GERMAN-MONGOLIAN INSTITUTE FOR RESOURCES AND TECHNOLOGY

The present work was submitted to the Faculty of Engineering

Identification the types of battery used in Mongolia due to find opportunity of recycling

Bachelor Thesis

by

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24th of May, 2019

STATUTORY DECLARATION

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I hereby affirm in lieu of an oath that I provided the submitted bachelor thesis

IDENTIFICATION THE TYPES OF BATTERY USED IN MONGOLIA
DUE TO FIND OPPORTUNITY OF RECYCLING

Independently and without undue external help. I did not use any sources other than those stated. In case that the work is additionally submitted on a data medium, I declare that the written and the electronic form are completely identical. The work was not submitted in the same or similar form to any examination authority.

Ulaanbaatar/Nalaikh, 24th of May, 2019

Place, Date

Signature

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ABSTRACT

This bachelor thesis aimed to determine the types of battery used in Mongolia due to find opportunity of recycling. The 21st century is battery's era, all of electrical devices related to battery. The battery is modern world necessary portable energy resources. Battery is converted chemical energy to electrical energy.

In Mongolia a numerous type of battery used. Mongolian Customs provide us the data and information of batteries used in Mongolia. The data displays between 2011 and 2018 of battery types and actual amount. In the data, only expression manganese dioxide, lithium-ion, zinc-air and silver oxide. Other types of batteries not included data of Mongolian Customs. China, Federal Republic of Germany, Republic of Korea, United States of America and Japan are the main exporter countries of Mongolia.

There are several types of batteries. This thesis mostly considers about lithium-ion battery because usage of lithium-ion battery is rather high in Mongolia. Many types of process to recycling lithium-ion battery. As well as hydrometallurgical recycling, pyrometallurgical recycling, intermediate recycling process, direct recycling, bioleaching and mechanochemical process.

ACKNOWLEDGEMENT

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I would like to thank GMIT Engineering faculty for giving me a great opportunity to apply my knowledge in real case. Especially thank my supervisor Prof. Dr-Ing. Bayanmunkh Myagmarsuren and co-supervisor Ph.D. Ariuntuya Tserendorj for their guidance, helpful advice, support and helping complete this bachelor thesis.

I would also like to Mongolian Customs, they provide me necessary data and materials.

Finally, I would like to express thank my family, all of classmates and friends for support and understanding the situation during course of bachelor thesis.

1. INTRODUCTION

The background of my thesis is massive that it is hard to cover. Although possibility of battery recycling was researched in my thesis. Thesis is limited within borders of Mongolia. Currently economy level of Mongolia is not so good due to most of electrical goods imported from other big countries even wholly kind of batteries.

In our daily life, we generate waste in every aspect. We utilize consumer products, which produce wastes and disposal. In 2016 approximately 2.01 billion tons of municipal solid waste was produced by urban resident globally and amounting to a footprint of 0.74 kilograms per person per day. This number expected to increase by 70% from 2016 level to 3.4 billion tons in 2050(1). Waste of electronic and electrical equipment (WEEE) is one of the fastest growing waste streams causal to this increase. Increasing amount of waste requires more disposal land.

Lithium-ion batteries are the one of most common type of battery, which used in portable electric devices and their use is increasing. Lithium-ion batteries contain a lower toxic material than other battery types. About countries are considered suitable for disposal to landfill, even developed countries reflect batteries are classified as hazardous waste and there are laws concerning where and how they are transported. If we do not landfill with batteries and overloaded landfills are poison our earth. Because chemicals leak out of corroded shells water, those dangerous elements go into rivers and airs.

Battery recycling process has beneficial to the environment. Recycling lithium-ion batteries in particular reduces energy consumption, greenhouse gas emissions and as a result 51.3% natural resources saving when compared to landfill. However, it is not possible to recycle WEEE without any environmental effect. Currently in Mongolia, not any recycling of lithium-ion batteries processes proceeded. Despite that, there are numerous lithium-ion recycling processes used in the worldwide.

Mongolia is not battery producer country. A hundred percent of all types of batteries imported from other countries. Also, there is no official disposal place in the country. In future, demand of battery consumption will be increase due to growing economy. If we can recycle waste batteries and produce new battery in our country, it is very helpful to economy of Mongolia. However, in our country there is not good enough systematic research of battery recycling to solve it.

2. LITERATURE REVIEW

2.1 BATTERY

Batteries are in modern world necessary portable energy resources. Battery is converted chemical energy to electrical energy. Batteries handle two or more electrochemical reactions. Battery's process is opposite direction of electrowining. Electrowinning needs energy input. Batteries extract electrical energy using separate conducting electrodes(2). Batteries are divided two main groups. Primary batteries and secondary batteries.

Primary batteries on the other hand nonrechargeable. Common types of that kind of batteries are zinc-manganese dioxide and zinc-silver oxide batteries. Most of the primary batteries contain an alkaline electrolyte. A battery that involving lithium, the electrolytes are nonaqueous. Nonaqueous means needed to avoid water hydrolysis at the low potentials associated with lithium. Irreversible reactions and water hydrolysis are major reasons of nonrechargeable property of primary batteries. One of the common types of primary battery is zinc-manganese dioxide alkaline cells. That kind of batteries based on reactions involving manganese dioxide at the cathode and zinc metal at the anode. The half-cell reactions are(2):

Cathodic reaction

$$2MnO_2 + 2H_2O + 2e^- \leftrightarrow 2MnO(OH) + 2OH^- \qquad E = 0.132 \qquad (2)$$

Anodic reaction

$$Zn(NH_3)_2^{2+} + 2H_2O + 2e^- \leftrightarrow Zn + 2OH^- + 2NH_4^+ \qquad E = -1.17 \qquad (2)$$

Overall reaction written as

$$Zn + 2MnO_2 + 2NH_4^+ \leftrightarrow 2MnOOH + Zn(NH_3)_2^{2+} \qquad E_{ocell} = 1.30V \qquad (2)$$

Another group of battery is secondary batteries mean rechargeable batteries. Most famous type of secondary battery is lead-acid battery. Lead-acid batteries mostly used in primarily in automobiles. Other common types are nickel-cadmium battery, metal-hydride battery and lithium-ion batteries. Lead-acid battery has high charge storage capacity, high recharge ability, low cost and low maintenance. That kind of battery consist of lead plates. These plates are at least partially covered porous layers of either lead dioxide or lead sulfate. In this case anode is lead dioxide and cathode is lead sulfate. The chemical reactions are as follows(2):

Cathodic reaction

$$PbO_2 + H_2SO_4 + 2H^+ + 2e^- \leftrightarrow PbSO_4 + 2H_2O \qquad E_o = 1.636V \qquad (2)$$

Anodic reaction

$$PbSO_4 + 2H^+ + 2e^- \leftrightarrow Pb + H_2SO_4 \qquad E_o = -0.295V \qquad (2)$$

Overall cell reaction

$$PbO_2 + 2H_2SO_4 + Pb \leftrightarrow 2PbSO_4 + 2H_2O \qquad E_o = 1.931V \qquad (2)$$

From this group lithium-ion batteries are getting popular in the worldwide in past decade. Application of lithium-ion is wide ranged such as mobile, telephones, laptops and video cameras. They are also used in larger application such as electrical vehicle and aerospace applications(3).

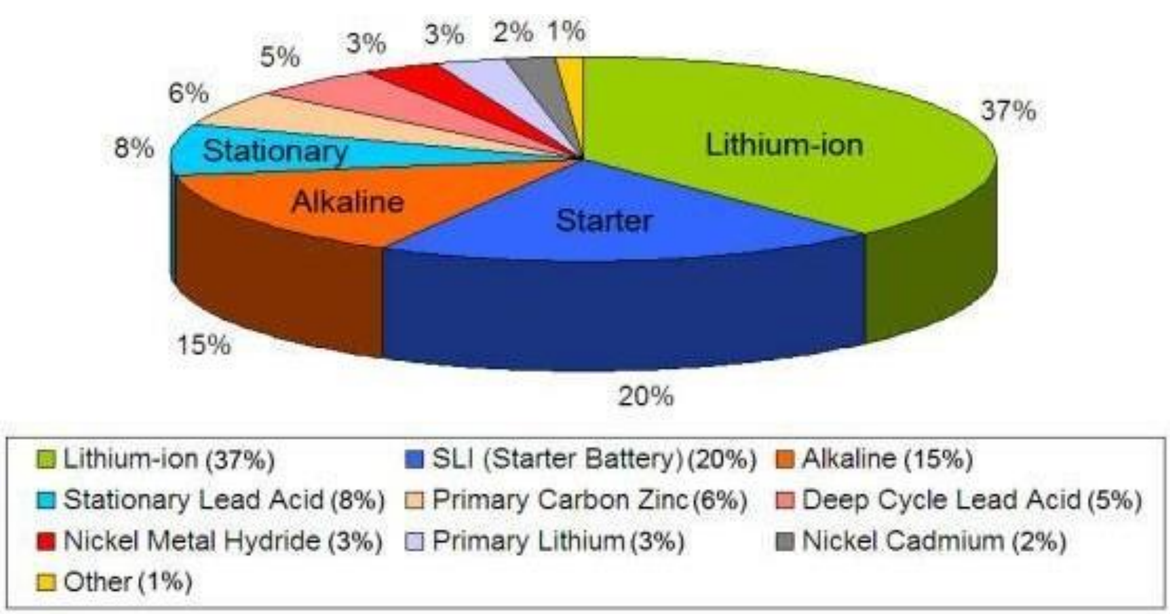

Figure 1 Revenue contribution by different battery chemistries in 2009 (4)

According to the Frost and Sullivan, in 2009, the battery market was reached to the global revenue of $47.5 billion. For secondary batteries made up 76.4% of this revenue. Expected to increase to 82.6% in 2015(4).

Specifications	**Li-ion**	**Ni-MH**	**Lead-acid**
Working voltage (V)	3.7	1.2	2
Gravimetric energy density (Wh/kg)	130-200	60-90	30-40
Volumetric energy density (Wh/L)	340-400	200-250	130-180
Cycle life (cycles)	500	400	300
Capacity self-discharge rate (% per month)	5%	30%	10%
Memory effect	None	40%	None
Coulombic efficiency ($C_{discharge}/C_{charge}$)	99%	70%	75%
Weight comparison for the same capacity	1	2	4
Size comparison for the same capacity	1	2	4
Reliability	High	Low	High

Table 1 Comparisons of among three battery technologies (5)

According to the table 1 lithium ion batteries have more advantages. First of all, lithium ion batteries have high specific energy. Same amount of batteries, lithium ion battery can produce more energy than other rechargeable batteries. Lithium ion higher energy density range between 130Wh/kg and 200Wh/kg. Next advantage is lithium ion battery has high open circuit voltage compare to the other batteries. High open circuit voltage means we can increase amount of power that can be transferred at a lower current. Another advantages are can work in wide temperature range, environmental safe because they contain no poison elements and as you can see Table 1, lithium ion batteries have longer life cycle(5).

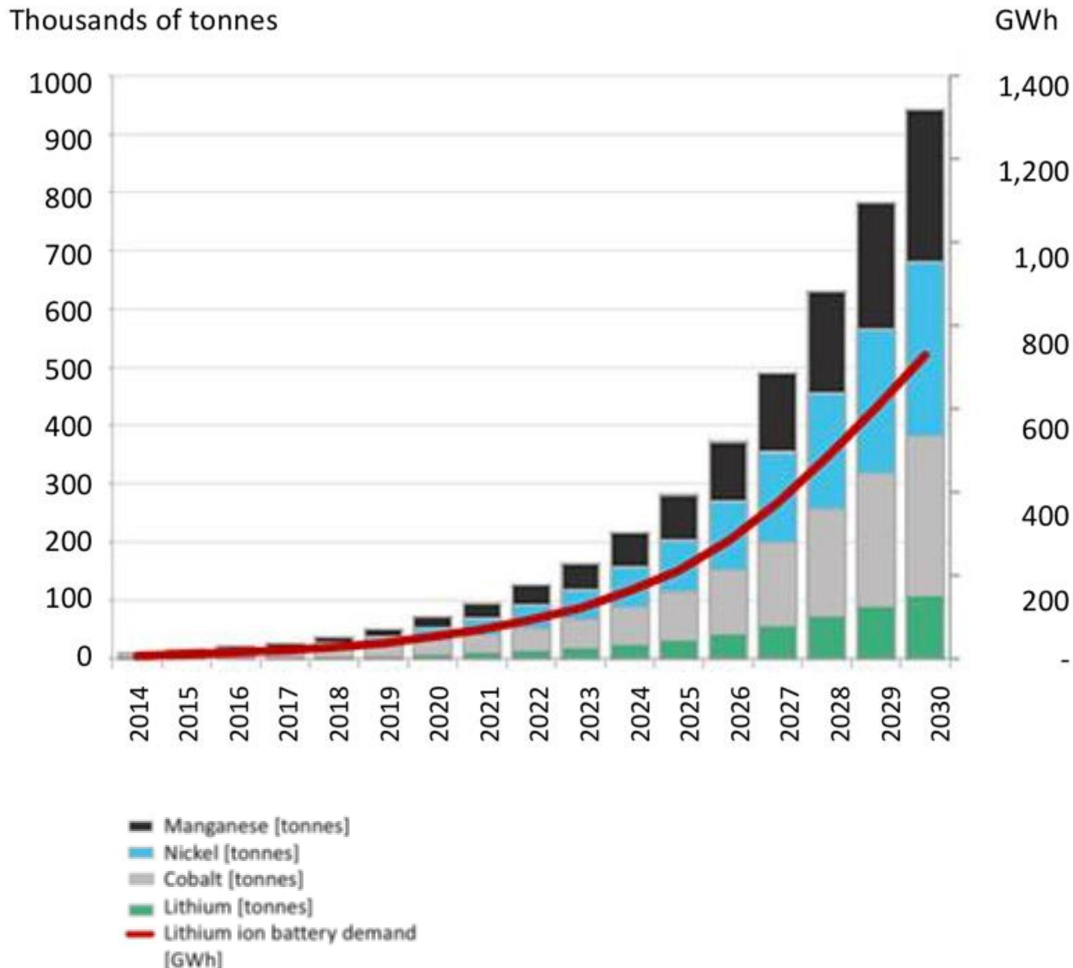

Figure 2 Global lithium ion battery demand and material forecast of electric vehicle sales (6)

According to this graph future lithium ion battery demand are steadily increasing. Not only lithium ion batteries, raw materials such as manganese, nickel, cobalt and lithium are expected to increase year by year(6).

2.2.1 Working principle of battery

2.2.1.1 Alkaline battery

Another one of common type of battery is alkaline batteries. Alkaline batteries produce energy in chemical reaction zinc and manganese dioxide. This type of battery is named alkaline because potassium hydroxide is pure alkaline substance. Following pictures shows us alkaline batteries structure and how alkaline batteries produce electricity(7).

General alkaline battery consists of container, cathode, separator, anode, electrolyte and collector.

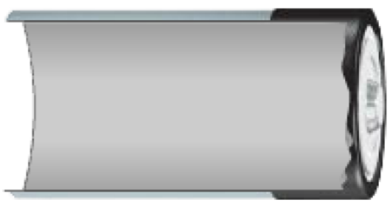

Figure 3 Container of alkaline battery (6)

Container made of steel serving shell to form cathode for electrochemical reaction

Figure 4 Cathode mix of alkaline battery (6)

Cathode is a mixture of carbon, manganese dioxide. Cathodes are the electrodes reduced by the electrochemical reaction. Cathode mix is attached to inside wall of steel container.

Figure 5 Separator of alkaline battery (6)

Separator is non-woven and fibrous fabric, which keeps cathode from contact anode.

Figure 6 Anode of alkaline battery (6)

Anodes are oxidized electrodes, where chemical reaction is going on. It bears negative electric charge and along with electrolyte is pumped into different containers.

Figure 7 Electrolyte of alkaline battery (6)

Electrolyte is potassium hydroxide solution in the water. It is a climate for movement of ions inside the battery.

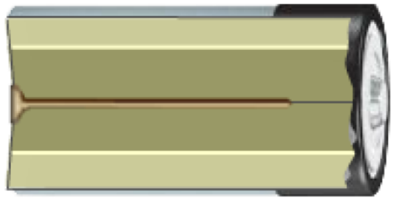

Figure 8 Collector of alkaline battery (6)

A brass pin middle of the cell is collector. Collector leads electricity to the outside circuit.

Next few pictures show us how does battery produce electricity.

A battery entered into device, then circuit become complete and chemical reaction starts

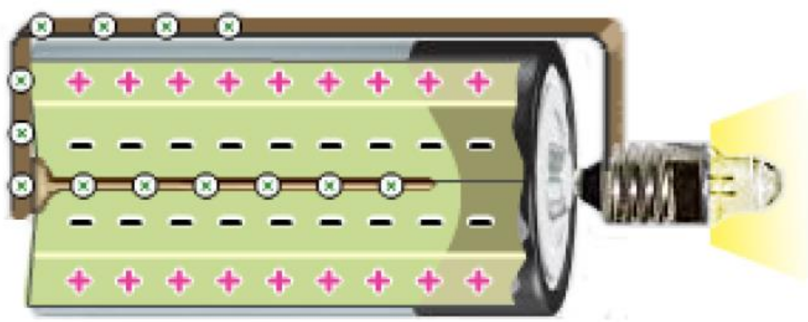

Figure 9 Process of chemical reacts (6)

Electrolyte oxides the anode's zinc when device responds. In cathode mixed carbon and manganese dioxide starts react with oxidized zinc in order to produce energy.

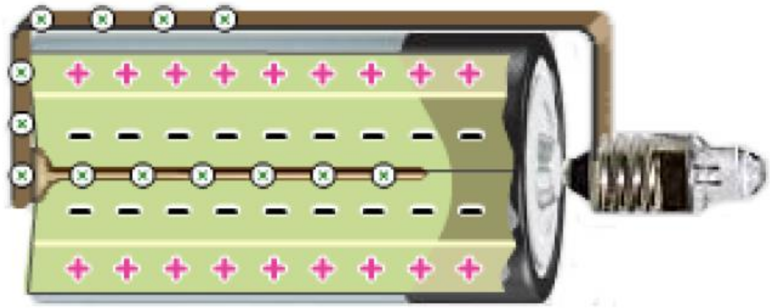

Figure 10 how batteries work (6)

Zinc and electrolyte produce reaction products. As a result, cell's action slows down and voltage drops(7).

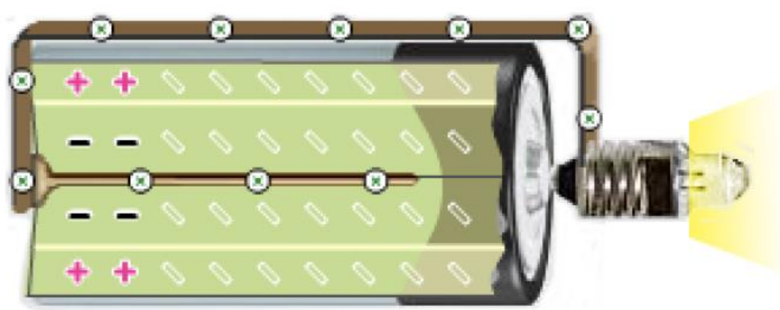

Figure 11 Process of voltage drop (6)

2.2.1.2 Lithium-Ion battery

Lithium-ion battery is member of rechargeable family. Lithium ions move from the negative electrode to the positive electrode during discharge, and opposite when charging(8).

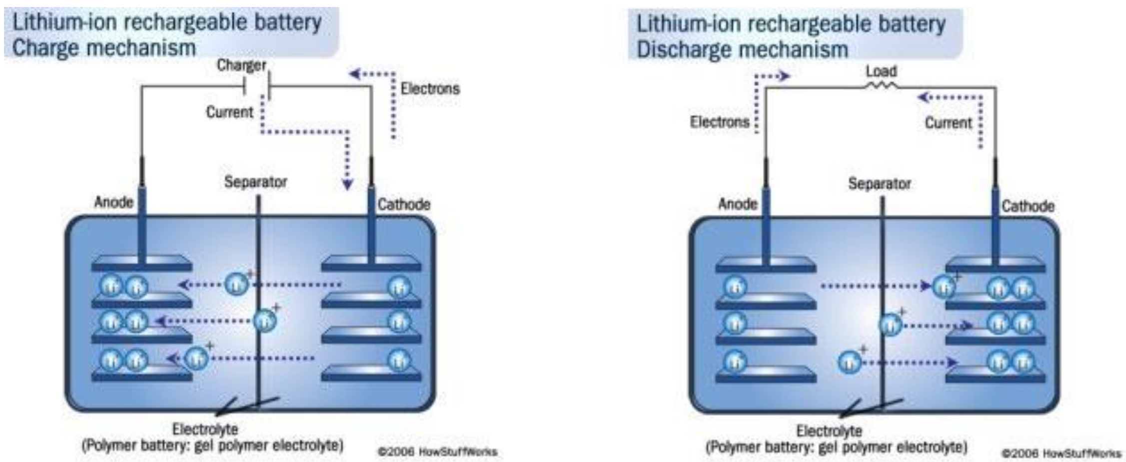

Figure 12 Mechanism of discharging and charging in lithium ion batteries (8)

When a lithium-based cell is discharging, lithium ions are extracted from the anode, move through the electrolyte and inserted into the cathode. When the cell is charging, the reverse occurs(8).

The positive electrode half-reaction (cathode reaction), take $LiCoO_2$ as an example

$$LiCoO_2 \qquad Li_{1-x}CoO_2 + xLi^+ + xe^- \qquad (8)$$

The negative electrode half-reaction is:

$$xLi^+ + xe^- + 6C \qquad Li_xC_6 \qquad (8)$$

Overall cell reaction:

$$C + LiCoO_2 \qquad Li_xC + Li_{1-x}CoO_2 \qquad (8)$$

During charging, the transition metal cobalt is oxidized from Co^{3+} to Co^{4+}, and reduced from Co^{4+} to Co^{3+} during discharge(8).

2.2 MATERIALS USED IN LITHIUM-ION BATTERIES

Li-ion batteries generally consist of four parts: cathode, anode, electrolyte and separator. Electrodes contain particulate active material, carbon conductive additive, polymeric binder and current collector. Carbon conductive additives are required to deliver sufficient electron transport to the electron intercalation in electrode. Carbon spheres, carbon black, carbon fibers and carbon tubes are all of the mass fraction of the additives. These additives are sufficiently high and outpace the percolation threshold, there is enough carbon to form a connected, percolating network through the electrode. Polyvinylidene difluoride (PVDF) is generally used as the binder, but environmentally friendly binders using carboxymethyl cellulose (CMC) or styrene butadiene rubber SBR instead of PVDF. One of lavishly available light metal aluminum is used as the current collector for the cathode. Because it forms a passivation layer to inhibit oxidative corrosion(9).

- Active materials

Li-ion batteries have a range of possible active materials. There are different mechanisms for lithium uptake and release. These mechanisms include: intercalation into crystalline host, electroplating, alloying with metals, conversion reaction and other types of insertion such as in amorphous carbon(9).

Graphite is widely used as the anode material. Graphite has a high specific capacity and shows a low interaction potential. Lithium titanate ($Li_4Ti_5O_{12}$, LTO) has a low energy density, but works in electrochemical windows in which the organic electrolyte is perfectly stable. During lithium intercalation, come from no irreversible charge losses and no formation of SEI (solid electrolyte interphase)(9).

- Electrolyte

The electrolyte has an important impact on battery performance. The rate capability, cycle life, coulombic efficiency, operation temperature range and safety of Li-ion batteries are all of them depend on electrolyte composition. Salt and solvent are two main components of liquid electrolytes. Few salts such as $LiPF_6$, $LiClO_4$, $LiAsF_6$ and $LiBF_4$ have been explored for batteries. The solvent is consisting of mixtures of alkyl carbonates such as ethylene carbonate (EC), propylene carbonate (PC), dimethyl carbonate (DMC) and diethyl carbonate (DEC). In addition electrolyte additives such as vinylidene carbonate (VC) are improve the cycle life and safety Li-ion batteries(9).

- Separator

The separator is a one of the important components in Li-ion batteries, serving two main purposes. First one is, to prevent physical contact of the electrodes and to avoid internal short circuiting. Another purpose is to be responsible for iconic conduction path for the liquid electrolyte. Most of the Li-ion batteries membranes are porous polyolefin. Because of their inclusive advantages of performance, safety and cost. The polyolefin consists of polyethylene (PE), polypropylene (PP), their mixtures such as PE-PP, high density polyethylene (HDPE) and ultrahigh molecular polyethylene (UHMWPE). Nowadays, a ceramic separator for good mechanical and thermal stability has been developed(9).

2.3 CURRENT METHODOLOGY

Recycling process of lithium-ion battery has 6 different recycling processes. Hydrometallurgical recycling, pyrometallurgical recycling, intermediate recycling process, direct recycling, bioleaching and mechanochemical process.

- Hydrometallurgical recycling

Hydrometallurgical recycling process of one of the methods to recover metals from the battery's active materials. First step of this process, spent Li-ion batteries are decomposed into cells. The cell physically separated into parts of cathode, anode and casing after cells are discharged. The cathode is soaked in NMP (N-Methyl-2-Pyrrolidone) in 100 degree Celsius to isolate cathode from aluminum foil. After soaking, the active materials goes crushing in a planetary ball mill, after crushing calcination process at 705 degree Celsius. The next leaching step includes reduction of the cobalt metal to a more soluble divalent form by hydrogen peroxide. After following chelation of the cobalt and lithium metals with the organic acid. Lithium is already soluble(10).

- Pyrometallurgical recycling (smelting)

In this recycling process, lithium-ion batteries are going to a high-temperature shaft furnace along with a slag agent which typically includes limestone, sand and slag. This process recovers an alloy of cobalt, copper, nickel and iron. These metals are recovered from alloy, as a result of leaching. The slag includes lithium, aluminum, silicon, calcium, iron and any manganese. In gas cleanup step, necessary to avoid release potential toxic byproducts. It is economical for batteries with cathode materials containing cobalt and nickel(10).

- Intermediate recycling process

This process commercially used in Canada. Firstly, batteries go to size reduction in a hammer-mill and shaker table separates mixed plastic and metals. Filtering of the aqueous stream exit the hammer –mill yields mixed metal oxides, carbon and a liquid stream. The liquid stream can be mix with soda ash to precipitate Li_2O_3. The metals separated and directed to the recycling. As with pyrometallurgical recycling, however the process is reasonable if cobalt and nickel are contained in cathodes of the battery(10).

- Direct recycling

Discharged and breached cells are in the placed in container, then added CO_2 and temperature and pressure are elevated to CO_2 above critical point. The supercritical carbon dioxide extracts the electrolyte (ethyl methyl carbonate, diethyl carbonate and $LiPF_6$) from the cells and removed. If battery is determined to be economic, can be recycled for use batteries. The cells, undergo pulverization or other size-reduction steps, possibly in the absence of water or oxygen to avoid contamination of materials. Subsequently, the cell components are separated through techniques that exploit differences in electronic conductivity, density, or other properties. Cathode materials may need to undergo re-lithiation prior to reuse in batteries(10).

- Bioleaching

Solid waste bio-hydrometallurgical process is alike a natural biogeochemical metal cycle. It is based on the ability of microorganisms to convert insoluble solid compounds into soluble elements can be recovered. The microbial from metabolites, which is activity to help leach the metals from the waste(10).

- Mechanochemical process

Mechanochemical method consist of co-grinding $LiCoO_2$ with polyvinyl chloride (PVC) in laboratory ball mill in air to form Li and Co-chlorides subsequent leaching with water of the ground product to extract Co and Li. In the grinding stage, reaction between $LiCoO_2$ and PVC generate to form chlorides which is soluble in water. Grinding is supporting mechanochemical reaction, and the extracted return of both Co and are Li improved. If we want recoveries of Co and Li are nearly 100%, we need approximately 30 minutes grinding. The aim of this process is to recycle useful materials from the wastes of battery and PVC(10).

2.4 RELATED SCIENTIFIC PAPERS

Linda Gaines (2014) studies "The future of automotive lithium-ion battery recycling: Charting a sustainable course"(11). In the introduction part Linda Gaines introduce about types of recycling batteries and recycling methods. Alkaline batteries recycling has some benefits and the materials available being non-toxic because they not contain mercury. About automotive batteries are potential economic benefits: usable materials can recover from them and less raw materials need to be extracted from the limited supplies in the ground. Some batteries are classified hazardous waste. Lithium-ion batteries are Class 9, which meets the definition of miscellaneous hazardous material. Lead-acid batteries (Pb-acid) are belong to Class 8, corrosive hazardous materials. Linda Gaines notes the types of recycling: lead-acid battery, nickel-metal-hydride batteries (Ni-MH), and lithium-ion batteries.

In the United States, 99% of lead-acid batteries are turned in for recycling which is the best percentage of recycling compared to the other major consumer products(12). Pb-acid batteries are also recycling in European countries and Japan(13).

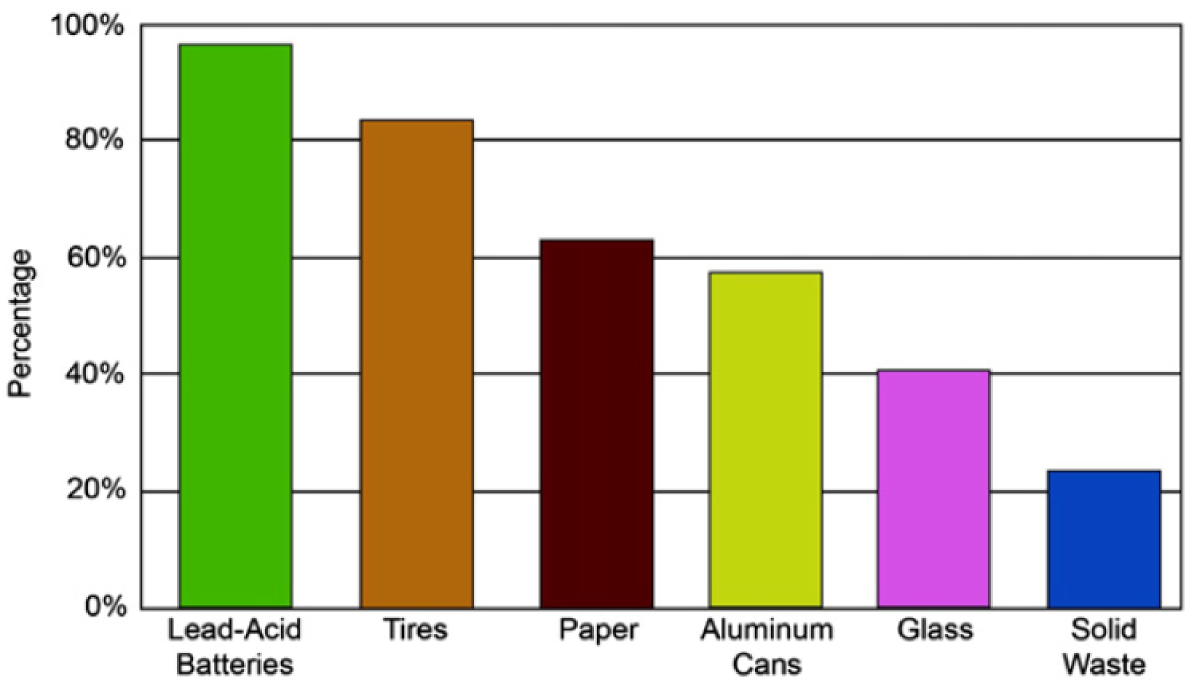

Figure 13 Highest recycled consumer products (13)

For automotive batteries, the Pb-acid batteries mostly used for starting-lighting-ignition (SLI), and found from under the hood of most cars. Nickel-metal-hydride batteries are used in hybrid cars and lithium-ion batteries are used in plug-in vehicles and a few number of hybrids. Structure of these batteries similar but chemically they are quite different. Each of these consist of electrode active materials on grid or foil. Charge between the electrodes helping with electrolyte(13).

Lead-acid battery recycling is quite simple process. Firstly, the battery case is open, after sulfuric acid electrolyte is drained out and collected. Then, the plate and connecter from the case can be separated. After drainage, the battery should go to the size reduction. Hammer-mill is suitable for them. Using sink-float device can be separate the plastic and lead. The recovered lead is remelted and purified to make new battery. The plastic is melted and mold to the new cases. The general battery design is standard, that means battery consist of lead, lead oxide, and sulfuric acid in a polypropylene case and all manufacturers use same raw materials. That is why recycled of lead –acid battery successful(13).

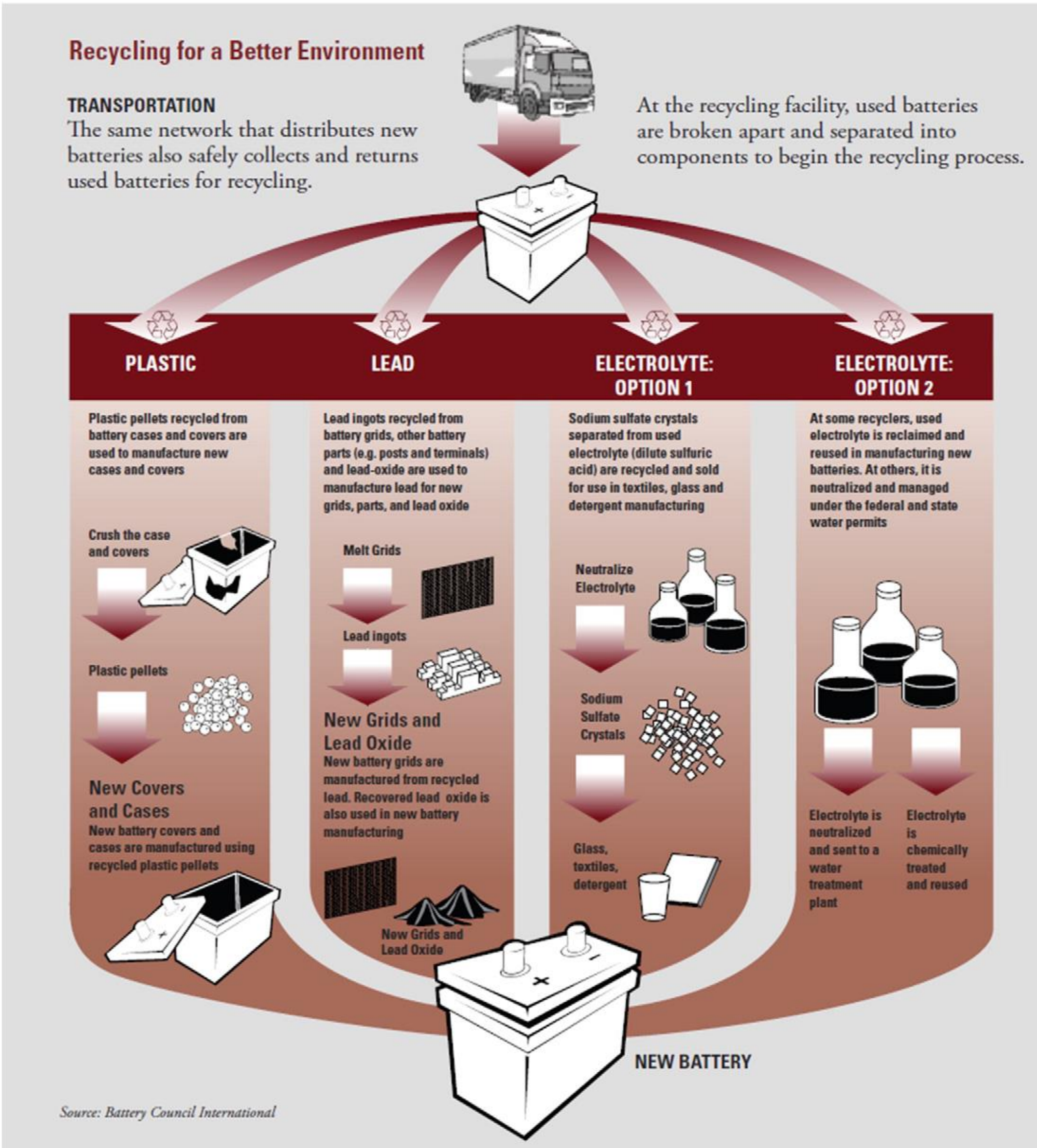

Figure 14 Lead-acid batteries recycle (13)

Nickel-metal-hydride batteries (which include earth rare elements) are used in hybrid cars. Ni-MH batteries all have similar chemistry structure and mix of earth rare elements in the hydride may slightly. Some companies recover earth rare from Ni-MH batteries(13).

Lithium-ion battery recycling is more complicated than Pb-acid and Ni-MH battery recycling. Each coil of Li-ion battery has a lot of materials of which active materials are in form of powder, covered into metal foil and during the recycling these different materials are separated from each other. Generally, Li-ion battery recycle has three types. First one is pyro metallurgical recycling, which is a fed to a high temperature shaft furnace. The electrolyte and plastics burn to supply of energy. Next one is intermediate recycling process, in which batteries go to size reduction which is hammer mill then goes to shaker table after being mixed with plastics and metals. Last one is a direct recycling process, in which recovered battery materials are reinserted to the battery supply chain with no additional processing(14) .

Although battery recycling has some benefits, there are also a few problems. Li-ion batteries in the input stream of secondary lead smelter can cause fires and explosions. For the Pb-acid batteries, the cost is high. Recyclers have to pay for their desired input material. The used batteries to recyclers in huge loads about 3000/h to 70000/day(13).

The future of recycling batteries is bright. Next years, recycling process is likely to improve and other types of batteries will be needed. In future, batteries tend to be recycled in different ways with easy processing and less cost. Generally, we should avoid irreversible and not recycled materials(13).

A.M. Bernardes, D.C.R. Espinosa and J.A.S. Tenorio studied the “Recycling batteries: a review of current processes and technologies”. Last two decade, recycle batteries has been very good process. During this period a lot of research paper published. A.M. Bernardes, D.C.R. Espinosa and J.A.S. Tenorio’ research paper mainly dedicated collection, sorting, disposal and technologies applied to recycle portable batteries(15).

A.M. Bernardes, D.C.R. Espinosa and J.A.S. Tenorio determined a battery is an electrochemical device, which has ability to convert chemical energy to electrical energy. The general battery consists of an anode, a cathode, an electrolyte, separators and the external case. The difference of different battery types is the materials used as electrodes and electrolytes. The potentially hazardous batteries include mercury, lead, copper, zinc, cadmium, manganese, nickel and lithium. The household type battery is we used in daily items such as telephones, TV, radios and so on. Basically there are two types of household batteries single use primary cells and rechargeable secondary cells(16). Single use primary batteries are mostly zinc-carbon and alkaline-manganese batteries. Typical sizes are AAA, AA, C, D and 9V(17).

The zinc-carbon batteries contain zinc electrode, which used to have lead concentrations from 0.05 to 0.5% and the cadmium from 0.01 to 0.05%. That kind of batteries may contain mercury, which used to coat the zinc electrode to reduce corrosion and enhance battery performance. NiCd (nickel-cadmium), NiMH (nickel-metal-hydride) batteries are typical household batteries. NiCd battery is considered one of the most hazardous in terms of disposal. NiMH batteries are more upgraded version of NiCd. NiMH batteries are environmentally friendly and can replace NiCd in many applications. Li-ion (primary lithium) batteries are new and rechargeable battery. Li-ion batteries contain none toxic metals that is why demand was high in the 1990s(18).

A.M. Bernardes, D.C.R. Espinosa and J.A.S. Tenorio mentioned alternatives of final disposition of batteries. These are landfill, stabilization, incineration and recycling. About recycling is hydrometallurgical and pyrometallurgical processes can recycle metals present in the batteries. The release metals from battery into landfill is quite challenging. The main issue is metals to contaminate the groundwater. The incineration of batteries also poses two major environmental concerns. First one is the release of metals into the ambient air and the second is the concentration of metals in the ashes that must be landfilled(15).

By the time people can realize recycling of battery has environmental benefits. Then some countries started collect and sort batteries. Alkaline and zinc-carbon batteries collected then to minimize the impact associated. After the collecting, in the steel industry separate the materials for recycling process. This process has significant benefit for environment, which is avoid additional transportation emissions. Some European countries installed the battery collection boxes. The result of the collection was good but it is depending on the behavior of consumers. Batteries weight is not so heavy. After collecting process, they should sort by magnetic properties, mass and size. First a high-speed battery sorting machine was operated in Netherlands. The process has 99% accuracy but sensor can identify one battery each 2 seconds. That rate is slow. After development a modern sorting machine has also 99% accuracy and at the rate of 24 batteries/s(15).

Batteries recycling processes are generally divided to hydrometallurgical and pyrometallurgical. Pyrometallurgical processes are usually associated with the production of steel, ferromanganese and other metallic alloys. In pyrolysis furnaces control the atmosphere and apply pre-treatment step to remove mercury and organic matter such as paper, plastic. Hydrometallurgical processes are connected with leaching in acid or alkaline medium and purification processes. Recover metal solutions, which could use by the chemical industry(15).

Hydrometallurgical process is efficient method for recovering metals from raw materials. One company name is MMM-Sedema is located in Belgium. In this company recycling of zinc-carbon and manganese-alkaline batteries. The batteries recover a metallic fraction by using mechanical process. The wastes consist of a black powder composed of carbon, manganese and zinc. When powder is leached, a solution is rich of manganese and zinc produced(15).

Pyrometallurgical processes, there are two possibilities. First one is use batteries as a raw material. One of good process of battery recycling is steel production. In this case metals from batteries such as iron, chromium, nickel and manganese, can be used as feed materials in steel industry. Some hazardous compounds such as cadmium, copper and zinc are diluted during this process. Utilization of batteries as a raw material in steel production is restricted to batteries without mercury and pre-sorted. Next one is created processes for especially for batteries. That processes consist of three techniques. Pyrolysis: Water and mercury evaporated, separated and condensed. Organic compounds are destroyed then emitted as a gas together with the water. Reduction: After pyrolysis process some metallic fraction remains in the furnace. This remain fraction going to be treated by reduction at temperatures around 1500 degree Celsius. Incineration: After reduction process, the gas generated in pyrolysis is incinerated at temperature around 1000 degree Celsius. The sludge generated on the process contains mercury and should be treated by distillation(15).

3. BATTERY IN MONGOLIA

Mongolia has imported all type of battery from other countries. According to the Mongolian Customs' data, totally 49 countries import to Mongolia all kind of batteries.

Country	Quantity									
	Year									
	2010	2011	2012	2013	2014	2015	2016	2017	2018	Total
Albania								460.00		460.00
Australia	.03	24.25	.10	.65	.25	.02	10.02	.02	.09	35.43
Belgium	30.31	22.86	57.99	20.91	21.53	50.54	90.60		.31	295.05
Canada	.03	.03	3.02	3.03					.01	6.12
China	1798.24	18828.49	2190.01	4600.66	2115.98	3339.88	4880.95	9098.59	6929.49	53782.29
Columbia									24.00	24.00
Czech Republic				.04	.30	.11			.05	.50
Denmark		.01	.26	.01	.70	.69	10.80	.64	.82	13.93
Estonia			.10							.10
Federal Republic of Germany	6103.46	97.46	70.99	708.95	145.29	89.22	197.71	1971.47	170.16	9554.71
Finland						12.00				12.00
France	.65	.01	1.02	.05	.04			.16		1.93
Hong Kong	185.44	701.59	139.53	89.88	.14	53.66	.29	87.36	3.12	1261.01
Hungary								.70		.70
India				.62						.62
Indonesia	57.01	12.21	24.22	106.01	439.32	85.23	158.95	143.53	516.00	1542.48
Ireland	.01							.02		.03
Israel	.09	.15	50.15	60.38	.17	.18	.26	.33	1.18	112.89
Italy		.52						.02	.10	.64
Japan	10.38	14.06	.73	23.11	31.42	118.99	28.78	235.44	76.68	539.59
Lithuania							.01			.01
Malaysia	7.29	17.03	9.27	15.16	24.72	15.25	29.48	23.02	28.01	169.23
Mexico	.01		.01					.18		.20
Netherlands					1.00	.04				1.04

New Zealand		.04	.01		.03		.01			.09
Philippines									.01	.01
Poland									.02	.02
Republic of Korea	3.60	64.61	107.29	91.81	20280.21	84.80	118.44	123.83	140.37	21014.96
Republic of South Africa			.01							.01
Russian Federation			.01			1.00		.07		1.08
Singapore	150.19	28.49	24.70	100.21	3.72	18.40	538.69	153.02	75.27	1092.69
Spain			.09	.11	.01	.02		.02	.02	.27
Swaziland									.01	.01
Sweden									.02	.02
Switzerland	.05	.01	34.75	.04	.01				7.90	42.76
Taiwan	.14	.06	.05	.01	.02	6.04	.12	.02		6.46
Thailand		5.00	1.06	2.69	8.06	6.05	.03	50.35	27.38	100.62
United Arab Emirates						.16				.16
United Kingdom	1.07	.01	.03	.02	76.02			1.68	.03	78.86
United States of America	76.42	397.02	3147.92	44.82	1285.13	61.14	24.55	91.47	37.51	5165.98
Vietnam					.01	3.06	.10			3.17
Total	8424.42	20213.91	5863.32	5869.17	24434.08	3946.48	6089.79	12441.94	8038.56	95321.67

Table 2 Imported batteries by year and country

In this table we can see last ten years of total batteries imported to Mongolia including all 33 exporter countries. Mongolia has mainly imported lithium-ion and manganese dioxide batteries from United States of America, China, Republic of Korea, Indonesia, Singapore, and Federal Republic of Germany and so on. The unit is thousand pieces.

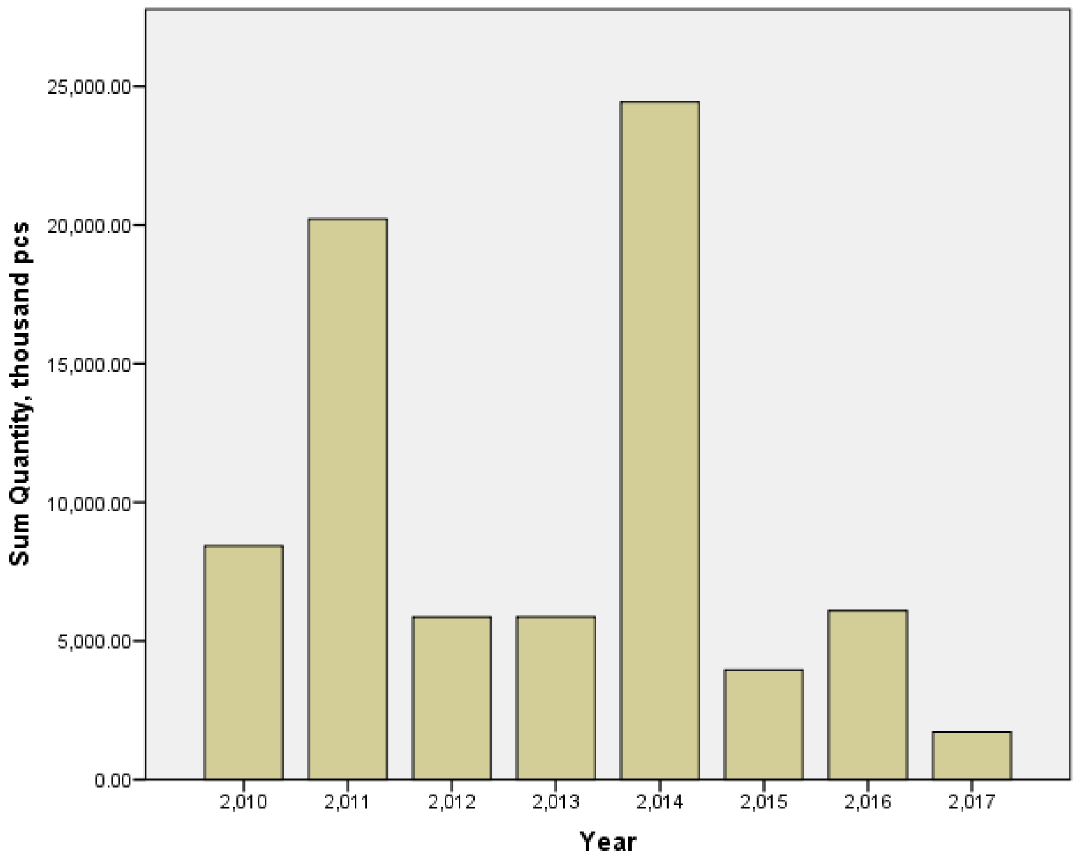

Figure 15 Battery amounts by year

In this bar chart show us all type of batteries consumption year by year. From this chart, years 2011 and 2014 our battery consumption was high due to the increase usage of automobile cars and electron products.

Sum

Year	Quantity							
	Type batteries							
	Lithium-ion	Manganese dioxide	Mercury battery	Other element and batteries	Parts	Silver oxide	Zinc-air	Total
2010	165.31	23.24		2104.53	65.00		6066.34	8424.42
2011	74.34	26.77		20060.35	6.10	.01	46.34	20213.91
2012	376.27	3236.04		2160.49	.09		90.43	5863.32
2013	747.09	2069.01		2873.81	.62	15.26	163.38	5869.17
2014	38.10	347.91		13884.52	1.00	.03	10162.52	24434.08
2015	16.56	88.20		3766.78	1.00	9.00	64.94	3946.48
2016	3.22	167.98		5839.40	.01		79.18	6089.79
2017	145.92	477.08		9917.12	.01	.11	1901.70	12441.94
2018	52.39	246.98	11.70	7626.52	.01	9.80	91.16	8038.56
Total	1619.20	6683.21	11.70	68233.52	73.84	34.21	18665.99	95321.67

Table 3 Imported different battery types

This table is imported battery types and quantities of last decade. Most of them belong to other elements and batteries section. That kind of batteries not same as lithium-ion, manganese dioxide and mercury batteries.

Year	**Lithium-ion quantity [thousand pcs]**
2010	165.31
2011	74.34
2012	376.27
2013	747.09
2014	38.10
2015	16.56
2016	3.22
2017	145.92
2018	52.39
Total	1619.20

Table 4 Lithium-ion imported batteries year by year

In this table, totally how many batteries imported to Mongolia in last 9 years.

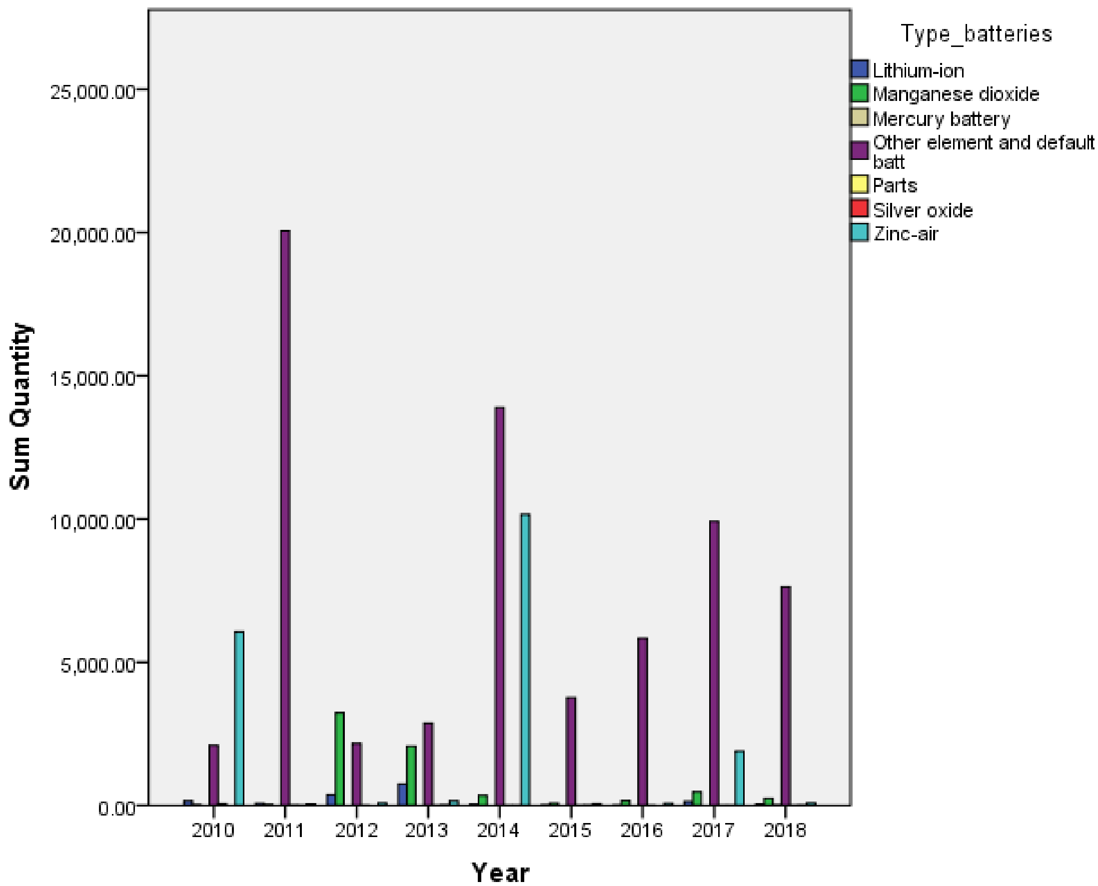

Figure 16 Imported types of batteries by year

According to the figure 16, most of imported batteries are belong to other elements and batteries. Moreover zinc-air, manganese dioxide and lithium-ion batteries numbers are high. However, last four years usage of battery is decreasing compare to the 10 years ago.

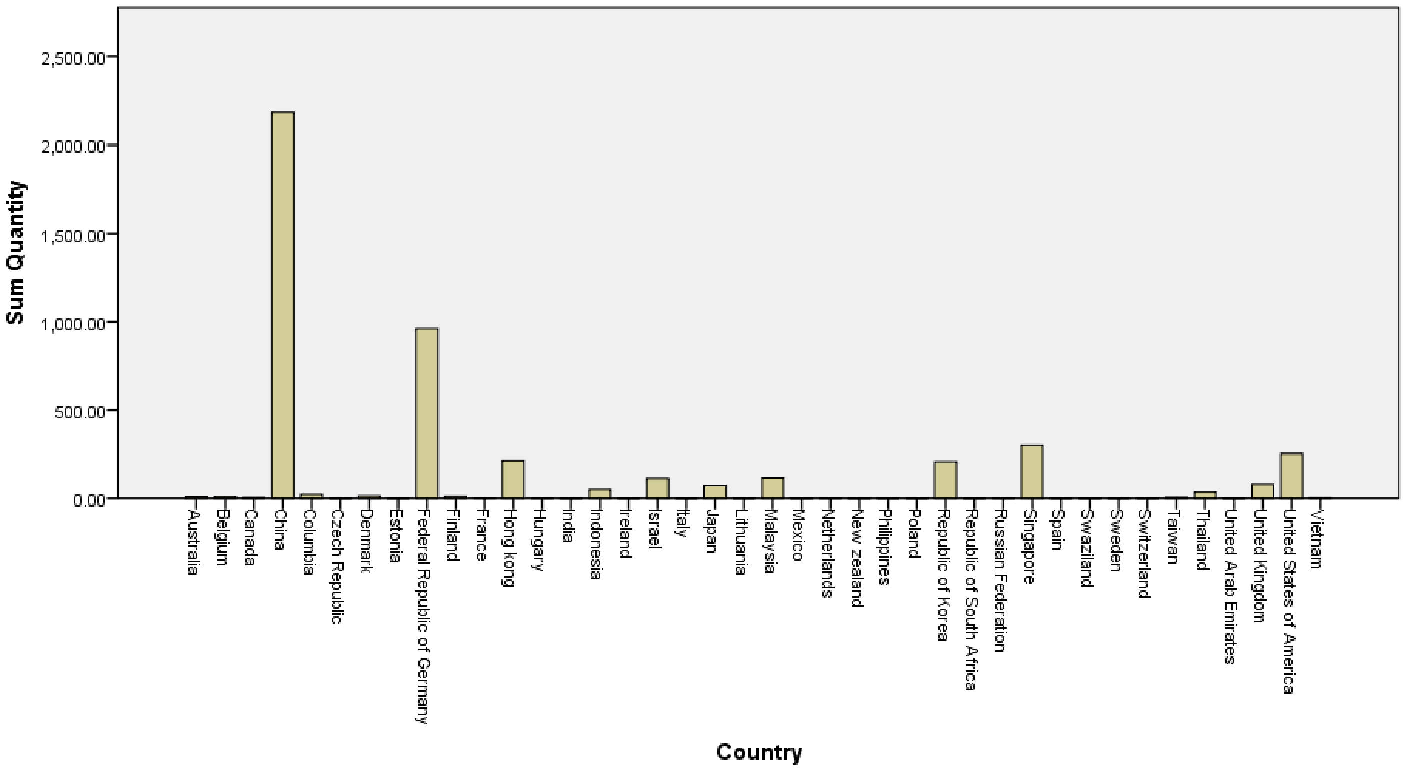

Figure 17 Lithium-ion battery exporter country

In this bar chart illustrate exporter countries of lithium-ion battery with numbers. According to the chart China, Federal Republic of Germany, Singapore, Republic of Korea and United States of America are main exporter countries. They are good developed countries and besides producer of high qualified battery.

4. METHODOLOGY

The data was collected from the Mongolian Customs. Mongolian Customs provide us data of consumption of battery in last 10 years. From life ended lithium-ion battery, to get new lithium-ion battery and only lithium.

Three different charges of Li-ion battery scrap are processed. Two of them are pure production types with different manganese components. These two are used in laboratory tests. Last one is mixture of spent Li-ion battery with no manganese content. This charge is used in technical-scale.

First step, during pre-treatment the Li-ion batteries pack disassembled then battery cells are laid open. Thus, a material fraction is generated, a material fraction consists of electronic parts and plastics. Because the copper content of this material fraction can be considered as valuable secondary raw material. Best solution is to sell the companies that are specialized in copper recycling.

The second process step include a pyrolysis, which can resistance heated furnace at temperature of maximum 250 degree Celsius. The battery cells deactivated carefully and volatile organic electrolyte vanishes in a downstream condenser.

In the third process step the deactivated cells are into crushed safely in a second mill and in a disintegrator. After this step, a classification and sorting are complete by vibrating screen, magnetic separation in a drum separator and air separation in zigzag classifier. An electrode foil fraction and a fine fraction which contains electrode materials, from battery casing an iron-nickel and an aluminum are generated material fractions(19).

Figure 18 Metal containing material fractions (from left to right; iron-nickel fraction, aluminum fraction, electrode foil fraction) (18)

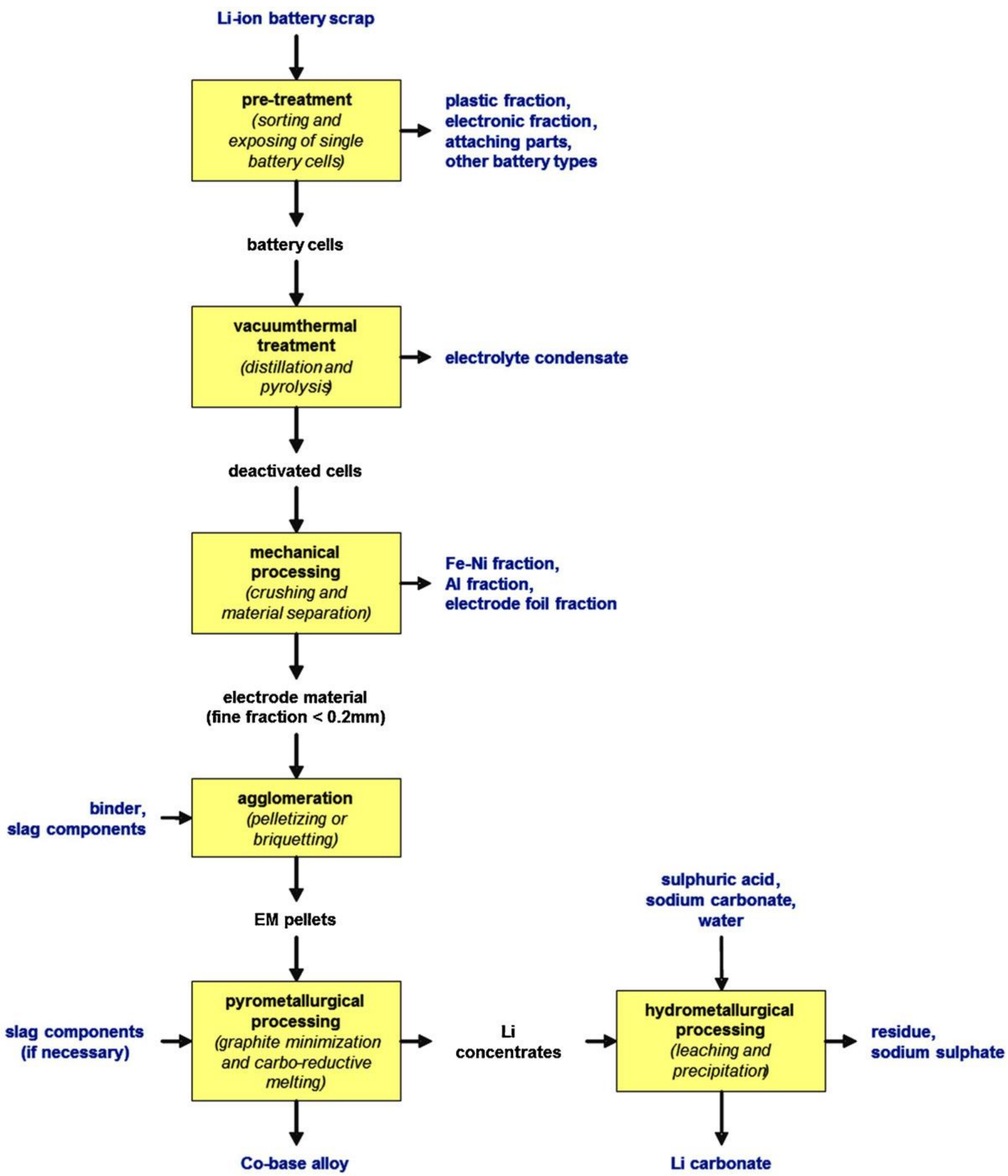

Figure 19 Alternate recycling process of Li-ion batteries (18)

5. RESULT AND DISCUSSION

Mongolian Customs provided us the data of numbers of batteries imported to Mongolia and what countries imported to our country. In the tables contain types of batteries and quantity of these types. The types are only: manganese dioxide, mercury battery, silver oxide, lithium-ion, zinc-air, other element default batteries and other parts. That means very challenging to discuss about Mongolian battery consumption. Because data is not including sufficient information about battery types and quantity.

Brief information can be read from the table. For instance, in 2018, total 8038.55 thousand pieces batteries imported to Mongolia. 246.98 thousand pieces of them are manganese dioxide, 11.7 thousand pieces are mercury batteries, 9.8 thousand pieces are silver oxide, 52.37 thousand pieces are lithium-ion batteries and 91.16 thousand pieces are zinc-air batteries. Rest batteries are belonging to other elements and default batteries section and related to some parts. About the countries, China imported 6929.49 thousand pieces batteries to Mongolia. Most of them are belong to other elements and default battery. Indonesia imported to Mongolia 515.99 thousand pieces batteries. 170.16 thousand pieces batteries imported to Mongolia from Federal Republic of Germany. Republic of Korea imported 140.37 thousand pieces batteries imported to Mongolia in 2018. Large number of them are zinc-air batteries. Moreover, another big country such as Japan, United States of America, and Singapore are import huge number of different batteries in every year.

Moreover, the average size of lithium-ion battery is 18mm x 65.2mm. Last 10 years of consumption lithium-ion battery was 179.91 thousand pieces. If we consider all of these batteries will landfill, need 211.1423 meters square area. If we can recycle these batteries, can reduce the landfill area.

6. CONCLUSION

Mongolia has imported 100% of all types of battery from other countries. Also, there is no official landfill sites and recycling process plants. Then about 50 countries import to Mongolia all kind of batteries, including manganese dioxide, lithium-ion, zinc-air, silver oxide and so on. In this case not good at Mongolian economy.

In this study, we identification all types batteries used in Mongolia and general information of battery, how it is work. In other chapters research how recycle batteries in other developed countries. We study many different processes of recycle battery, mostly lithium-ion batteries. According to the result, lithium-ion battery is one of the common battery types used in Mongolia. We aim to determine types and actual amount of battery has been used since 1980. But it is impossible to determine all batteries since 1980. Mongolia Customs provide us data of battery types and amount between 2011 and 2018. Moreover, that data not sufficient to determine all types of battery.

Nowadays, a lot of recycling process proceed in worldwide. Many of them possible to use in Mongolia.

7. RECOMMENDATIONS FOR FUTURE RESEARCH

For future research related to the battery used in Mongolia, firstly to determine the all kind of batteries used in Mongolia. Mongolian Customs will support for this task, but it is difficult to catch exactly correct number and information.

Next key point is laboratory experiment and survey. In the laboratory we can do various experiments, such as compare energy output of old and new batteries. Take a survey is also main part of successful research. Acquire an information from a survey, how people landfill the batteries, how many batteries do the people use for a week.

In Mongolia has no official landfill sites and recycling plant. Then the future research works are strongly dedicated for developing recycling processes.

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9. APPENDIX

Year	Battery types	Exporter countries	quantity [thousand pieces]
2018	Manganese dioxide	China	104.39
	Manganese dioxide	Singapore	70.25
	Manganese dioxide	United States of America	30.21
	Manganese dioxide	Indonesia	20.63
	Manganese dioxide	Thailand	17.30
	Manganese dioxide	Hong Kong	1.61
	Manganese dioxide	Japan	1.31
	Manganese dioxide	Federal Republic of Germany	1.07
	Manganese dioxide	Belgium	0.14
	Manganese dioxide	Republic of Korea	0.06
	Manganese dioxide	Malaysia	0.01
	Mercury battery	Republic of Korea	11.70
	Silver oxide	Switzerland	7.90
	Silver oxide	Japan	1.90
	Lithium-ion	Republic of Korea	16.24
	Lithium-ion	China	16.12
	Lithium-ion	Federal Republic of Germany	11.10
	Lithium-ion	Singapore	5.02
	Lithium-ion	Japan	1.20
	Lithium-ion	Israel	1.18
	Lithium-ion	Denmark	0.82
	Lithium-ion	Indonesia	0.36
	Lithium-ion	Belgium	0.17
	Lithium-ion	Czech Republic	0.05
	Lithium-ion	Spain	0.02
	Lithium-ion	Sweden	0.02
	Lithium-ion	United Kingdom	0.02

	Lithium-ion	Italy	0.02
	Lithium-ion	United States of America	0.02
	Lithium-ion	Australia	0.01
	Lithium-ion	Philippines	0.01
	Lithium-ion	Swaziland	0.01
	Lithium-ion	Lithuania	0.00
	Lithium-ion	Hong Kong	0.00
	Zinc-air	Republic of Korea	91.16
	Other element and batteries	China	6,808.98
	Other element and batteries	Indonesia	495.01
	Other element and batteries	Federal Republic of Germany	157.98
	Other element and batteries	Japan	72.27
	Other element and batteries	Malaysia	28.00
	Other element and batteries	Columbia	24.00
	Other element and batteries	Republic of Korea	21.21
	Other element and batteries	Thailand	10.08
	Other element and batteries	United States of America	7.28
	Other element and batteries	Hong Kong	1.51
	Other element and batteries	Italy	0.08
	Other element and batteries	Australia	0.08
	Other element and batteries	Poland	0.02
	Other element and batteries	Canada	0.01
	Other element and batteries	United Kingdom	0.01
	Other element and batteries	Taiwan	0.00
	Other element and batteries	Sweden	0.00
	Other element and batteries	Ireland	0.00
	Other element and batteries	Belarus	0.00
	Other element and batteries	Vietnam	0.00
	Other element and batteries	France	0.00
	Other element and batteries	Switzerland	0.00

	Parts	Federal Republic of Germany	0.01
	Parts	China	0.00

Table 5 Type and quantity of batteries imported in 2018

Year	Battery types	Exporter countries	quantity [thousand pieces]
2017	Manganese dioxide	Singapore	153.00
	Manganese dioxide	China	150.67
	Manganese dioxide	United States of America	79.97
	Manganese dioxide	Thailand	47.09
	Manganese dioxide	Indonesia	44.65
	Manganese dioxide	Hong Kong	1.21
	Manganese dioxide	Japan	0.42
	Manganese dioxide	Russian Federation	0.07
	Silver oxide	China	0.10
	Silver oxide	United States of America	0.01
	Lithium-ion	Federal Republic of Germany	99.41
	Lithium-ion	China	34.61
	Lithium-ion	Republic of Korea	5.76
	Lithium-ion	Indonesia	3.22
	Lithium-ion	Japan	1.18
	Lithium-ion	Denmark	0.64
	Lithium-ion	Hong Kong	0.57
	Lithium-ion	Israel	0.33
	Lithium-ion	United Kingdom	0.06
	Lithium-ion	United States of America	0.04
	Lithium-ion	France	0.03
	Lithium-ion	Italy	0.02
	Lithium-ion	Spain	0.02
	Lithium-ion	Taiwan	0.01
	Lithium-ion	Ireland	0.01

	Lithium-ion	Australia	0.01
	Lithium-ion	New Zealand	0.00
	Lithium-ion	Norway	0.00
	Zinc-air	Federal Republic of Germany	1,807.86
	Zinc-air	Republic of Korea	93.24
	Zinc-air	United Kingdom	0.60
	Other element and batteries	China	8,913.20
	Other element and batteries	Albania	460.00
	Other element and batteries	Japan	233.84
	Other element and batteries	Indonesia	95.66
	Other element and batteries	Hong Kong	85.58
	Other element and batteries	Federal Republic of Germany	64.20
	Other element and batteries	Republic of Korea	24.83
	Other element and batteries	Malaysia	23.02
	Other element and batteries	United States of America	11.45
	Other element and batteries	Thailand	3.26
	Other element and batteries	United Kingdom	1.02
	Other element and batteries	Hungary	0.70
	Other element and batteries	Mexico	0.18
	Other element and batteries	France	0.13
	Other element and batteries	Singapore	0.02
	Other element and batteries	Ireland	0.01
	Other element and batteries	Australia	0.01
	Other element and batteries	Taiwan	0.01
	Other element and batteries	Finland	0.00
	Other element and batteries	Netherlands	0.00
	Other element and batteries	Vietnam	0.00
	Other element and batteries	Belarus	0.00
	Parts	China	0.01

Table 6 Type and quantity of batteries imported in 2017

Year	Battery types	Exporter countries	quantity [thousand pieces]
2016	Manganese dioxide	Belgium	90.60
	Manganese dioxide	China	39.18
	Manganese dioxide	Indonesia	31.47
	Manganese dioxide	United States of America	2.38
	Manganese dioxide	Federal Republic of Germany	1.58
	Manganese dioxide	Republic of Korea	1.50
	Manganese dioxide	Malaysia	1.08
	Manganese dioxide	Japan	0.19
	Lithium-ion	Denmark	1.00
	Lithium-ion	China	0.81
	Lithium-ion	Republic of Korea	0.35
	Lithium-ion	Israel	0.26
	Lithium-ion	Indonesia	0.19
	Lithium-ion	Hong Kong	0.16
	Lithium-ion	Federal Republic of Germany	0.16
	Lithium-ion	United States of America	0.13
	Lithium-ion	Japan	0.11
	Lithium-ion	Thailand	0.03
	Lithium-ion	Australia	0.01
	Lithium-ion	Singapore	0.01
	Lithium-ion	United Kingdom	0.00
	Lithium-ion	New Zealand	0.00
	Lithium-ion	Switzerland	0.00
	Zinc-air	Republic of Korea	75.36
	Zinc-air	Singapore	2.62
	Zinc-air	Indonesia	1.20
	Other element and batteries	China	4,840.95
	Other element and batteries	Singapore	536.06
	Other element and batteries	Federal Republic of Germany	195.97

	Other element and batteries	Indonesia	126.09
	Other element and batteries	Republic of Korea	41.23
	Other element and batteries	Japan	28.48
	Other element and batteries	Malaysia	28.40
	Other element and batteries	United States of America	22.04
	Other element and batteries	Australia	10.01
	Other element and batteries	Denmark	9.80
	Other element and batteries	Hong Kong	0.13
	Other element and batteries	Taiwan	0.12
	Other element and batteries	Vietnam	0.10
	Other element and batteries	Lithuania	0.01
	Other element and batteries	New Zealand	0.01
	Other element and batteries	France	0.00
	Other element and batteries	United Kingdom	0.00
	Other element and batteries	Ireland	0.00
	Other element and batteries	Sweden	0.00
	Parts	China	0.01

Table 7 Type and quantity of batteries imported in 2016

Year	Battery types	Exporter countries	quantity [thousand pieces]
2015	Manganese dioxide	Belgium	50.54
	Manganese dioxide	United States of America	20.85
	Manganese dioxide	Indonesia	9.80
	Manganese dioxide	China	6.60
	Manganese dioxide	Republic of Korea	0.20
	Manganese dioxide	Japan	0.11
	Manganese dioxide	Federal Republic of Germany	0.10
	Manganese dioxide	Romania	0.00
	Silver oxide	United States of America	9.00
	Lithium-ion	Taiwan	6.00
	Lithium-ion	United States of America	3.02
	Lithium-ion	Vietnam	3.00
	Lithium-ion	Republic of Korea	2.01
	Lithium-ion	China	1.43
	Lithium-ion	Denmark	0.69
	Lithium-ion	Israel	0.18
	Lithium-ion	Japan	0.11
	Lithium-ion	Netherlands	0.04
	Lithium-ion	Hong Kong	0.04
	Lithium-ion	Federal Republic of Germany	0.03
	Lithium-ion	Australia	0.01
	Lithium-ion	Mexico	0.00
	Lithium-ion	Singapore	0.00
	Lithium-ion	Sweden	0.00
	Lithium-ion	United Kingdom	0.00
	Lithium-ion	Liechtenstein	0.00
	Zinc-air	Republic of Korea	64.92
	Zinc-air	Spain	0.01
	Zinc-air	China	0.01

	Other element and batteries	China	3,331.84
	Other element and batteries	Japan	118.77
	Other element and batteries	Federal Republic of Germany	89.09
	Other element and batteries	Indonesia	75.43
	Other element and batteries	Hong Kong	53.62
	Other element and batteries	United States of America	28.27
	Other element and batteries	Singapore	18.40
	Other element and batteries	Republic of Korea	17.67
	Other element and batteries	Malaysia	15.25
	Other element and batteries	Finland	12.00
	Other element and batteries	Thailand	6.05
	Other element and batteries	United Arab Emirates	0.16
	Other element and batteries	Czech Republic	0.11
	Other element and batteries	Vietnam	0.06
	Other element and batteries	Taiwan	0.04
	Other element and batteries	Spain	0.01
	Other element and batteries	Australia	0.01
	Other element and batteries	France	0.00
	Other element and batteries	United Kingdom	0.00
	Other element and batteries	Switzerland	0.00
	Other element and batteries	New Zealand	0.00
	Other element and batteries	Italy	0.00
	Parts	Russian Federation	1.00

Table 8 Type and quantity of batteries imported in 2015

Year	Battery types	Exporter countries	quantity [thousand pieces]
2014	Manganese dioxide	Indonesia	287.44
	Manganese dioxide	Belgium	20.89
	Manganese dioxide	Japan	20.02
	Manganese dioxide	China	10.32
	Manganese dioxide	Malaysia	8.41
	Manganese dioxide	United States of America	0.72
	Manganese dioxide	Republic of Korea	0.10
	Manganese dioxide	Federal Republic of Germany	0.01
	Silver oxide	Japan	0.02
	Silver oxide	United States of America	0.01
	Lithium-ion	Republic of Korea	17.37
	Lithium-ion	China	11.26
	Lithium-ion	Japan	4.30
	Lithium-ion	United States of America	4.02
	Lithium-ion	Denmark	0.70
	Lithium-ion	Israel	0.15
	Lithium-ion	Malaysia	0.10
	Lithium-ion	Hong Kong	0.06
	Lithium-ion	Indonesia	0.05
	Lithium-ion	Australia	0.03
	Lithium-ion	Federal Republic of Germany	0.02
	Lithium-ion	Spain	0.01
	Lithium-ion	France	0.01
	Lithium-ion	Switzerland	0.01
	Lithium-ion	United Kingdom	0.01
	Lithium-ion	Poland	0.00
	Lithium-ion	Canada	0.00
	Zinc-air	Republic of Korea	10,162.50
	Zinc-air	Hong Kong	0.02

	Other element and batteries	Republic of Korea	10,100.24
	Other element and batteries	China	2,093.40
	Other element and batteries	United States of America	1,280.38
	Other element and batteries	Indonesia	151.83
	Other element and batteries	Federal Republic of Germany	145.26
	Other element and batteries	United Kingdom	76.01
	Other element and batteries	Malaysia	16.21
	Other element and batteries	Thailand	8.06
	Other element and batteries	Japan	7.08
	Other element and batteries	Singapore	3.72
	Other element and batteries	Netherlands	1.00
	Other element and batteries	Belgium	0.64
	Other element and batteries	Czech Republic	0.30
	Other element and batteries	Australia	0.22
	Other element and batteries	Hong Kong	0.06
	Other element and batteries	New Zealand	0.03
	Other element and batteries	France	0.03
	Other element and batteries	Taiwan	0.02
	Other element and batteries	Israel	0.02
	Other element and batteries	Vietnam	0.01
	Other element and batteries	Russian Federation	0.00
	Other element and batteries	Canada	0.00
	Other element and batteries	Malta	0.00
	Other element and batteries	Sweden	0.00
	Other element and batteries	Bulgaria	0.00
	Parts	China	1.00

Table 9 Type and quantity of batteries imported in 2014

Year	Battery types	Exporter countries	quantity [thousand pieces]
2013	Manganese dioxide	China	1,941.06
	Manganese dioxide	Indonesia	103.50
	Manganese dioxide	Belgium	20.28
	Manganese dioxide	Malaysia	3.00
	Manganese dioxide	United States of America	0.93
	Manganese dioxide	Republic of Korea	0.20
	Manganese dioxide	Japan	0.03
	Manganese dioxide	Federal Republic of Germany	0.01
	Silver oxide	Japan	8.50
	Silver oxide	China	5.76
	Silver oxide	Hong Kong	1.00
	Lithium-ion	Federal Republic of Germany	640.51
	Lithium-ion	Israel	60.30
	Lithium-ion	Hong Kong	25.34
	Lithium-ion	Republic of Korea	12.04
	Lithium-ion	Japan	3.76
	Lithium-ion	China	3.03
	Lithium-ion	Singapore	1.08
	Lithium-ion	United States of America	0.68
	Lithium-ion	Australia	0.14
	Lithium-ion	Indonesia	0.13
	Lithium-ion	France	0.05
	Lithium-ion	Canada	0.02
	Lithium-ion	Denmark	0.01
	Lithium-ion	Belgium	0.00
	Lithium-ion	Taiwan	0.00
	Lithium-ion	Hungary	0.00
	Zinc-air	Republic of Korea	70.68
	Zinc-air	Hong Kong	63.36

	Zinc-air	Singapore	19.24
	Zinc-air	Japan	10.10
	Other element and batteries	China	2,650.81
	Other element and batteries	Singapore	79.89
	Other element and batteries	Federal Republic of Germany	68.43
	Other element and batteries	United States of America	43.21
	Other element and batteries	Malaysia	12.16
	Other element and batteries	Republic of Korea	8.89
	Other element and batteries	Canada	3.01
	Other element and batteries	Thailand	2.69
	Other element and batteries	Indonesia	2.38
	Other element and batteries	Japan	0.72
	Other element and batteries	Belgium	0.63
	Other element and batteries	Australia	0.51
	Other element and batteries	Hong Kong	0.18
	Other element and batteries	Spain	0.11
	Other element and batteries	Israel	0.08
	Other element and batteries	Czech Republic	0.04
	Other element and batteries	Switzerland	0.04
	Other element and batteries	United Kingdom	0.02
	Other element and batteries	Taiwan	0.01
	Other element and batteries	Netherlands	0.00
	Other element and batteries	Turkey	0.00
	Other element and batteries	France	0.00
	Other element and batteries	Denmark	0.00
	Parts	India	0.62
	Parts	United States of America	0.00
	Parts	China	0.00

Table 10 Type and quantity of batteries imported in 2013

Year	Battery types	Exporter countries	quantity [thousand pieces]
2012	Manganese dioxide	United States of America	3,019.94
	Manganese dioxide	China	104.52
	Manganese dioxide	Belgium	57.99
	Manganese dioxide	Switzerland	34.63
	Manganese dioxide	Singapore	10.68
	Manganese dioxide	Malaysia	6.00
	Manganese dioxide	Indonesia	2.28
	Lithium-ion	China	310.17
	Lithium-ion	Israel	50.02
	Lithium-ion	Republic of Korea	9.42
	Lithium-ion	Federal Republic of Germany	3.03
	Lithium-ion	Singapore	2.02
	Lithium-ion	United States of America	1.01
	Lithium-ion	Denmark	0.24
	Lithium-ion	Indonesia	0.15
	Lithium-ion	Estonia	0.10
	Lithium-ion	Japan	0.05
	Lithium-ion	United Kingdom	0.02
	Lithium-ion	France	0.02
	Lithium-ion	Russian Federation	0.01
	Lithium-ion	Taiwan	0.01
	Zinc-air	Republic of Korea	90.42
	Zinc-air	Mexico	0.01
	Other element and batteries	China	1,775.23
	Other element and batteries	Hong Kong	139.53
	Other element and batteries	United States of America	126.97
	Other element and batteries	Federal Republic of Germany	67.96
	Other element and batteries	Indonesia	21.79
	Other element and batteries	Singapore	12.00

	Other element and batteries	Republic of Korea	7.45
	Other element and batteries	Malaysia	3.27
	Other element and batteries	Canada	3.02
	Other element and batteries	Thailand	1.06
	Other element and batteries	France	1.00
	Other element and batteries	Japan	0.68
	Other element and batteries	Israel	0.13
	Other element and batteries	Switzerland	0.12
	Other element and batteries	Australia	0.10
	Other element and batteries	Spain	0.09
	Other element and batteries	Taiwan	0.04
	Other element and batteries	Denmark	0.02
	Other element and batteries	United Kingdom	0.01
	Other element and batteries	Republic of South Africa	0.01
	Other element and batteries	New Zealand	0.01
	Other element and batteries	Mexico	0.00
	Other element and batteries	Italy	0.00
	Other element and batteries	Turkey	0.00
	Parts	China	0.09
	Parts	United Kingdom	0.00
	Parts	United States of America	0.00

Table 11 Type and quantity of batteries imported in 2012

Year	Battery types	Exporter countries	quantity [thousand pieces]
2011	Manganese dioxide	Belgium	22.86
	Manganese dioxide	China	3.08
	Manganese dioxide	Indonesia	0.77
	Manganese dioxide	United States of America	0.05
	Manganese dioxide	Switzerland	0.01
	Manganese dioxide	Poland	0.00
	Manganese dioxide	Federal Republic of Germany	0.00
	Silver oxide	United States of America	0.01
	Lithium-ion	United States of America	50.02
	Lithium-ion	China	10.40
	Lithium-ion	Singapore	6.00
	Lithium-ion	Thailand	5.00
	Lithium-ion	Republic of Korea	1.52
	Lithium-ion	Japan	1.04
	Lithium-ion	Indonesia	0.20
	Lithium-ion	Israel	0.13
	Lithium-ion	Federal Republic of Germany	0.01
	Lithium-ion	Hong Kong	0.01
	Lithium-ion	Taiwan	0.01
	Lithium-ion	Mexico	0.00
	Lithium-ion	Malaysia	0.00
	Lithium-ion	Italy	0.00
	Lithium-ion	United Kingdom	0.00
	Zinc-air	Republic of Korea	46.32
	Zinc-air	United States of America	0.02
	Other element and batteries	China	18,815.01
	Other element and batteries	Hong Kong	701.58
	Other element and batteries	United States of America	340.92
	Other element and batteries	Federal Republic of Germany	97.45

	Other element and batteries	Australia	24.25
	Other element and batteries	Singapore	22.49
	Other element and batteries	Malaysia	17.03
	Other element and batteries	Republic of Korea	16.77
	Other element and batteries	Japan	13.02
	Other element and batteries	Indonesia	11.24
	Other element and batteries	Italy	0.42
	Other element and batteries	Taiwan	0.05
	Other element and batteries	New Zealand	0.04
	Other element and batteries	Canada	0.03
	Other element and batteries	Israel	0.02
	Other element and batteries	France	0.01
	Other element and batteries	United Kingdom	0.01
	Other element and batteries	Denmark	0.01
	Other element and batteries	Switzerland	0.00
	Other element and batteries	Finland	0.00
	Parts	United States of America	6.00
	Parts	Italy	0.10
	Parts	United Kingdom	0.00

Table 12 Type and quantity of batteries imported in 2011

Year	Battery types	Exporter countries	quantity [thousand pieces]
2010	Manganese dioxide	Belgium	22.18
	Manganese dioxide	China	0.91
	Manganese dioxide	Federal Republic of Germany	0.13
	Manganese dioxide	Singapore	0.01
	Manganese dioxide	France	0.01
	Lithium-ion	Hong Kong	120.51
	Lithium-ion	Indonesia	27.17
	Lithium-ion	China	11.42
	Lithium-ion	Japan	6.09
	Lithium-ion	Israel	0.05
	Lithium-ion	United States of America	0.04
	Lithium-ion	Federal Republic of Germany	0.03
	Lithium-ion	Canada	0.00
	Zinc-air	Federal Republic of Germany	6,031.00
	Zinc-air	Indonesia	22.93
	Zinc-air	Malaysia	6.32
	Zinc-air	Japan	3.36
	Zinc-air	China	2.72
	Zinc-air	Mexico	0.01
	Other element and batteries	China	1,783.18
	Other element and batteries	Singapore	150.18
	Other element and batteries	United States of America	76.15
	Other element and batteries	Federal Republic of Germany	72.29
	Other element and batteries	Belgium	8.13
	Other element and batteries	Indonesia	6.91
	Other element and batteries	Republic of Korea	3.57
	Other element and batteries	United Kingdom	1.07
	Other element and batteries	Malaysia	0.97
	Other element and batteries	Japan	0.93

	Other element and batteries	France	0.64
	Other element and batteries	Hong Kong	0.21
	Other element and batteries	Taiwan	0.14
	Other element and batteries	Switzerland	0.05
	Other element and batteries	Israel	0.04
	Other element and batteries	Canada	0.03
	Other element and batteries	Australia	0.03
	Other element and batteries	Ireland	0.01
	Other element and batteries	Denmark	0.00
	Other element and batteries	Italy	0.00
	Other element and batteries	Netherlands	0.00
	Parts	Hong Kong	64.72
	Parts	United States of America	0.23
	Parts	Republic of Korea	0.03
	Parts	Federal Republic of Germany	0.01
	Parts	China	0.01
	Parts	Australia	0.00

Table 13 Type and quantity of batteries imported in 2010