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Material Flow Analysis of Lead in Lead Acid Batteries Supply Chain Toward Circular Economy

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Abstract

In Thailand, number of cars using conventional Internal Combustion Engine (ICE) is increasing every year. Due to incomplete combustion by the engine, these cars produce PM 2.5 particles which are dangerous to human health. End of Life (EOL) batteries from these cars, if not properly managed, also cause environmental risks. In this study both primary and secondary data are collected and used for MFA analysis of lead in lead acid batteries. It was found that Thailand produced 17,841,371 batteries (equivalent to 245,140 tons of lead per year) in 2018. Some of these batteries were exported to neighboring countries (equivalent to 82,798 tons of lead per year). Some were sold in country for use in industrial factories and for use in vehicles (equivalent to 5,478 tons and 155,269 tons of lead per year, respectively). The total quantity of lead in battery wastes was 160,747 tons per year. The total quantity of lead recycled by 9 legally registered smelters was only 86,900 tons per year. The remaining 73,847 tons of lead in battery wastes were lost from proper recycling system. The management of this portion of battery wastes remains unknown. Proper recycling by legal smelters can reduce the quantity of lead imported from other countries and decreases the demand for natural resources. The researchers propose the following strategies as a guideline for management of lead in vehicle battery industry toward persistent circular economy. They propose that the government should give support to smelters by offering more tax incentive measures and should support the increasing in their productivity. The government should cooperate with battery manufacturers to nominate representative agency governed by governmental officers to buy EOL batteries from both small and big antique shops. The government should liberalize the investment or invest jointly with private sectors in building lead smelters.

Keywords : Material Flow Analysis (MFA); Lead Acid Batteries; Circular Economy

Introduction

In Thailand, batteries used in most cars are lead acid batteries which are the types of batteries used for vehicles with Conventional Internal Combustion Engine (ICE). Thailand can produce lead acid batteries for their own use and for export to other countries. About 80% of the cars in Thailand use lead acid batteries [1]. This type of batteries has the average life span of 2 to 3 years [2]. After the end of life (EOL), it is considered to be a hazardous waste. The main element from battery wastes that is hazardous is lead. If not properly managed, lead from lead acid battery wastes can contaminate the environment such as water reservoirs, the earth and surrounding air, spreading to human, animals and plants. It can cause environmental and health risks. Lead enters human body through respiration or digestive system. Inside the body it accumulates in the blood, soft tissues, teeth and bones and can cause lead toxicity. It causes adverse effects on central and peripheral nervous system, reproductive organs, kidneys, cardiovascular system and vitamin D metabolism [3]. Also perinatal and neonatal exposures to lead can cause the decrease of neurobehavioral and visual-motoric functions. Lead may also have carcinogenic effect. Recycling is one of the proper methods to manage the lead wastes from EOL batteries. Used batteries are collected and sent to legally registered smelters for proper lead recycling.

However, for some reasons, some of used batteries might be sent to illegal smelters and are not properly managed. At these illegal plants they employ workers to cut the batteries using axes and smelt the batteries together with their plastic boxes and lead grids in a reverberatory furnace without any protective equipment. The recovery efficiency of this technology is very low with high emission of pollutants. It is dangerous to employees and the environment as well [4]. Proper battery recycling not only reduces the amount of wastes, but also decreases the demand for natural resources.

Material flow analysis is a systematic assessment of the flows and stocks of materials within a system defined in space and time. It is an invaluable tool used in resource management, waste management and environmental management. It was postulated by Greek philosophers more than 200 years ago. After that, around 40 years back, Abel Wolman introduced the term “metabolism of cities” which coined the city as a living organism with inputs, stocks and outputs of material and energy [5]. MFA is a tool to analyze the metabolism of materials in order to analyze material flows and stocks within a given system [6]. It can be applied to Evaluate the importance and relevance of the flows and stocks ,Control material flows and stocks to support certain goals such as sustainable development, Assess resource utilization and environmental impacts, Set up long term environmental policy and resource management strategy and Understand and control material flow of heavy metal containing batteries.

In the management system for circular economy, system must be viewed holistically, at the beginning, the middle and the end of material flow to get the highest cyclical flow (life cycle) starting from the utilization of raw materials for battery production. This study applied Material Flow Analysis (MFA) as a tool to trace lead flow and stock in lead acid batteries supply chain in Thailand in order to analyze the current status of lead management and the way for improvement towards circular economy.

Methodology

This study applied Material Flow Analysis (MFA) as a tool used for systematic assessment of the flows and stocks of materials in each unit and the whole system within a defined temporal and spatial system [7]. The research methodology of this study could be described in 4 steps as follow:

1) Setting the scopes of the analysis study, identifying the system boundary and components

The target and the boundaries of time and space were decided. The target in this study was to establish the material flow system of lead in lead acid battery. The time or temporal boundary was the year 2018 and the spatial boundary was Thailand. The life cycle chain of lead in lead acid battery consisted of three stages, as shown in **Figure 1**, including product manufacturing, product use and waste management. It should be noted that there was no lead mining in this life cycle chain. In Thailand there has been no lead mining since 2001 [8], because of environmental problems, such as contamination of stream water by lead ore tailings, impacts on health and well being of people in the local area. Lead which is a raw material for battery production came from import and recycling only. The life cycle chain of lead in lead acid battery in Thailand was different from other studies in that there was no resource mining. Most other studies included resource mining as a stage of the life cycle chain.

2) Data acquisition (Data collection)

Both primary and secondary data were collected.

(1) The secondary data were collected by searching the official websites of governmental offices such as the Department of Primary Industries and Mines, the Department of Land Transport and the Office of Industrial Economics, and the articles published in local language or Thai. The data about the quantity of lead and lead acid battery in Thailand were gathered from the official websites of governmental offices.

(2) The primary data were collected by interviewing the customers or battery users and the battery selling shops in Chiang Mai.

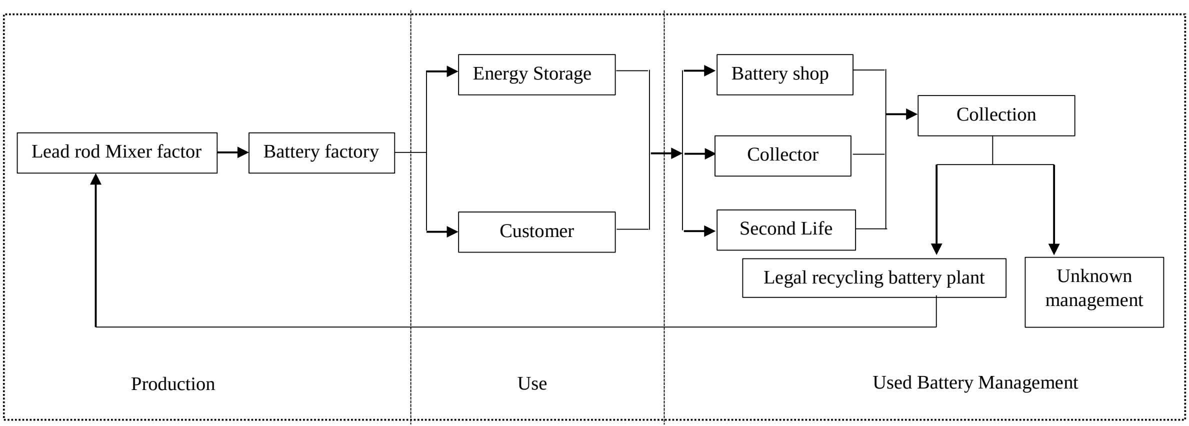

Figure 1 Scope of MFA of lead in Lead Acid Batteries

3) Schematic modeling and balance for material flow system framework

This step constructs the system to use the data collected above. When some data was not acquired, the mass balance or so-called mass conservation, i.e. mass-in is equal to mass-out can be used to balance the materials. Software STAN was used to do Material Flow Analysis of the real current situation.

4) Interpreting MFA result for lead in lead acid battery

In this step, the results of the above MFA for lead in lead acid battery were interpreted, to find out the appropriate method for battery waste management system in Thai.

Results and Discussions

It was shown in this **table 1** that the total number of lead acid batteries produced in Thailand in the year 2018, was 17,841,371. Out of this number, 11,300,511 were sold in country for use in vehicles (cars and motorcycles), 398,711 for use in industrial factories and 6,026,025 were exported to other countries. (**Figure 2** shows the diagram of the material flow of lead in lead acid battery via the MFA method)

Table 1 The quantity of lead in lead acid battery in each process

No.	Process	No. of battery per year	Estimated quantity of lead (Kg prt year)*	Quantity of lead (Tons per year)	Source
1	Import lead	-	-	161,050	Department of Primary Industries and Mines 2018
2	Export Battery	6,026,025	82,797,584	82,798	Office of Industrial Economics 2018
3	Lead rod /mixer factory	-	-	247,950	Import Lead-Legal recycle
4	Battery factory	17,841,371	245,140,438	245,140	Office of Industrial Economics 2018
4.1	Energy storage	398,711	5,478,289	5,478	Batteries sold in country (11,699,222) – No. transportation vehicles (11,300,511) = 398,711
4.2	Customer	11,300,511	155,269,021	155,269	Department of Land Transport 2018
4.2.1	Battery shop	8,136,368	111,793,695	111,794	72% of customer (from interview data)
4.2.2	Collector	1,695,077	23,290,353	23,290	15% of customer (from interview data)
4.2.3	Second life	1,469,066	20,184,973	20,185	13% of customer (from interview data
5	Collection	-	-	160,747	Energy storage +Battery shop +Second life + Collector
5.1	Legal recycling battery plant	-	-	86,900	Article on material flow of lead in lead acid battery 2017
5.2	Unknown management	-	-	73,847	Collection-Legal recycling

*estimation was based on "quantity of lead in lead acid battery =13.74 kg/battery

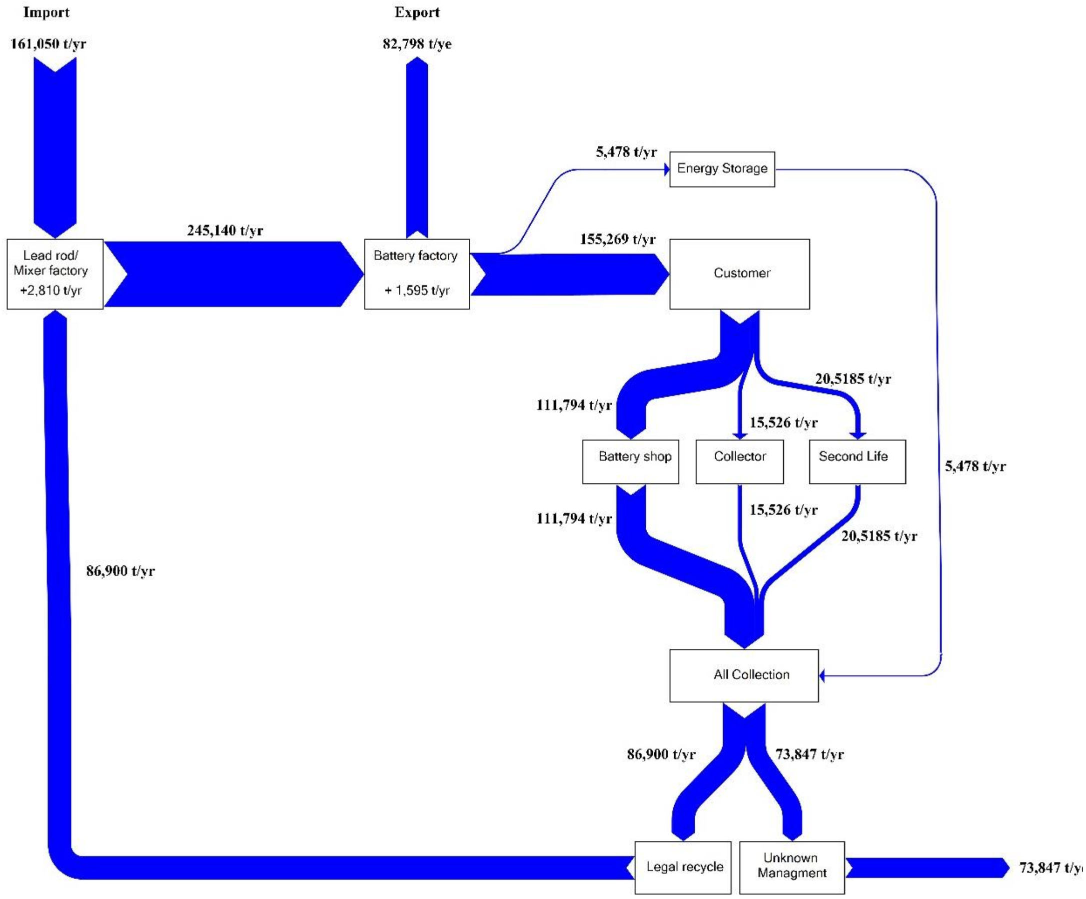

Figure 2 Diagram showing the material flow of lead in lead acid battery by MFA method

The overall input of lead in the year 2018 was 161,050 tons. It was found that in Thailand there has been no lead mining in Thailand since 2001 [8], because of environmental problems, such as contamination of stream water by lead ore tailings, impacts on health and well being of people in the local area. Therefore, lead which is a raw material for battery production came from import and recycling. This amount of lead input was totally imported in the form of lead rod from other countries. The imported and the recycled lead were, after that, used in the production of lead acid batteries. The total amount of lead used in battery production was 245,140 tons [9]. Data from the Department of Land Transport 2018 showed that The amount of lead in lead acid batteries that were exported to neighboring countries was 82,798 tons. The amount of lead in batteries that were sold in country for use in industrial factories and for use in vehicles was 5,478 and 155,269 tons respectively.

The lead acid batteries that have been used for a long time and lost their capacity to the point when no longer suitable for use in vehicles.The primary data from interviewing with the customers showed that among the old (EOL) batteries 72% of them were traded in for new ones in battery shops, 15% were sold to antique shops for recycling and 13% were reused as stationary storage for photovoltaic (PV) energy in second life application. Using these percentages of EOL batteries for calculation, it was found that the amount of lead in lead acid batteries which were traded in for new ones in battery shops, sold to waste collection and recycling shop and reused in second life application were 111,794 tons, 23,290 tons and 20,185 tons respectively.

From interviewing with the battery selling shops, it was found that about 30% of the old EOL batteries that they bought were resold to antique shops, and 50% were resold to the company shops bigger than the antique shops. There was no information about how the remaining 20% of EOL batteries were managed.

The old EOL batteries collected at battery selling shops, small antique shops and bigger company antique shops eventually were sent to smelters for recycling. Thailand has only 9 lead smelters that are legally registered [10]. The quantity of lead recycled by these smelters was only 86,900 tons per year. Compared with the lead demand of the country, the quantity of lead recovered from recycling process is still not adequate. To get adequate quantity of lead for the production of new batteries, 161,050 tons of lead was imported.

The total quantity of lead in lead acid battery wastes was 160,747 tons per year. The quantity of lead recycled by the legally registered smelters was only 86,900 tons per year. It is not known how the remaining 73,847 tons per year of lead in battery wastes were managed. This amount of lead in battery wastes were not in the legally registered recycling system. It could be assumed that some portion of this amount of lead was sold for battery recycling, to lead smelters which are not registered to the Department of Industrial Works. This is because the illegal or unregistered smelters paid a higher price to the EOL batteries than the legally registered smelters. The other portion might be sold to unregistered smelters for production of lead rods. These lead rods would be sold to factories making ball bearings, trawl, seine, fishnet etc. Illegal smelting that does not meet the standard can cause danger. People will have the chance to directly expose to lead by inhalation or direct contact. Prolonged and continued exposure to lead can cause lead toxicity. It can cause death if the body suddenly receives a large quantity of lead. People may receive lead indirectly by drinking water or eat meat and vegetables contaminated with lead etc.

Waste and Hazardous Substances Management Bureau, Pollution Control Department [11] states that EOL batteries are considered to be hazardous wastes from the community. Forty per cent (40%) of the battery wastes were managed properly. Sixty per cent (60%) of them were not properly managed. The main problem is that the garbage dumping place cannot prevent the dissemination of hazardous wastes. The hazardous wastes are thrown away mixing with general wastes. The Waste and Hazardous Substances Management Bureau, Pollution Control Department has therefore the policy to manage the hazardous wastes following the environment control management plan as follows by Reduce the quantity of wastes by the 3R principle, namely reduce, reuse, recycle and encourage the use of materials that are friendly to environment, Have the system to bring back hazardous wastes from used products and Promote the investment of private sector to build smelter or the center for proper discarding hazardous wastes.

The quantity of lead imported from other countries would be reduced if the 73,847 tons of lead in battery wastes were brought into an appropriate or proper recycling system, making the system move closer to circular economy. Nevertheless, there must be a thorough study on how to collect and send the EOL lead acid batteries into a correct management system.

From this study, the problem in management was found to be at the step of collection of EOL batteries before sending them to smelters. Battery shops sold EOL batteries to small antique shops, and the small antique shops resold them to bigger antique shops. After that it was not clear how they were managed. They could be sold to legally registered smelters or to unregistered smelters. It is not known how many of them were sold to legally registered smelters and how many to unregistered smelters.

The researchers propose the following strategies to manage lead acid battery wastes. They propose that the government should give support to smelters by offering more tax incentive measures and should support the increasing in productivity of the smelters. The government should also cooperate with battery manufacturers to nominate representative agency governed by governmental officers to buy EOL batteries from both small and big waste collection and recycling shop. The government should also liberalize the investment of private sectors or make joint investment with them in building lead smelters.

Conclusion

In the year 2018, Thailand could produce totally 17,841,371 batteries. Lead (in the form of lead rod) which is the raw material for battery production came from import (from other countries) and from recycling (in country). Lead acid batteries produced in Thailand were exported to neighboring countries, used in industrial factories and vehicles in country. About 73,847 tons of lead in battery wastes were lost from the system of collection and sending to legally registered smelters. It is possible that this amount of lead in battery wastes were sent to the illegal or unregistered smelters that did not meet the standard and could cause bad effects or problems to the environment. The quantity of lead imported from other countries would be reduced if the 73,847 tones of battery wastes were brought into an appropriate or proper recycling system, making the system move closer to circular economy. Nevertheless, there must be a thorough study on how to collect and send the EOL lead acid batteries into a correct management system. The proposed strategic plan for EOL battery managements are:

(1) The government gives supports to smelters by offering more tax incentive measures.

(2) Support the Increase in productivity of smelters.

(3) The government cooperates with battery manufacturers to nominate representative agency governed by governmental officers in each province to buy EOL batteries from both small and big antique shops.

(4) The government liberalizes the investment or invests jointly with the private sectors in building lead smelters.

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