EMBO reports

31.)

viewpoint

Phytoremediation

Molecular biology, requirements for application, environmental protection, public attention and feasibility

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Over centuries, human industrial, mining and military activities as well as farming and waste practices have contaminated large areas of developed countries with high concentrations of heavy metals and organic pollutants. In addition to their negative effects on ecosystems and other natural resources, these sites pose a great danger to public health, because pollutants can enter food through agricultural products or leach into drinking water (EC, 2002; EEA, 2003). In the EU alone, an estimated 52 million hectares—more than 16% of the total land area—are affected by some level of soil degradation. The largest and probably most heavily contaminated areas are found near industrialized regions in northwestern Europe, but many contaminated areas exist around most major European cities (EEA, 2003). There could be between 300,000 and 1.5 million of these sites in the EU (EC, 2002)—the uncertainty in this estimate is due to the lack of common definitions and a scarcity of accurate data on the size and the level of contamination of affected sites.

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Cleaning up contaminated soil is a costly enterprise—the overall cost to remediate affected sites in the EU is estimated to be between €59 and €109 billion (EC, 2002). Furthermore, current methods of soil remediation do not really solve the problem. In Germany, for instance, only 30% of soils from contaminated sites are cleaned up in soil remediation facilities (SRU, 2004); the remaining soil must be stored in waste disposal facilities. This does not solve the problem, it merely transfers it to future generations. Obviously, there is an urgent need for alternative, cheap and efficient methods to clean up heavily contaminated industrial areas.

This could be achieved by a relatively new technology known as phytoremediation, which uses plants to remove pollutants from the environment. Due to its elegance and the extent of contaminated areas, it has already received significant scientific and commercial attention (Salt *et al*, 1998; Gleba *et al*, 1999; Meagher, 2000; Dietz & Schnoor, 2001; Guerinot & Salt, 2001; Krämer & Chardonnens, 2001; McGrath & Zhao, 2003; Peuke & Rennenberg, 2005). Phytoremediation uses wild or genetically modified plants (GMPs) to extract a wide range of heavy metals and organic pollutants from the soil. Initial experiments with transgenic plants have shown that they are indeed efficient in drawing metals from heavily contaminated soils. However, despite this and other advantages, the progress and application of this technology to tackle widespread environmental problems is being hampered by ideology-driven, restrictive legislation over the use and release of GMPs in Europe, and particularly in Germany.

Phytoremediation comes in several forms. Phytoextraction removes metals or organics from soils by accumulating them in the biomass of plants. Phytodegradation, or phytotransformation, is the use of plants to uptake, store and degrade organic pollutants; rhizofiltration involves the removal of pollutants from aqueous sources by plant roots. Phytostabilization reduces the bioavailability of pollutants by immobilizing or binding them to the soil matrix, and phytovolatilization uses plants to take pollutants from the growth matrix, transform them and release them into the atmosphere.

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Most scientific and commercial interest in phytoremediation now focuses on phytoextraction and phytodegradation, which use selected plant species grown on contaminated soils. These are then harvested to remove the plants together with the pollutants that have accumulated in their tissues. Depending on the type of contamination, the plants can either be disposed of or used in alternative processes, such as burning for energy production. In essence, phytoextraction removes pollutants from contaminated soils, concentrates them in biomass and further concentrates the pollutants by combustion.

It is also possible to recover some metals from plant tissue (phytomining), which humans have done for centuries in the case of potassium (potash), and which may even become economically valuable (Meagher, 2000). In addition to accumulating toxic minerals in their tissues, plants are also able to take up a range of harmful organic compounds, including some of the most abundant environmental pollutants such as polychlorinated biphenyl (PCB), halogenated hydrocarbons (trichloroethylene, TCE) and ammunition wastes (nitroaromatics such as trinitrotoluene (TNT) and glycerol trinitrate (GTN)). Subsequent metabolism in plant