK	1999	NA	NA	Hybrid Poplar	TCE, DCE, PCE	o							0.3		o
http://www.afcee.brooks.af.mil/products/techtrans/phytorem.asp or *http://www.afcee.brooks.af.mil/products/techtrans/monitorednaturalattenuation/nastatus.xls* (Overall Status Tab)																
Amboer Road	OR	NA	NA	GW, Soil	Hybrid Poplar, Sweet Gum, Silver Maple, Magnolia	PCE, Degradation Products		x	x					5		x
http://www.rtdf.org/public/phyto/siteprof/usersearch/phyto_detail.cfm?TrackID=203																
Anonymous	WA	1996	NA	Soil	Hybrid Poplar	TCE, PCE, Carbon Tetrachloride			x					0.25		x
http://myprofile.cos.com/gordonm15 or *http://clu-in.org/download/studentpapers/hoffnagle-phytoremediation.pdf* (Page A32)																
Argonne National Laboratory: 317/319 Area	IL	1999	NA	GW, Soil	Eastern Gamagrass, Hybrid Poplar, Golden Weeping Willow, Hybrid Prairie Cascade Willow, Laurel-Leaved Willow	PCE, TCE, Arsenic, Chloroform, Carbon Tetrachloride, Lead, Tritium, Zinc	o	o	o	o		o		4	o	
http://web.ead.anl.gov/phyto/																
Ashland Inc.	WI	2000	NA	GW, Soil	Hybrid Poplar, Understory Grasses	DCA, PCE, TCE, BTEX, Gasoline, DRO	x		x			x		0.4	x	
http://www.ecolotree.com/apps2.html																

Note: Some of these projects were successful in remediating contamination, while others were not.
More detailed information, including points of contact, for these projects can be found in "Phytoremediation Field Studies Database for Chlorinated Solvents, Pesticides, Explosives, and Metals" (EPA 2004)
GW=Groundwater; NA=Not Available; HC=Hydraulic Control; PD=Phytodegradation; PE=Phytoextraction; PS=Phytostabilization; PV=Phytovolatilization; RD=Rhizodegradation; RF=Rhizofiltration; *=Superfund; o=Federal or Military Site; x=All Other Sites

Site Name	State	Planting Date	End Date	Medium	Vegetation Type	Contaminants Treated	Phytomechanisms							Site Size and Project Scale		
							HC	PD	PE	PS	PV	RD	RF	Acreage	Full-Scale	Pilot/Field Scale
Bofors-Nobel Superfund Site	MI	1999	2002	GW, Soil	Norway Maple, Hackberry, Honey Locust, Eastern Red Cedar, Black Hills Spruce, Jack Pine, Hybrid Poplar, Bur Oak, White Willow	3,3-Dichlorobenzene, VC, PCE, Aniline, Azobenzene, Benzidine, Toluene		*	*			*		20		*
http://cfpub.epa.gov/supercpad/cursites/csitinfo.cfm?id=0502372																
Carswell Naval Air Station	TX	1996	2006	GW, Soil	Eastern Cottonwood	TCE, DCE	o	o		o	o			0.5		o
http://www.clu-in.org/PRODUCTS/NEWSLTRS/tnandt/view.cfm?issue=0903.cfm#4																
Combustion, Inc. Superfund	LA	2002	NA	GW	Eucalyptus, Poplar, Native Willows	DCA, PCB, Benzene, Lead, Mercury, Nickel, Silver, Toluene, Toluenediisocynate, Toluene Diamine	*				*	*		NA	*	
http://cfpub.epa.gov/supercpad/cursites/csitinfo.cfm?id=0600472																
Edward Sears Property	NJ	1996	2004	GW, Soil	Hybrid Poplar	PCE, TCE, DCM	o	o						1		o
http://www.epa.gov/tio/download/partner/98annual.pdf (Page 41) or *http://www.epa.gov/ORD/NRMRL/lrpcd/rcb/phytohaz.htm*																
Ellsworth Air Force Base	SD	2001	NA		Hybrid Poplar	TCE, DCE	o							1		o
http://www.afcee.brooks.af.mil/products/techtrans/monitorednaturalattenuation/nastatus.xls (Overall Status Tab)																
ERP Site 17, Beale Air Force Base	CA	2000	NA	GW	Native Cottonwood, Live Oak, Deer Grass, Meadow Barley, Clustered Field Sage, Narrow-Leaved Willow	TCE, DCM	o							5		
http://clu-in.org/download/studentpapers/hoffnagle-phytoremediation.pdf (Page A43)																
Fairchild Air Force Base	WA	2001	NA	NA	Hybrid Poplar	TCE, DCM	o							1		o
http://www.afcee.brooks.af.mil/products/techtrans/phytorem.asp or *http://www.afcee.brooks.af.mil/products/techtrans/monitorednaturalattenuation/nastatus.xls* (Overall Status Tab)																

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Site Name	State	Planting Date	End Date	Medium	Vegetation Type	Contaminants Treated	Phytomechanisms							Site Size and Project Scale		
							HC	**PD**	**PE**	**PS**	**PV**	**RD**	**RF**	**Acreage**	**Full-Scale**	**Pilot/Field Scale**
Fringe Drain Area	IL	1999	NA	GW, Soil	Hybrid Poplar, Willow	TCE	o	o						5	o	
http://www.treemediation.com/ or *http://clu-in.org/download/studentpapers/hoffnagle-phytoremediation.pdf* (Page A46)																
Grand Forks Air Force Base	ND	2001	NA	GW, Soil	Eastern Cottonwood, Hybrid Poplar, Russian Olive	TCE, DCM	o	o			o	o		0.7		o
http://www.afcee.brooks.af.mil/ms/msp/center/summer2002/treegrandforks.asp																
Hill Air Force Base: OU 4	UT	NA	NA	GW, Soil	Hybrid Poplar	DCA, DCE, PCE, TCA, TCE, Chromium, Cadmium, Manganese, Arsenic	o				o			NA		o
http://www.afcee.brooks.af.mil/products/techtrans/phytorem.asp or *http://www.afcee.brooks.af.mil/products/techtrans/monitorednaturalattenuation/nastatus.xls* (Overall Status Tab)																
Jones Island Confined Disposal Facility	WI	2001	NA	Soil	Clover, Corn, Willow	PCBs, PAH, DRO, Metals						o		NA		o
http://www.epa.gov/ORD/NRMRL/pubs/540r04508/540r04508a.pdf																
Kauffman & Minteer	NJ	1998	NA	GW, Soil	Hybrid Poplar, Black Willow	DCA, TCE, PCE, DDT, Endosulfan Sulfate, Ethyl Benzene, 2-Methylnapthalene, Styrene, Toluene						x		5		
http://www.epa.gov/ORD/NRMRL/lrpcd/rcb/phytohaz.htm																
Metal Plating Facility	OH	1997	NA	Soil	Hybrid Poplar, Rye Grass, Indian Mustard	TCE	x		x					0.23	x	
http://clu-in.org/products/site/ongoing/demoong/phytotec.htm																
Montezuma West	OR	1997	NA	GW, Soil	Hybrid Poplar	TCA		x	x					1		x
http://www.deq.state.or.us/wmc/ECSI/ecsidetail.asp?seqnbr=79																
NASA Kennedy Space Center: Hydrocarbon Burn Facility	FL	1998	NA	GW, Soil	Hybrid Poplar, Understory Grasses	DCE, TCE, VC, Chromium, TPH	o		o		o	o		3	o	
http://www.rtdf.org/public/phyto/siteprof/usersearch/phyto_detail.cfm?TrackID=186																

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Site Name	State	Planting Date	End Date	Medium	Vegetation Type	Contaminants Treated	Phytomechanisms							Site Size and Project Scale		
							HC	PD	PE	PS	PV	RD	RF	Acreage	Full-Scale	Pilot/Field Scale
Naval Undersea Warfare Station	WA	2001	2009	GW	Hybrid Poplar	TCA, Halogenated VOCs		*	*					8		*
http://cfpub.epa.gov/supercpad/cursites/csitinfo.cfm?id=1001102																
Northern Iowa Chlorinated Solvent Plume	IA	2001	NA	GW, Soil	Hybrid Poplar, Understory Grasses	DCE, PCE, TCE	x		x			x		1	x	
http://clu-in.org/download/studentpapers/hoffnagle-phytoremediation.pdf (Page A59)																
Oregon Poplar	OR	1997	NA	Soil	Hybrid Poplar, Cottonwoods	DCA, DCE, DCE, PCE, TCE, VC, BTEX	x	x			x			NA	NA	NA
http://www.epa.gov/superfund/phyto.htm																
Portsmouth Gaseous Diffusion Plant: X-740 TCE Plume	OH	1999	NA	GW, Soil	Hybrid Poplar	TCE, PCE, DCE, VC	o							2.6		o
http://www.epa.state.oh.us/sedo/portsmouth/us_doe_portsmouth.htm																
Portsmouth Gaseous Diffusion Plant: X-749/X-120 TCE Plume	OH	2003	NA	GW	Hybrid Poplar	TCE, PCE, DCE, VC	x							41	x	
http://www.epa.state.oh.us/sedo/portsmouth/us_doe_portsmouth.htm																
Savannah River Site	SC	2001	2004	GW, Soil	Grass, Legume, Herb, Loblolly Pine, Hybrid Poplar	PCE, DCE, TCE, Chloroform	x	x				x		4		x
http://cfpub.epa.gov/supercpad/cursites/csitinfo.cfm?id=0403485 or *http://sti.srs.gov/fulltext/ms2000897/ms2000897.html*																
Solvent Recovery Service New England	CT	1998	2030	GW, Soil	Hybrid Poplar, White Willow, Pin Oak, River Birch, Sweet Gum, Silver Maple, Tulip Tree, Eastern Red Bud, Eastern White Pine	TCA, DCA, DCE, VC, PCB	x				x	x		0.8		x
http://www.phytokinetics.com/publications.php?id=27																

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Site Name	State	Planting Date	End Date	Medium	Vegetation Type	Contaminants Treated	Phytomechanisms							Site Size and Project Scale		
							HC	PD	PE	PS	PV	RD	RF	Acreage	Full-Scale	Pilot/Field Scale
Tibbetts Road	NH	1998	2015	GW, Soil	Hybrid Poplar, Understory Grasses	TCE, PCBs, Arsenic, Benzene, Toluene	*		*					2	*	
http://yosemite.epa.gov/r1/npl_pad.nsf/8b160ae5c647980585256bba0066f907/c875c2d48055e87a8525691f0063f6fe!OpenDocument																
Travis Air Force Base	CA	1998	NA	GW	Red Ironbark	TCE	o							2.5		o
http://www.afcee.brooks.af.mil/products/techtrans/phytorem.asp or *http://www.afcee.brooks.af.mil/products/techtrans/monitorednaturalattenuation/nastatus.xls* (Overall Status Tab)																
Union Carbide Corporation	TX	NA	NA	GW, Soil	Poplar and Mulberry	DCA, BCEE	x							NA	x	
http://clu-in.org/download/studentpapers/hoffnagle-phytoremediation.pdf (Page A69)																
Unspecified Chemical Manufacturing Facility	IL	2000	NA	NA	Hybrid Poplar, Willow	TCE	x	x						NA	NA	NA
http://www.treemediation.com/ or *http://clu-in.org/download/studentpapers/hoffnagle-phytoremediation.pdf* (Page A71)																
Vandenberg Air Force Base	CA	2001	NA	NA	Hybrid Poplar	DCE, PCE, VC	o							1	NA	NA
http://www.vandenberg.af.mil/30sw/30_msg/30_ces/IRP/pdf/irpclnup.pdf																
Wayne County	MI	1997	2002	GW, Soil	Hybrid Poplar	DCE, PCE, VC		x						NA	x	
http://www.treemediation.com/ or *http://clu-in.org/download/studentpapers/hoffnagle-phytoremediation.pdf* (Page A73)																
Wisconsin	WI	2004	NA	GW, Soil	Hybrid Poplar	TCE								NA	NA	NA
http://www.ecolotree.com or *http://clu-in.org/download/studentpapers/hoffnagle-phytoremediation.pdf* (Page A75)																
Pesticides																
Aberdeen Pesticides Dumps	NC	1999	NA	GW, Soil	Hybrid Poplar; Ground-Cover Grasses	Dieldrin, Hexachlorobenzene, Hexachlorahexane	*	*				*		NA	*	
http://cfpub.epa.gov/supercpad/cursites/csitinfo.cfm?id=0403099																
Amana #1 and #2	IA	NA	NA	GW, Soil	Corn, Fescue, Hybrid Poplar, Sunflower	Atrazine, Alachlor		x	x					NA		x
http://clu-in.org/download/studentpapers/hoffnagle-phytoremediation.pdf (Page A78)																

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							Phytomechanisms							Site Size and Project Scale		
Site Name	**State**	**Planting Date**	**End Date**	**Medium**	**Vegetation Type**	**Contaminants Treated**	**HC**	**PD**	**PE**	**PS**	**PV**	**RD**	**RF**	**Acreage**	**Full-Scale**	**Pilot/Field Scale**
Bofors-Nobel Superfund Site	MI	1999	NA	GW, Soil	Hybrid Poplar	3,3-Dichlorobenzene, VC, PCE, Aniline, Azobenzene, Benzidine, Toluene		*	*			*		NA		*
http://cfpub.epa.gov/supercpad/cursites/csitinfo.cfm?id=0502372																
Cantrall	IL	1992	NA	GW, Soil	Hybrid Poplar	Nitrate, Herbicides/Insecticides, Atrazine, Alachlor		x		x		x		2	x	
http://www.thomasconsultants.com/cantrall.html																
Clarence Coop Martelle Plant	IA	1993	NA	GW, Soil	Hybrid Poplar, Grasses	Atrazine, Herbicides, Nitrate, Ammonia			x	x		x		0.3	x	
http://www.rtdf.org/public/phyto/siteprof/usersearch/phyto_detail.cfm?TrackID=43																
Fort Wainwright	AK	1997	2002	Soil	Felt Leaf Willow	Aldrin, DDD, DDT, Dieldrin, Petroleum Hydrocarbons			o			o		0.18	o	
http://www.epa.gov/ORD/NRMRL/lrpcd/rcb/phytohaz.htm																
Illinois Fertilizer/Herbicide Spill Site	IL	1999	NA	GW, Soil	Hybrid Poplar, Grasses	Nitrogen, Herbicides	x		x			x		NA	x	
http://www.ecolotree.com/apps4.html																
Lockwood Farm	CT	NA	2002	Soil	*Cucurbita pepo*	p-p'-DDE								NA	NA	NA
http://www.caes.state.ct.us/Biographies/WhiteJ.htm																
MidLakes Farm Service Cooperative	WI	1996	NA	GW, Soil	Hybrid Poplar, Grasses	Pesticides, Herbicides, VOC	x		x	x		x	x	0.3	x	
http://www.rtdf.org/public/phyto/siteprof/usersearch/phyto_detail.cfm?TrackID=194																
Oconee	IL	1988	NA	GW, Soil	Hybrid Poplar	Alachlor, Atrazine, Metoachlor, Metribuzin						x		1.5	x	
http://www.treemediation.com/Oconee.htm																
Whitewater	WI	1990	NA	GW, Soil	Grasses, Hybrid Poplar, Legumes	Nitrate, Herbicides, Insecticides, Atrazine, Silvex	x							10	x	
http://www.treemediation.com/Business/Projects.htm																
Wilmington	NC	1992	2002	GW, Soil	Hybrid Poplar	Nitrate, Pesticides, Ammonium	x							6	x	
http://www.treemediation.com/ or *http://clu-in.org/download/studentpapers/hoffnagle-phytoremediation.pdf* (Page A95)																

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Site Name	State	Planting Date	End Date	Medium	Vegetation Type	Contaminants Treated	Phytomechanisms							Site Size and Project Scale		
							HC	PD	PE	PS	PV	RD	RF	Acreage	Full-Scale	Pilot/Field Scale
Explosives and Propellants																
ICI Explosives Americas Engineering	MO	1996	NA	GW, Soil	Bald Cypress, Hybrid Poplar, Ninebark, Willow	Ammonium Nitrate, DNT			x			x		3.2		x
http://www.rtdf.org/public/phyto/siteprof/usersearch/phyto_detail.cfm?TrackID=198																
Longhorn Army Ammunition Plant: Burning Ground #3	TX	2003	2004	GW	Hybrid Poplar	Perchlorate		o				o		0.7		o
http://clu-in.org/download/contaminantfocus/perchlorate/LHAAPfinalSchnoor.pdf																
Weldon Spring Former Army Ordnance Works	MO	1993	NA	Soil	NA	TNT, DNT, Lead	NA	NA	NA	NA	NA	NA	NA	NA		o
http://www.epa.gov/ORD/SITE/reports/540r95529a.pdf																
Metals																
Anaconda Smelter Site	MT	1995	NA	Soil	Grasses	Arsenic, Cadmium, Copper, Zinc				x				1.5	x	
http://cfpub.epa.gov/supercpad/cursites/csitinfo.cfm?id=0800403																
Anderson	SC	1993	NA	GW, Soil	Grasses, Hybrid Poplar	Lead, Cadmium, Sulfate, Nitrate				x				17	x	
http://clu-in.org/download/studentpapers/hoffnagle-phytoremediation.pdf (Page A111)																
Argonne National Laboratory: 317/319 Area	IL	1999	NA	GW, Soil	Eastern Gamagrass, Hybrid Poplar, Golden Weeping Willow, Hybrid Prairie Cascade Willow, Laurel-Leaved Willow	PCE, TCE, Carbon Tetrachloride, Chloroform, Zinc, Lead, Arsenic, Tritium	o		o	o				4	o	
http://web.ead.anl.gov/phyto/																
Argonne National Laboratory West	ID	1999	2002	Soil	*Koshia scoparia*, Hybrid Willow	Cesium-137, Silver, Mercury, Chromium			*					0.61		*
http://www.epa.gov/superfund/sites/rods/fulltext/r1098061.pdf																
Austin Residential Site	TX	2003	2003	Soil	Hyperaccumulating Fern	Arsenic			x					0.01		x

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Site Name	State	Planting Date	End Date	Medium	Vegetation Type	Contaminants Treated	Phytomechanisms							Site Size and Project Scale		
							HC	PD	PE	PS	PV	RD	RF	Acreage	Full-Scale	Pilot/Field Scale
http://www.edenspace.com/ or *http://clu-in.org/download/studentpapers/hoffnagle-phytoremediation.pdf* (Page A118)																
Bayonne	NJ	1996	NA	Soil	Indian Mustard	Lead			x					0.02		x
http://www.edenspace.com/qualification.html																
Central Louisiana Wood Treatment Facility	LA	NA	NA	GW, Soil	Loblolly Pines	Arsenic, Chromium, PAH, CCA, Creosote	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
http://premiercorp-usa.com/index.htm or *http://clu-in.org/download/studentpapers/hoffnagle-phytoremediation.pdf* (Page A124)																
Firing Range, Chilliwack	BC	1999	2001	Soil	Garden Pea, Indian Mustard	Lead, Copper			x					NA		x
http://www.rmc.ca/academic/gradrech/environment9_e.html																
Abandoned Hat Factory	CT	2003	NA	Soil	Eastern Cottonwood	Mercury					x			0.33		x
http://clu-in.org/download/studentpapers/hoffnagle-phytoremediation.pdf (Page A130)																
Dearing Phytostabilization Demonstration	KS	1994	1998	Soil	Hybrid Poplar	Lead, Zinc, Cadmium			x	x				1		x
http://scitation.aip.org/getabs/servlet/GetabsServlet?prog=normal&id=PPHMF8000006000003000177000001&idtype=cvips&gifs=yes																
Dorchester	MA	1996	1998	Soil	Indian Mustard, Hybrid Poplar	Lead			x					0.03		x
http://www.edenspace.com/qualification.html																
East Palo Alto	CA	1981	NA	Soil	Eucalyptus, Tamarisk	Arsenic, Sodium			x					1	x	
http://clu-in.org/download/studentpapers/hoffnagle-phytoremediation.pdf (Page A134)																
Ensign-Bickford Company	CT	1998	1998	Soil	Indian Mustard, Sunflower	Lead			x	x				2.35	x	
http://yosemite.epa.gov/R1/npl_pad.nsf/0/7e6c98dcbb2aa65d85256c29006e78c4?OpenDocument																
Fort Dix	NJ	1997	2002	Soil	Indian Mustard, Sunflower, Grasses	Lead			o					1.25		o
http://aec.army.mil/usaec/technology/fes48.html#Fort or *http://www.dix.army.mil/ENVIRONMENT/greenrange090399.htm*																
Galena Field Study	KS	1995	2000	Soil	Tall Fescue	Cadmium, Lead, Zinc			x	x				NA		x
http://scitation.aip.org/getabs/servlet/GetabsServlet?prog=normal&id=PPHMF8000006000004000212000001&idtype=cvips&gifs=yes																
Unnamed Gary Site	IN	2002	NA	Soil	Bullrush, Sedges, Cattails	Arsenic, Lead			x	x				3		x
http://www.wtamu.edu/~crobinson/Soils/forphytremd.htm or *http://clu-in.org/download/studentpapers/hoffnagle-phytoremediation.pdf* (Page A139)																

Note: Some of these projects were successful in remediating contamination, while others were not.
More detailed information, including points of contact, for these projects can be found in "Phytoremediation Field Studies Database for Chlorinated Solvents, Pesticides, Explosives, and Metals" (EPA 2004)
GW=Groundwater; NA=Not Available; HC=Hydraulic Control; PD=Phytodegradation; PE=Phytoextraction; PS=Phytostabilization; PV=Phytovolatilization; RD=Rhizodegradation; RF=Rhizofiltration; *=Superfund; o=Federal or Military Site; x=All Other Sites

Site Name	State	Planting Date	End Date	Medium	Vegetation Type	Contaminants Treated	Phytomechanisms							Site Size and Project Scale		
							HC	PD	PE	PS	PV	RD	RF	Acreage	Full-Scale	Pilot/Field Scale
Jones Island Confined Disposal Facility	WI	2002	NA	Soil	Eastern Cottonwood, Eastern Gamagrass, Coffee Weed, Ovalhead Sedge, Big Bluestem, Common Rush, Sunflower, Red Mulberry, White Mulberry	Anthracene, PCBs, Heavy Metals			x					0.06		x
http://www.epa.gov/ORD/NRMRL/pubs/540r04508/540r04508a.pdf																
Magic Marker	NJ	1996	NA	Soil	Indian Mustard, Sunflower	Lead			x					1.35	x	
http://www.epa.gov/ORD/NRMRL/lrpcd/rcb/phytlead.htm or *http://www.edenspace.com/qualification.html*																
Metal Plating Facility	OH	1996	1997	Soil	Hybrid Poplar, Ryegrass, Indian Mustard	Cadmium, Zinc	x		x					0.23	x	
http://clu-in.org/products/site/ongoing/demoong/phytotec.htm																
Former Orchard Site	NJ	2001	NA	Soil	Brake Fern	Arsenic			o					0.23	o	
http://www.hq.usace.army.mil/isd/PUBS/DIGEST/PWDigest_may_june_02.pdf (Page 21) or *http://www.washingtonpost.com/wp-dyn/articles/A33716-2004Aug25.html*																
Port Colborne	ON	2001	2003	Soil	Corn, Soybeans, Radish, Oats, Alyssum	Arsenic, Cobalt, Copper, Nickel				x				0.37		x
http://www.inco.com/portcolborne/																
Savannah River Site	SC	1987	1992	Soil	Bush Beans	Cadmium, Thallium, Vanadium			x					NA		x
http://cfpub.epa.gov/supercpad/cursites/csitinfo.cfm?id=0403485 or *http://sti.srs.gov/fulltext/ms2000897/ms2000897.html*																
Spring Valley	DC	2004	NA	Soil	Hyperaccumulating Fern	Arsenic			o					0.06		o
http://www.hq.usace.army.mil/cepa/pubs/oct04/STORY12.HTM or *http://www.washingtonpost.com/wp-dyn/articles/A33716-2004Aug25.html*																
C-H Plant Area: Texas City Chemicals	TX	NA	NA	GW	Eucalyptus, Salt Cedar	Cadmium, Copper, Lead, High Salinity	x		x	x				27		x
http://clu-in.org/download/studentpapers/hoffnagle-phytoremediation.pdf (Page A125) and Exhibit 4																

Note: Some of these projects were successful in remediating contamination, while others were not.
More detailed information, including points of contact, for these projects can be found in "Phytoremediation Field Studies Database for Chlorinated Solvents, Pesticides, Explosives, and Metals" (EPA 2004)
GW=Groundwater; NA=Not Available; HC=Hydraulic Control; PD=Phytodegradation; PE=Phytoextraction; PS=Phytostabilization; PV=Phytovolatilization; RD=Rhizodegradation; RF=Rhizofiltration;
*=Superfund; o=Federal or Military Site; x=All Other Sites

Site Name	State	Planting Date	End Date	Medium	Vegetation Type	Contaminants Treated	Phytomechanisms							Site Size and Project Scale		
							HC	PD	PE	PS	PV	RD	RF	Acreage	Full-Scale	Pilot/Field Scale
Twin Cities Army Ammunition Plant	MN	1998	1999	Soil	Corn, White Mustard	Antimony, Arsenic, Barium, Beryllium, Chromium, Lead, Thallium			o					0.2		o
http://aec.army.mil/usaec/technology/cleanup04b.html																
Whitewood Creek	SD	1991	1998	Soil	Hybrid Poplar	Arsenic, Cadmium, Copper			x	x				1		x
http://clu-in.org/download/studentpapers/hoffnagle-phytoremediation.pdf (Page A153)																

Note: Some of these projects were successful in remediating contamination, while others were not.
More detailed information, including points of contact, for these projects can be found in "Phytoremediation Field Studies Database for Chlorinated Solvents, Pesticides, Explosives, and Metals" (EPA 2004)
GW=Groundwater; NA=Not Available; HC=Hydraulic Control; PD=Phytodegradation; PE=Phytoextraction; PS=Phytostabilization; PV=Phytovolatilization; RD=Rhizodegradation; RF=Rhizofiltration;
*=Superfund; o=Federal or Military Site; x=All Other Sites

APPENDIX B

Examples of Phytotechnology Projects in Countries Other Than the United States and Canada

APPENDIX B

EXAMPLES OF PHYTOTECHNOLOGY PROJECTS IN COUNTRIES OTHER THAN THE UNITED STATES AND CANADA

Site Name	Location	Contaminants Treated	Site Size and Project Scale			Status
			Size	Full-Scale	Pilot/Field Scale	
Contaminated Paint Factory	Czech Republic	PCBs	NA		x	Unknown
Eka Chemicals Site	Gothenberg, Sweden	PCDFs, Chlor-alkalis	NA	NA	NA	Unknown
Werk Tanne	Harz, Germany	TNT	25 by 20 square meters	NA	NA	Planted in May 1999
Cooperative Farm	Bytom, Poland	Cadmium, Lead, Zinc	0.5 hectares	x		Ongoing (Planted in Spring 1997)
Caslano	Caslano, Switzerland	Cadmium, Copper, Zinc	Four 1 by 1 square meter plots		x	Completed (1997-2001)
Dornach	Dornach, Switzerland	Cadmium, Copper, Zinc	Four 1 by 1 square meter plots		x	Completed (1997-2001)
Ecological Experimental Station of Red Soil	Yingtan, Jangxi Province, China	Cadmium, Lead, Zinc	NA		x	Completed
Lechang Lead and Zinc Mine Tailings	Lechang City, Guangdong Province, China	Cadmium, Copper, Lead, Zinc	NA		x	Completed

* This table contains examples of international phytotechnology projects and is not intended to be comprehensive. For more information regarding international phytotechnology research, refer to European Cooperation in the Field of Scientific and Technical Research (COST) Action 859: “Phytotechnologies to Promote Sustainable Land Use and Improve Food Safety” (*http://cost.cordis.lu/src/pdf/859-e.pdf*).