Biomass and Bioenergy 83 (2015) 328–339

Contents lists available at ScienceDirect

Biomass and Bioenergy

journal homepage: http://www.elsevier.com/locate/biombioe

Review

Integrating phytoremediation with biomass valorisation and critical element recovery: A UK contaminated land perspective

Ying Jiang [a], Mei Lei [b], Lunbo Duan [c], Philip Longhurst [a,*]

[a] Centre for Bioenergy & Resource Management, School of Energy, Environment & Agrifood, Cranfield University, Cranfield, MK43 0AL, UK
[b] Centre for Environmental Remediation, Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, Beijing, 100101, China
[c] Key Laboratory of Energy Thermal Conversion and Control, Ministry of Education, School of Energy and Environment, Southeast University, Nanjing, 210096, China

ARTICLE INFO

Article history:
Received 27 May 2015
Received in revised form
30 September 2015
Accepted 14 October 2015
Available online 24 October 2015

Keywords:
Phytoremediation
Elemental contaminant
Biomass to energy
Monte carlo simulation
Risk analysis

ABSTRACT

In the UK, the widespread presence of elemental contaminants such as arsenic and nickel in contaminated sites and more widely release of platinum group metals into the biosphere are growing concerns. Phytoremediation has the potential to treat land contaminated with these elements at low cost. An integrated approach combining land remediation with post-process biomass to energy conversion and high value element recovery is proposed to enhance the financial viability of phytoremediation.

An analytical review of plant species suitable for the phytoremediation of nickel, Arsenic and platinum group metals is reported. Additionally, a preliminary model is developed to assess the viability of the proposed approach. A feasibility appraisal using Monte Carlo simulation to analyse project risk suggests high biomass yield plant species can significantly increase the confidence of achieving financial return from the project. The order of financial return from recovering elements was found to be: Ni > Pt > As.

Contents

1. Introduction

Soils contaminated with metal and metalloid elements pose a major environmental and human health risk. Amongst the identified elemental contaminants, Arsenic (As) and nickel (Ni) are two of the most common ones. Due to their ubiquitous occurrence on contaminated sites, concentration levels and high risk factors, both elements are listed as priority inorganic contaminants under the UK Part 2A regime [1]. Platinum group metals (PGMs) on the other hand, have only limited distribution in the environment and inert chemical and biochemical properties; therefore have not been

* Corresponding author.
E-mail address: P.J.Longhurst@cranfield.ac.uk (P. Longhurst).

http://dx.doi.org/10.1016/j.biombioe.2015.10.013

recognised as priority soil contaminants. However, the increasing use of PGMs in the past few decades in vehicle exhaust catalysts, as well as in several other industrial and medical applications has led to a heightened soil concentration of PGMs, especially in urban high-traffic areas [2] as well as high value losses in mining areas. Consequently, these increases have given rise to public health concerns [2].

In the UK, metals and metalloids are the most widespread soil contaminants present in over 80% of all identified sites in England and Wales [3]. Management and remediation of these sites is clearly of public interest. From an environmental perspective it is desirable to rehabilitate contaminated sites to the highest possible standard, regardless of the potential costs. In practice, such approaches impose a heavy financial burden on government expenditure, as demonstrated by the Dutch government since their adoption of this approach in the early 1980s. According to Honders et al. [4], it was estimated that if all the identified sites in Holland were treated to the standard required by legislation, the total remediation costs would be in the order of 50 billion euros. By 1997, it was evident that the 'Dutch system' was not financially sustainable and the government changed their system to a more cost-effective 'function-orientated' approach adopting a risk-based management system, similar to the UK [5].

UK contaminated land is regulated by a framework of legislation and policies underpinned by the contaminated land regime (as stipulated in Part 2A of the Environmental Protection Act 1990, or simply Part 2A) and land-use planning regime Within this regime the Town and Country planning Act 1990 is the most important). The underlying concept of the UK system emphasises on a risk-based approach [6] and reliance on the land-use planning system (87% in England and 79% in Wales) to fund remediation work when the site is developed and redeveloped [3]. This approach, in contrast to the 'Dutch system' has proved to be more cost-effective for government intervention. However this approach is limited to urban areas where there is a rapidly expanding land requirement for residential and commercial development, and no lack of financial drive for developers to undertake remediation work. In rural and lower value areas where commercial land development is less competitive, there remain a large number of contaminated sites with remediation work pending due to financial barriers. According to the latest survey carried out by UK Environmental Agency, by the end of 2007, of the 746 contaminated sites which had been identified under Part 2A, only 144 were reported as completely remediated [3].

Remediation of elemental soil pollutants presents distinct scientific and technical challenges, as unlike organic pollutants these cannot be degraded further into non-harmful products. Therefore the only way to remediate toxic elemental pollutants is to remove or sequester them from the soil. Current technologies available for remediation of elemental pollutant including in-situ or ex-situ chemical treatment, biological treatment, soil washing, soil flushing, vitrification, incineration and landfilling [7].

Remedial treatments for contaminated sites in the UK are currently dominated by excavation and off-site disposal of material. This practice is used almost exclusively for remedial work of this type and regarded as the likely solution for all future work in the view of Environmental Agency [3]. Preference for this 'dig and dump' approach is due to its straightforward operation and short project time frame. However, volatile emissions, odour nuisance and noise during the excavation stage as well as possible secondary contamination during transport and landfill are evident risks. In addition to the environmental concern, increasing landfill taxation result in this method not being variable/feasible in the long term [8].

Phytoremediation technology uses plants to extract and translocate contaminants to above-ground tissues for later harvest, i.e. phytoextraction; converting the element to a less toxic chemical species, i.e. transformation; or at the very least sequestering the element in roots to prevent leaching from the site i.e. phytostabilisation. As a competing technology, phytoremediation offers a low cost, albeit slower alternative to physical and chemical treatment methods [9] and is viable in mitigating contamination levels for a wide range of organic and inorganic contaminants. However, as a biological method, phytoremediation is limited by a number of factors such as the long treatment time and site/contaminant specificity etc. In addition, a key inhibiting factor for commercial implementation of phytoremediation is the disposal of large quantities of contaminated plant biomass material that accumulate throughout the process [10,11]. When contaminant concentrations in the biomass exceed specific levels, the biomass material is regarded as potentially hazardous, therefore must be stored or disposed of appropriately [12]. Here, a radical approach to address this disposal problem by incorporating a thermochemical conversion of biomass to renewable energy followed by a metal(loid) recovery stage to the process is proposed. The feasibility of using phytoremediation technology to remediate selected elements from contaminated sites which are not on the local authorities' priority list is reviewed, then follows discussion of the feasibility of such an integrated approach to maximise economic benefit from phytoremediation alongside biomass energy production and high value metal recovery.

2. Phytoremediation and plant selection

Phytoremediation as a discipline in environment sciences was established in late 1970s following the discovery of a series of hyperaccumulators [13]. Since then the field has developed attracting not only scientific interest but attention from private and industrial site owners, regulators and the environmental engineering community [9]. To date, intensive research in this area has resulted in a significant improvement in knowledge of hyperaccumulators and their elements of affinity. It is now generally agreed that in order to distinguish 'hyperaccumulator' from normal or accumulator, a set of threshold values of elemental concentrations in plant biomass (dry weight) are used to define hyperaccumulation: Mn and Zn hyperaccumulators contain >10,000 μg/g [14], hyperaccumulators of As, Co, Cu, Ni, Se, and Pb have >1000 μg/g [14,15], and hyperaccumulators of Cd have >100 μg/g [14].

The mechanism and rationale of phytoremediation has been discussed in a number of reviews [16–20]. Depending on contaminants, the site conditions, level of clean-up required and the plant species, it involves the use of plants to extract, sequester, and/or detoxify pollutants [21]. The concept of using plants to uptake environmental contaminants from soil is not new, however it is only in the twentieth century, after a series of discovery of hyperaccumulator and vast advance of analytical techniques, has the concept of phytoremediation been rapidly developed [14].

In recent years, research on phytoremediation has shown the overall environmental and economic benefits from land remediation. Current research trends are focusing on maximising the use of by-products from phytoremediation process. Researchers are also exploring the use phytoremediation biomass as a renewable energy source [22,23]. In addition, the concept of moving from 'phytoremediation' to 'phytomining' to reclaim potentially valuable elements for further economic benefits is underway.

The greatest advantage of phytoremediation is low cost. According to a European scale study [7], the average cost for on-site phytoremediation and off-site landfilling are 122 and 231 Euro per m^3, respectively. In the American market, similar cost advantages from phytoremediation exist. It is generally agreed that the