Chapter 1
Biological Remediation of Soil: An Overview of Global Market and Available Technologies

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1.1 Introduction

Due to a wide range of industrial and agricultural activities, a high number of chemical contaminants is released into the environment, causing a significant concern regarding potential toxicity, carcinogenicity, and potential for bioaccumulation in living systems of various chemicals in soil. Although microbial activity in soil accounts for most of the degradation of organic contaminants, chemical and physical mechanisms can also provide significant transformation pathways for these compounds. The specific remediation processes that have been applied to clean up contaminated sites include natural attenuation, landfarming, biopiling or composting, contained slurry bioreactor, bioventing, soil vapor extraction, thermal desorption, incineration, soil washing and land filling (USEPA 2004).

Biological remediation using microorganisms and plants is generally considered a safe and less expensive method for the removal of hazardous contaminants. The microorganisms have the primary catalytic role in degrading or mineralizing various contaminants and converting non-toxic by-products during soil bioremediation processes (Seshadri and Heidelberg 2005; Head et al. 2006; Gomez et al. 2007). Plants have an inherent ability to detoxify some xenobiotics in soil by direct uptake of the contaminants, followed by subsequent transformation using enzymes similar to detoxification enzymes in mammals, transport and product accumulation (Macek et al. 2008). Phytoremediation, with the associated role of rhizospheric microorganisms, is therefore an important tool in bioremediation processes. Various bioremediation configurations as options for treatment of different classes of chemicals have been evaluated (Hughes et al. 2000). Natural attenuation and electron

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donor delivery were considered as options for remediation of chlorinated solvents, biostimulation for treatment of chlorinated solvents and phenols, bioventing for polycyclic aromatic carbons (PAHs); landfarming or composting were options for nitroaromatics, phenols, monoaromatic hydrocarbon and PAHs (Prince 1998; Mishra et al. 2001). Slurry bioreactor processes were considered suitable for treatment of all of the above mentioned chemicals. Optimizing the environmental conditions in bioremediation processes ensures that the physiological and biochemical activities are directed towards biodegradation of the target contaminants. Environmental factors influencing biological activity include moisture, temperature, pH, oxygen, soil type and chemical nature of contaminant for aerobic degradation and redox potential for anaerobic degradation (Van Hamme et al. 2003).

Bioremediation of some recalcitrant xenobiotic chemicals may require a combination of chemical, physical and biological steps to increase the efficacy of contaminant destruction. Risk assessment is an emerging multi-disciplinary scientific practice used to evaluate health and ecological risks posed by chemical contaminants. Such evaluation helps in devising risk-based management plans to achieve target risk reduction. However, to develop a cost-effective remedial action plan, there is a need to introduce a systematic and scientifically sound methodology to assess the associated risks at a site and identify appropriate remediation technologies.

1.2 Global Remediation Market

In 2001, the global environmental market, including hazardous waste management and disposal, approaches to brownfield redevelopment and site remediation was reported to be of the order of $1 trillion (Masons Water Yearbook 2000–2001). Based on current literature, the international market for the remediation sector is estimated to be in the range US$30–35 billion. The application of bioremediation and phytoremediation cleanup technologies is rapidly expanding and according to an estimate, worldwide demand for these biological technologies is thought to be valued in the region of $1.5 billion per annum. The soil remediation sector has a ready market in countries such as the US, Canada, Western European countries, Japan and Australia. More developed Eastern European, Latin American and Asian countries represent emerging markets for the remediation sector. Understandably, it is not as easy to quantify the value of these emerging remediation markets, especially since comprehensive catalogues of contaminated sites in these countries have not been established. Remediation markets usually develop after a country has dealt with air, water and waste management priorities. The US is possibly the only country that has undergone such an extensive assessment of contamination for federal sites which contributes to solid market evaluation data. As a result, market figures for many jurisdictions are variable, limited and/or inexact.

Nevertheless, the global remediation business is undergoing a process of change and is exhibiting indications of attaining a state of market maturity. Many contaminated sites are in the post-remedial action phase, and have benefited from better and more

reliable technology and the availability of greater process performance information. Many other contaminated sites have been characterized as essentially ready for implementation of a preferred remediation process. Clearly, many other contaminated sites have yet to be formally identified, declared or characterized. There has also been a shift in the general factor(s) motivating remedial action. Up to the mid-1990s, implementation of cleanup of contaminated properties was driven by regulatory compliances, and guided by clean-up end points or residual limits which bore little relationship to the proposed use of the remediated land. More recently, great attention has been placed on relating remedial action to the intended use of the property, as well as remediation economics and risk assessment. Analysis of international environmental markets in the following subsections clearly shows that substantial growth will occur over the next decade in markets throughout the world. The discussion on marketing potential is assembled mainly from data cited by CTCS (2002), The Delphi group (2003), AEGIS (2003), USEPA (2004), Statistics Canada (2004), EcoLog Group (2005), JETRO (2007) and Industry Canada (2008).

1.2.1 North America

The current estimated hazardous remediation market in the United States is pegged at around $12 billion, which represents about 30% of global demand. Based on currently applicable regulatory standards in the United States, an estimated quarter of a million sites require some form of remediation, but the number of contaminated sites is larger than that if all brownfield sites are taken into account (see below). Most of these sites have one or combinations of the most common contaminants – solvents, petroleum products, VOCs and heavy metals, the nature and concentrations of which will influence technology choice. These contaminated sites can be divided into seven groups depending on which government agency/regulations have enforcement and/or decontamination responsibility: Superfund, Resource Conservation and Recovery Act (RCRA) Corrective Action, Underground Storage Tanks (UST), Department of Defense (DOD), Department of Energy (DOE), Civilian Federal Agencies, and States (USEPA 2004). The majority of these sites requires the collaboration of multiple stakeholders for successful cleanup, as well as the development and implementation of innovative remedial solutions. The United States Environmental Protection Agency (USEPA) enforcement of the Superfund program is still encouraging remediation by potentially responsible parties at the majority of highly contaminated sites. This is evident based on USEPA's precedent-setting order requiring General Electric to pay nearly half a billion dollars for the cleanup of polychlorinated biphenyls (PCBs) in the Hudson River.

EPA estimates that up to $100 billion will be spent during the next 30 years to meet new underground storage tank regulations. The USEPA brownfield development program promotes the remediation and redevelopment of industrial sites by enhancing the acceptance of cleanups based on the concept of risk-based standards and restricted future land use. The USEPA estimates that over half a million brownfield

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