



e-ISSN No.: 2582-4228

Journal of Indian Association for Environmental Management

Journal homepage: [www.http://op.niscair.res.in/index/php/JIAEM/index](http://op.niscair.res.in/index/php/JIAEM/index)



An Overview and Challenges of Lead Acid Battery Waste Management in Delhi and the National Capital Region

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Submitted: 05February 2024 Revised: 11April 2024 Accepted: 12April 2024

Abstract: With the economic growth and industrialization after economic liberalization in India, the demand for energy raised exponentially to meet the daily needs of energy. An uninterrupted power supply became necessary, so is the power back up appliances like inverter. With increase in population the Indian automobile sector grew sharply because of rise in demand of automobiles, Lead acid battery is used for starting, lightning and ignition (SLI) purposes in automobiles, so consequently rise in lead acid battery (LAB) applications. LAB have an array of applications in day today life in various forms but after certain period they become obsolete i.e. become part of waste. So, for meeting the demand of present and future generations, recycling of waste LAB becomes necessary. But, if these waste Lead acid batteries takes informal pathways, then it poses health and ecological challenges along with resources scarcity. In the present study we are focusing over the present status of lead acid battery waste management in National Capital Region of Delhi India. Furthermore, this study shows the linkages between unsustainable recycling and DALY. And how it is contributing to DALY (Disability Adjusted Life Years) and resources scarcity consequently to burden over the economy.

Keywords: Lead Acid Battery, Waste Management, Recycling, Informal recycler, DALY

I. INTRODUCTION

The energy demand is increasing day by day apart from grid supply. We must be dependent upon alternatives, one of that is batteries. The production of lead acid batteries accounts for >85% uses of global lead. It is mainly used for starting lighting and ignition purposes in automobiles. LABs are used in almost all the world's 1.3 billion vehicles and in building backup power supplies worldwide. With the growth of electric vehicles, the demand for lead has increased, resulting in an unavoidable increase in lead acid battery waste. In lead acid batteries, lead is the main component, it is found in the earth's crust, It is heavy metal (Those elements having an atomic number greater than 20 and atomic density above 5 g cm^{-3}) (Raychaudhuri et al., 2021) and it is very hazardous because of its toxicity, it affects the environment as well as human health in shorter or longer terms (Hadjipaschalis et al., 2009).

Lead is a soft, heavy, and highly malleable metal, it is bluish-white when freshly cut but tarnishes grey when exposed. According to HZL, there is a short supply of lead vis-a-vis the demand in the market as per Indian Minerals year

book Part-B metals & alloys of 2015 Edition. The ever-increasing demand for lead especially from the lead acid battery sector is met by the thriving market of lead scrap recycling. It is estimated that more than fifty percent of lead refined worldwide is from recycled materials. Producing lead through this route requires around one-third of the energy needed to extract it from its ores. Recovery of secondary lead is economically more attractive because of certain advantages. Besides lower energy consumption, it also entails low capital cost, less environmental hazards, and high metal contents.

Many of the secondary lead-producing units have operating in the unorganized sector or known as the informal sector and they create major pollution by emission of lead vapor and SO_x. The small-scale units generally do not control process parameters, such as smelting temperature, charge-to-fuel ratio, leakages in the body, etc. As per the national ambient air quality standards, the permissible concentration of lead in ambient air is $0.50 \text{ } \mu\text{g/m}^3$ while the permissible limit for SO_x is $50 \text{ } \mu\text{g/m}^3$.

The amount of lead recycled is about 75% of the total lead production in India. More than 80% of lead consumed in the

country goes to the manufacturing of lead batteries as per Indian Minerals Yearbook of metals & alloys 2019 edition. As per recent research, In India future lead acid battery market is expected to rise at a compound annual growth rate (CAGR) of more than 9% for 2018–24 (Kalpna Varshney, 2020). Lead is considered one of the major potent pollutants in the world. Because of maximum utilities, the use of this metal is increased to 10 Mt per year. Out of this total amount, nearly 2 million tons per year are produced in Asia. China is the top producer of lead followed by Australia the United States, and Canada. Mexico, Peru, Russia, and Kazakhstan are other countries with major Lead deposits (Sze-yin Tan, 2019).

TABLE 1
World Reserves of Lead (By Major Countries)

(In '000' tonnes of lead content)

Country	Reserves
World: Total (Round off)	90000
Australia ^(a)	36000
Bolivia	1600
China	18000
India*	2500
Kazakhstan	2000
Mexico	5600
Peru	6300
Russia	6400
Sweden	1100
Turkey	860
Russia	5000
Other Countries	5000

Source: USGS, Mineral Commodity Summaries, 2020. (a) For Australia, the Joint Ore Reserve Committee complaint reserves were about 12 million tonnes.

* India's total reserve/resources of lead & zinc as per the National Mineral Inventory based on UNFC as of 01.04.2015 are 749.46 million tonnes.

The energy storage market was estimated at 12 GWh in 2018 and is expected to grow thirteen times in the coming years to reach 158 GWh by 2024. The battery storage market is gaining importance due to its wide range of applications from the renewable energy sector to consumer electronics. Battery storage cost reached \$156/kWh in 2019 compared to \$1000/kWh in 2010 (Zhang et al., 2016) and it is gradually becoming economical for many commercial uses.

The application of lead acid battery can be classified into the following Categories.

Immobile applications:

- Inverter applications, such as UPS
- A power storage device in electric vehicles (EV)
- The power source in hybrid electric vehicles and grid-scale energy storage component of electricity generated by renewable sources (solar/wind etc.) (Budde-Meiwes et al., 2013).

Mobile applications:

- Automotive or vehicular batteries are used for starting in vehicle, lighting, and ignition (SLI) (Garche et al., 2017).
- If the immobile application of lead-acid batteries were not there, power outages nearly occur every day as lead-acid batteries have come to the rescue, supplying large amounts of electricity for a short duration of time until supplementary power is added to the grid (McKeon et al., 2014).

Overview of secondary lead acid battery waste recycling:

Generally secondary lead is proffered over primary lead as it is easier to recover than primary lead from their ore as it is sustainable. The major source of secondary lead is discarded lead acid battery, it accounts approximately 85% of total secondary lead (Wang et al., 2020). In this article we are overviewing the major recycling practices in Delhi and national capital region (NCR) engaged in waste lead acid battery recycling. As from the field visit in Delhi and nearby localities, it was found that most of the used battery end up to the unorganized recycling centers popularly known as the informal smelters as they do not come into the preview of environmental institutions. So, they use crude methods to recycle lead from spent batteries. Below in fig. 1 the flow sheet is given how the spent batteries are recycle in an unorganized sector.

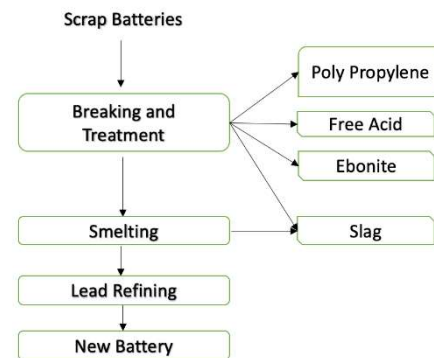


Fig 1: Flow sheet for recycling of lead acid batteries adopted by unorganized sector (Wang et al., 2020).

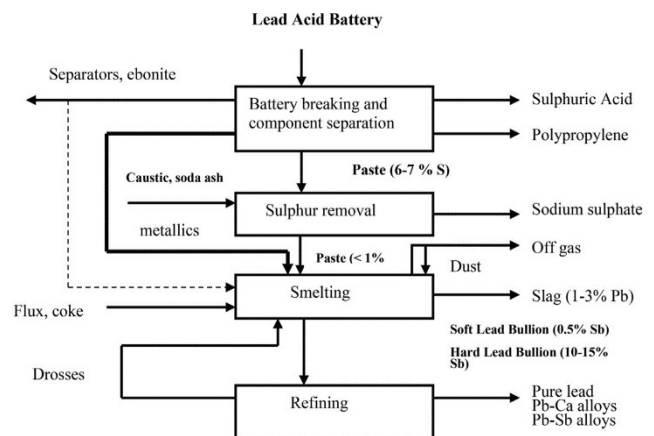


Fig 2: A typical flow diagram of secondary lead recycling (Varshney et al., 2019).

The traditional method of recycling spent lead acid battery is breaking battery into its components then followed by pyrometallurgy path. There has been development in the novel furnaces and equipment's in past few years. However, the basic method of lead acid battery recycling has been based on smelting method, it has not changed much for a long period of time. In fig. 2 the basic flow diagram of recycling secondary lead acid battery is given.

The working chemistry of lead acid battery: Generally, the anode in a lead acid battery is made up of lead (Pb) and the cathode is of lead oxide (PbO). These electrodes are dipped in an aqueous solution of sulphuric acid which is the electrolyte for the transfer of electrons from anode to cathode. When the battery produces electricity (energy), the lead ions migrate into the solution and combine with electrolyte to form lead sulfate (PbSO₄) and the PbO reacts to produce lead sulfate and water (Posada et al., 2017). This process is called the discharging of the battery. During the discharging process, there is an accumulation of lead sulfate on the electrode and water in the electrolyte. During charging the process gets reversed and the lead sulfate gets combined with water thereby producing lead and lead oxide (Posada et al., 2017).

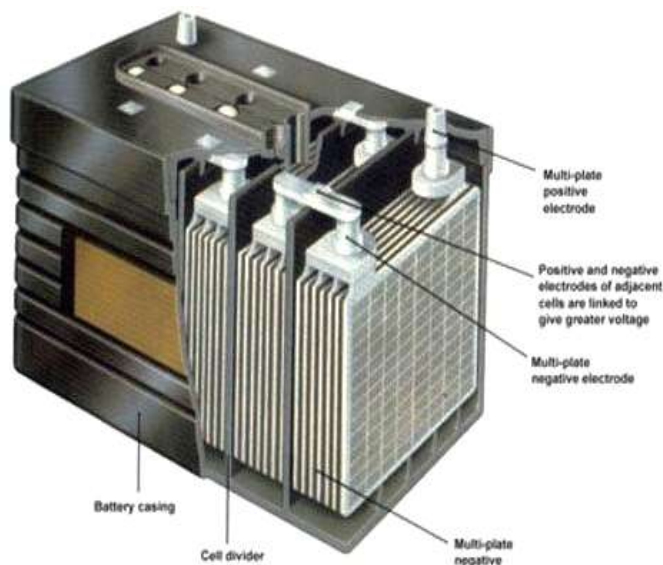
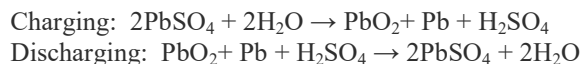


Fig 3: Fig: Schematic representation of components of lead acid battery

II. MATERIALS AND METHODS

Study Area: The present study is Delhi and the national capital region (NCR) based on lead acid battery recycling after they become out of work and focusing mainly an overview of lead acid battery recycling sector. The reason for choosing Delhi and NCR as study areas is, that it is the capital of the

country with large consumers residing in Delhi and national capital region along with existence of large recycling center around Delhi mainly in the informal sector. As we know from the field observation and interaction with major stakeholders involved in the lead acid battery waste management, it lies majorly in the informal sector. The lead acid battery waste management has vast scope to be explore as it is fast growing sector. The different stakeholders play major role in the supply chain of batteries from manufacturer to consumer and then back to recycling plants through various channels, depends upon the major factors, one of the main factors is economic incentives. Therefore, the economic incentives involved in LAB waste management, it has highest recycling rate in the world comparatively.

Data Base and Methods: This study is based on field observation of major stakeholders involved in the spent lead acid battery recycling and secondary data based on previous studies, reports of ministries, research organizations, environmental NGO's and websites of Indian Bureau of Mines and independent researchers.

Overview and current situation

Health Impact: Lead is ubiquitous, It affects virtually every system in the body. It can damage the nervous system, renal, and reproductive systems, cause high blood pressure, and affect growth and development, psychological behavior, and intelligence (Han et al., 2018). Lead exposure in young children is of particular concern because children absorb lead more readily than adults and the developing nervous system of children is particularly vulnerable to the adverse effects of lead. Blood lead levels (BLL) as low as 10 µg/dl (microgram/deciliter) are associated with harmful effects on children's learning and behavior (Mandal et al., 2023). Elevated BLL can result in learning disabilities, behavioral problems, and mental retardation. The standard value of lead particle presence set by WHO is 0.5 µg/m³ (Ericson et al., 2016).

TABLE 2
National Ambient Air Quality Standard of lead pollutant in few selected countries

Country	Air Quality Standard for Normal Air in one year
Australia	0.5 mg/m ³
China*	1 mg/m ³
Europe	0.5 mg/m ³

*The air quality standard for normal air: 0.5 mg/m³ average in one year, with a seasonal limit of 1 mg/m³ in China

lead (Pb) has received particular attention in recent decades for its ubiquitous pollution due to its use in gasoline and paints and the improperly controlled non-ferrous metallurgy (Bi et al., 2017; Han et al., 2012, 2018). Lead pollution resulted in 0.6% of the world's disease burden (Needleman, 2004) and 853,000 deaths in 2013 (WHO, 2017).

As the largest developing country, India should pay more attention to Pb poisoning due to its large emission of lead.

Blood lead level and Pb concentration in soil: The World Health Organization (WHO) calculated that the source of Pb exposure in children encompasses dust and soil (45%), food (47%), water (6%) and air (1%). Dietary lead exposure has gradually decreased with increased food security and effective control measurements, while exposure to dust has become a major reason for contamination, especially for children with hand-to-mouth activities(Han et al., 2018).

Blood lead level and PM10 in Air: The source of PM10 is mainly caused by metal smelting fossil fuel burning and vehicle emissions. According to a study by the United States Environmental Protection Agency, USA, it was found that Pb exposure through air particles decreased from 1.34 $\mu\text{g}/\text{m}^3$ in 1980 to 0.14 $\mu\text{g}/\text{m}^3$ in 2010 due to effective control of

emissions. Consequently, the BLLs of children decreased to 11.2 $\mu\text{g}/\text{L}$ from 2009 to 2010(Han et al., 2018).

Disability Adjusted Life Years (DALYs): It was calculated that cardiovascular disease attributable to lead exposure resulted in 2.7 million DALYs (95% CI: 2.3–3) in 2012 in the 9 states it was reviewed. It was further found that intellectual disability in children (age 0–4 years) attributable to lead exposure resulted in 2.2 million DALYs (95% CI: 1.6–2.6) in the same year in the 6 states reviewed. Altogether it was calculated that 4.9 million DALYs (95% CI: 3.9–5.6) were attributable to lead exposure in the geography. It was reviewed in 2012 to summarize attributable DALYs by sequelae and calculated BLLs (Ericson et al., 2018). In the following given tables the DALY attribution of cardiovascular disease due lead exposure, intellectual disability attribution due to pediatric lead exposure and the calculated DALYs attributable to lead exposure is shown

TABLE 3
DALY from cardiovascular disease attributable to lead exposure in 9 Indian States in 2012

	Hypertension	Ischemic	Cerebrovascular	Other CVD	Total DALYs (CVD)
Pooled mean (7.52 $\mu\text{g}/\text{dL}$)	93,082	1,146,922	1199438	286028	2725470
LCI (5.28 $\mu\text{g}/\text{dL}$)	79573	983168	1033822	244882	2341444
UCI (9.75 $\mu\text{g}/\text{dL}$)	103241	1269450	1322146	316886	3011723

(Abbreviation used CVD: Cardiovascular Disease; ICL:Indices of Cumulative Blood Lead Level; UCL: Umbilical Cord Blood Lead Level; LCI: Lower Confidence Interval; UCI: Upper Confidence Interval)

TABLE 4
DALY from intellectual disability attributable to pediatric lead exposure in 6 Indian states in 2012 (Ericson et al., 2018)

	Borderline	Mild	Moderate	Severe	Profound	Total DALYs (intellectual disability)
Pooled mean (6.86 $\mu\text{g}/\text{dL}$)	19,935	913231	777933	338963	147356	2197418
LCI (4.382 $\mu\text{g}/\text{dL}$)	14973	685936	584312	254598	110680	1650500
UCI (9.35 $\mu\text{g}/\text{dL}$)	23599	1081053	920892	401253	174435	2601233

TABLE 5
DALYs attributable to lead exposure in the reviewed states in India in 2012 (Ericson et al., 2018)

	Total DALYs (CVD)	Total DALYs (Intellectual Disability)	Total DALYs (all Sequelae)
Pooled mean	2725470	2197418	4922889
LCI	2341444	1650500	3991944
UCI	3011723	2601233	5612955

The above given Tables 3-5 summarize the attributable DALYs by sequelae and calculated BLLs. This calculation is taken from previous studies, in which 4.9 million DALYs attributed to lead exposure in six Indian states.

Environmental impact: The lead acid battery consists of four parts those are lead and lead alloy grid, lead paste and organics, and plastic, it includes lots of hazardous, toxic, and flammable, explosive substances that can easily pose potential risks. The material batteries are composed of might cause pollution accidents such as fires, explosions, poisoning and contaminating the environment, and damage to the ecosystem. The recognition scope of lead-acid batteries mainly focused on the pollutants involved in the process of centralized recovery, storage areas, and transport (Zhang et al., 2016). The main constituents of lead acid batteries are given in the below table.

TABLE 6
The main chemical compositions and contents of spent lead-acid batteries

Compositions	Contents (%)
Electrolyte	11-30%
Lead paste	30-40%
Lead & Lead alloy grid	24-30%
Organics and Plastic	22-30%

Chemical hazards and toxic substances pose a wide range of health hazards (such as irritation, sensitization, and carcinogenicity) and physical hazards (such as flammability, corrosion, and explosibility). According to “Hazardous Chemicals Directory 2015”, the pollutants and their risks in the process of centralized recovery, storage areas, and transport were listed in the Table Below.

TABLE 7
The pollutants and the risk of lead-acid batteries

Materials	Risk	Physical State	Source
Lead & Lead compound	Toxicity	Solid	Electrode & Grid
Sulphuric Acid	Corrosion	Liquid	Electrolyte
Antimony	Toxicity	Solid	Plates
Hydrogen	Explosiveness	Gas	Water Electrolysis

Lead and its compounds and antimony are toxic and have certain hazards both to humans and the environment, however, they are the internal structure of the battery whose main existing form is solid, which did not form the conditions of exposure and diffusion in recovery, storage, and transportation. The electrolyte exists in the form of liquid and the leakage would be caused due to the collision and the aging of the battery tray. The leakage of electrolytes and the leakage was the leading environmental risk of lead-acid batteries in production, processing, transportation, use, or storage (Zhang et al., 2016).

Sulfuric acid is a diprotic acid and shows different properties depending upon its concentration. Its corrosiveness

can be mainly ascribed to its strong acidic nature and, if concentrated, strong dehydrating and oxidizing properties. Sulfuric acid at a high concentration can cause very serious damage upon contact, since not only does it cause chemical burns via hydrolysis, but also secondary thermal burns through dehydration. It can lead to permanent blindness if splashed onto the eyes and irreversible damage if swallowed. Accordingly, safety precautions should be strictly observed when handling it (Zhang et al., 2016).

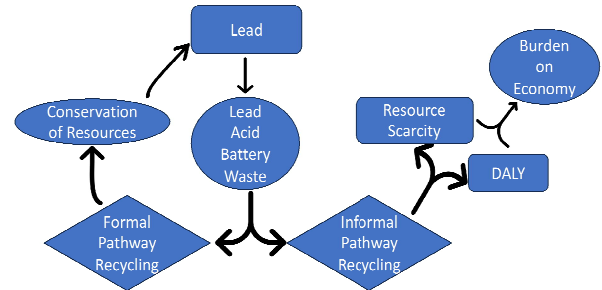


Fig 4: Flow diagram of Indian lead acid battery recycling and its consequent effects

The lead acid battery recycling pathways is associated with the resource recovery, DALY (disability adjusted life Years). As it is depicted in the above flow diagram that how the recycling pathway decide the course of resource recovery i.e. whether sustainable or unsustainable pathway. Furthermore, it shows that when spent lead acid battery are recycled via formal pathway means as per the waste recycling policies and practices standardized by government environmental institutions leads to resource conservation in sustainable way relatively. Whereas, when spent lead acid batteries are recycled via informal pathway i.e. through crude methods then how it adds on to burden on economy, because recycling in informal sector causes less resource recovery and pollution that further cause disease burden on economy.

Resource Scarcity: As we know earth has limited resources, so to meet the needs of future generations with the present generation needs, a sustainable resources strategy is need of the hour. So, sustainably recycling the waste materials is the only way.

Waste generation: With the growing population the demand for battery-driven instruments has also increased, and so has the lead acid battery waste. As we know India has witnessed tremendous growth in the automobile sector. As we know lead acid battery is used for SLI purpose that is Starting, lightning, and ignition in automobiles.

Here is some statistics on the Indian automobile sector by the society of Indian automobile manufacturer (SIAM). The industry produced a total of 2,59,31,867 vehicles including passenger vehicles, commercial vehicles, three wheelers, two wheelers, and quadricycles from April 2022 to March 2023, as against 2,30,40,066 units from April 2021 to March 2022. India is growing as the third-largest automotive industry in the world, which can result in an increase in demand by 2025.

Composition of Battery Waste:

The first major battery-breaking step is the dismantling or breaking of the battery to gain access to the lead units. There are numerous ways to do this, but the most common approach is via a hammer mill or a set of roller crushers. The fragmented product is fed to a sink/float or hydrodynamic separator where the various fractions are sorted. In the basic sink/float cell, the plastic fractions are floated off and removed to the plastics recovery section whereas the lead-bearing portion of metallics and compounds sinks to the bottom and is removed via conveyors or other means for further classification into metallic and oxide fractions (M, Lead Acid Batteries: Overview, 2009).

TABLE 8
Typical range of components

Material	Wt. %
Lead Sulphate	55-60%
Lead Dioxide	30-35%
Metallic Lead	1-8%
Other materials	5-12%

Collection: For the sustainable recycling of waste, the collection is the first step, it plays a pivotal role in deciding the path of recycling i.e. informal way or formal way. The spent batteries are collected by local kabaadivalah, as he is easily available at phone call distance. He prefers to sell the spent batteries to local LAB smelters as he gets better price without any document formality as in the otherwise case of dealing with registered recyclers.

Transportation: After collection safe transportation to a recycling center is very important. But because of lack of safe collection space for storage of used LAB, these batteries end up at unregistered recycling units. The one more reason is, used LAB contains hazardous components as mentioned above in above table i.e. Lead is Heavy metals have short and long effect if enters informal recycling centers, similarly other major component is sulphuric acid which is carcinogenic and flammable in nature and have potential to affect human beings particularly infants and pregnant women if not handled as per the protocol proposed by CPCBs' guidelines.

Recycling and Treatment: The major lead acid battery recycling processes are mentioned in below section.

(a) Electro-winning Process: It is a green process comparatively as it reduces wastewater and chemical discharges. It is beneficial for large lead recycling units. But it is a high-cost method as it requires a high electrical transformer and rectifier. It is a three-step process, first is the breaking of used batteries followed by the separation of plastic components and grids, and then second hydrometallurgical processing of leftover parts, and finally the pb++ lead in high concentration is obtained. One of the

electrowinning processes is PLACID process, for example, lead chloride is obtained by the reaction of spent lead paste with hydrochloric acid and sodium chloride. After solid-liquid separation, the $PbCl_2$ solution is purified, and pure lead is obtained by electrowinning. Although this process allows to obtain lead with a purity of 99.995% (Mondal et al., 2022).

(b) Pyrometallurgy process: Pyrometallurgy is widely used smelting process for recycling lead acid battery as it is easy to use even by unskilled workers. Initially battery is broken, and components are separated manually followed by Sulphur removal, smelting and then refining (Varshney et al., 2019). This process is use specifically for batteries, here batteries are used as a raw material. It includes different pyrometallurgical techniques as pyrolysis, reduction and incineration. During pyrolysis process water and volatile materials are evaporated, separated and condensed. And organic components are thermally destroyed and emitted as a gas together with water. During the reduction process, the remaining metallic fractions after pyrolysis treated by reduction at temperature 1500 °C here the carbon produced during pyrolysis process is used as reducing agent (Bernardes et al., 2004). The third step is Incineration, in which the gas generated during pyrolysis is incinerated as temperature about 1000°C and then quenched to avoid generation of other side products such as dioxins (Zhang et al., 2016).

(c) Hydrometallurgy process: This is efficient method of recovering metals from raw materials. In this process the batteries are mechanically processed to recover the metallic parts. Lead sulfate, which accounts for about 65% of exhausted lead paste, is very stable. For this reason, desulfurization that transforms lead sulfate into other lead compounds is a common pretreatment of pyrometallurgical recycling process. The hydrometallurgical processes can be divided in several subcategories. One of the novel methods is the "paste to paste" process in which an organic leaching is followed by a calcination stage that allows to obtain lead oxide used as active materials for battery production. Another proposed process is the one involving alkaline leaching followed by crystallization. In this process, the spent lead paste is dissolved in NaOH solution (Bernardes et al., 2004).

(d) Challenges of Collection Transportation, and Treatment: In India the lead acid battery waste recycling exists in informal sector majorly, because of economic incentives associated with exchange of spent LAB for new battery. The three main components of waste management's i.e. collection transportation and treatment of waste LAB plays important role in sustainable recycling of batteries, when all above mentioned three steps works in tandem. We can say based on the field visit in Delhi and national capital region (NCR) that LAB recycling exists mainly in informal sector. The main characteristic of Informal sector is it is unregulated beyond the ambit of state regulatory institutions, so it is very difficult to measure the level of pollution they cause. And for the

same reason it is difficult to ensure the sustainable recycling of LAB as government Institutions doesn't have any record about the exact volume of waste LAB exist there. As per the India's Central Pollution Control Board's (CPCB) battery waste management rules the batteries should be recycled at registered battery recycling centers only but because of leakage in waste batteries to informal sectors. Consequently, the waste lead acid battery ends up to informal recycling centers. And furthermore, the recycling of Waste LAB in an unsustainable way, and consequently harm to environment and human beings living around recycling units and adding to the Disability Adjusted Life Years.

III. CONCLUSION

The lead acid batteries are integral part of our daily life in the form of various home appliances, automobiles, and gadgets. With the growth of Indian economy and industrialization the consumption of lead acid battery has also risen sharply in the last few decades. One of major sector that contribute to large consumption of lead acid battery is automobile sector, wherein LAB are used as starting, lightening and ignition (SLI) purposes. With the urbanization rise in the living standard the demand of uninterrupted supply of energy has also increased, so is the demand in power back up appliances such as inverter also rises in case of power outage. As major countries are switching to green renewable energy sources the harnessed energy is stored in batteries. But after certain point of time these batteries become out of work and become part of waste, which poses ecological, economic and health challenges. So, to tackle these challenges the sustainable recycling of spent lead acid batteries become necessary. But, once these batteries become out of work, they end up recycling in informal sector, where these batteries are broken manually and components that carry economic incentives are recycled via using crude methods. The informal sector recycling of used LAB is rampant despite the strict Battery Waste Management Rules by central pollution control board (CPCB) Of Ministry of Environment Forest and Climate Change. Because of unsustainable recycling of spent lead acid Battery, it adds on to the burden on economy as the recycling by crude method cause lead poisoning affect people living in the vicinity of these recycling plants particularly children and pregnant women.

IV. ACKNOWLEDGEMENT

I would like to thank the CSIR-HRDG for providing me research stipend to carry out this research.

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