Available online at www.sciencedirect.com
ScienceDirect
Trans. Nonferrous Met. Soc. China 24(2014) 233−242
Transactions of Nonferrous Metals Society of China
www.tnmsc.cn

Changes in functions, forms, and locations of lead during its anthropogenic flows to provide services

Jian-su MAO, Lan MA, Jing LIANG

State Key Joint Laboratory of Environment Simulation and Pollution Control, School of Environment, Beijing Normal University, Beijing 100875, China

Received 24 April 2013; accepted 9 August 2013

Abstract: Knowledge of the changes in a material's function, form, and location during the transfer and transformation of materials to generate human services will improve our understanding of how humanity interacts with the environment and of how services are formed by human activities. We compared lead's anthropogenic and biogeochemical cycles and found that the services, pathways, and changes in form requiring the most attention. We traced lead through its life cycle and identified the changes in its functions, forms, and locations by examining technology and engineering information. Lead ore and scrap were the two main anthropogenic sources of lead. When lead provides human services, its main functions included the storage and delivery of electricity, anti-corrosion treatments, and radiation protection; the main forms of lead in these products were Pb, PbO_2 and $PbSO_4$, and the main location changed from lithosphere in central China to regions in eastern China.

Key words: service economy; material flow analysis; anthropogenic cycle; human activity; life cycle; transformation

1 Introduction

Along with the implementation of sustainable development strategies, the development of a services-oriented society is becoming an important measure to conserve natural resources and reduce environmental pollution [1]. A variety of studies on this topic have been carried out in recent years, and have focused mainly on the following aspects. 1) In terms of industrial economics, the goal is to increase the proportion of the economic structure accounted for by service industries, so that these sectors play a more important role in the economy [2]. 2) For products and services, it is important to improve the product's performance or the service's quality by means of ecological innovation, particularly if this can increase services and decrease the importance of the least-efficient or most polluting products [3]. 3) To guarantee that these processes occur, policies and regulations have been adopted to promote the implementation of a services-oriented society [4]. These researches have emphasized the services that materials can provide to humanity. In other words, the fate of these materials in the anthrosphere, i.e., the human socioeconomic system and the parts of the environment that are affected by humans, is as final products with specific functions [5] that are capable of meeting human needs for specific services.

In hybrid human–natural systems, most materials that flow through the anthrosphere originate in nature [6,7]. When a material flows from its natural state into the anthrosphere to satisfy human needs, the substance undergoes three main processes: 1) extraction from nature; 2) transformation into products with specific functions that meet human needs by means of a series of processes that extend from design to fabrication and manufacturing [5]; and 3) performance of these functions to provide human services in the form of final products. During these processes, materials inevitably undergo a series of important changes [8], which involve redistribution within the anthrosphere at different temporal and spatial scales, forming different service patterns [9−12]. The chemical and physical properties of the substance change, as do its states, the services that it provides, its functions, and the locations where it performs those functions, all are closely related to the substance's form [8]. The quantitative changes have been extensively studied for various anthropogenic cycles

Foundation item: Project (41171361) supported by the National Natural Science Foundation of China (General Program)
Corresponding author: Jian-su MAO; Tel: +86-10-59893089; E-mail: maojs@bnu.edu.cn
DOI: 10.1016/S1003-6326(14)63052-1

[10,11,13,14], but changes related to the form of a substance have also been studied by experts in engineering, technology, and basic sciences such as physics and chemistry [15]. However, due to a lack of communication among these disciplines, it is difficult to create a thorough picture of the main changes in a substance that result from human activities, thereby making it difficult to systematically analyze all the changes to a substance that occur during its flow through the anthrosphere to provide human services.

Lead is a good example of a material that flows through the anthrosphere and links it with the natural environment. Lead originates as a nonrenewable resource, in the form of lead ore [10], and its emission into the environment creates a high level of ecological risk, including threats to human health [16]. From the perspective of the human services that it provides, lead is mainly used to manufacture lead-acid batteries (LABs), which store and deliver electrical energy, and because good records are maintained for these products, they can be used to quantitatively describe the services provided by lead [17]. Lead also enters the economic components of the anthrosphere through trading of materials and marketing of products. Lead offers an additional advantage for such studies: its flows are easier to trace than those of compounds such as polymers and complex molecules. Furthermore, many previous studies on the anthropogenic lead cycle provide a sound foundation for a study of lead's life-cycle processes, uses, and service patterns, which make it easier to trace lead through the stages of its life cycle and, thus, to identify the functions, forms, and locations of lead. Such research represents a useful approach to understanding the interactions between humanity and nature that result from flows of materials for providing human services.

2 Analogy between anthropogenic flows and environmental flows

2.1 Factors influencing environmental lead flows

In natural systems, a substance such as lead has a certain temporal and spatial distribution patterns. The places where the substance is concentrated are termed "reservoirs", and the flows of the substance between reservoirs are called "fluxes" [7]. A substance generally flows in a certain direction, which is determined by the direction of the natural forces responsible for these flows (e.g., geological processes that concentrate minerals in certain locations, downhill flows of water that carries dissolved substances). These flows produce trends in the accumulation of the substance in specific locations, such as in deposits of lead-containing ore or in products.

Traditional studies on the fate of a material as a result of these processes originate in the fields of geochemistry and environmental chemistry, and include research that focuses on environmental pollutants and the sources, pathways, fates, and possible ecological risks of these substances in the environment [7]. Although there are some natural sources of pollution, most concentrated pollutants are anthropogenic, and enter the environment as gaseous emissions, wastewater discharges, solid wastes, and residues produced by human activities [18,19]. The pollutants then follow pathways between environmental components such as soils, plants, and water [18,19]. The environmental fates of the pollutants reflect the results of their flows through the environment. Many studies have shown that the main factors influencing the flows of pollutants through the environment are their physical and chemical properties, forms and locations [7]. The physical and chemical properties of a material reflect its internal atomic or molecular structure, which in turn determines the material's environmental behavior [20]. The existing forms of a substance affect the chemical bonds that form between the substance and various other substances in the environment [21]. The location of a substance determines its surrounding environment and how it contacts the environment, which in turn determines the kinds of natural forces that it will experience. The forms and locations of a substance change in responses to changes in the state of the environment. Thus, all flows of a material through the environment result from interactions between the natural attributes of the substance and those of the environment, which also determine the eventual fate of the material.

2.2 Relationships between anthropogenic and biogeochemical lead cycles

In nature, lead flows between the lithosphere, atmosphere, hydrosphere, pedosphere, and biosphere; these flows are referred to as the "biogeochemical" or "natural" cycle of lead [21]. Humans are the most active component of the biosphere, and both accelerate flows of lead into the anthrosphere and promote flows through the hybrid socioeconomic–environmental system; these flows are called the "anthropogenic" lead cycle [11,12]. The environment acts as both the source of lead to the anthrosphere and a sink for lead released from the anthrosphere, leading to important interactions between the anthropogenic and biogeochemical lead cycles (Fig. 1). In this work, we will focus on the anthropogenic part and how lead changes its role in response to providing human services.

2.3 Comparison of anthropogenic and environmental flows of lead

From the perspective of system theory [22], both the anthropogenic lead cycle and the flows of lead after it