B. Tech Project Report

On

E-Waste to Energy

(Recycling of LIthium Ion Batteries)

Submitted in Partial Fulfillment for the B.Tech
Second Year Core Course on Human Geography and Societal Needs
(HS202)

By

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This is to certify that the B. Tech project titled “E waste to energy: Recycling of Lithium Ion batteries ” prepared by (Hardik, Mehakpreet, Nalin, Suryansh, Tanesh) is approved for submission for the course on Human Geography and Societal Needs in the Department of Humanities and Social Sciences, Indian Institute of Technology, Ropar.

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Declaration

We hereby declare that the report entitled "**E waste to energy: Recycling of Lithium Ion Batteries** " submitted by us, for the partial fulfilment of the course on Human Geography and Societal Needs (HS 202) in the second year of the B. Tech programme in IIT, Ropar. The work carried out by us under the supervision of Dr. Devaraj. P, Assistant Professor, Department of Humanities and Social Sciences. We further declare that this written submission represents our ideas and other's ideas or words have been included. We also have adequately cited and referenced the original sources in the case of other's ideas or words. We have not misrepresented any idea/data/fact/source to the best of our knowledge. Therefore, we affirm that our group has adhered to all principles of academic honesty and integrity.

Place: Ropar

Date: 17/05/2021

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At last we would like to convey our thanks to Mr. Yash Sakaria, our sole point of contact from the field site who provided valuable information and data to us.

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List of abbreviation:

LIB	Lithium-ion battery
Li	Lithium
Ni	Nickel
Co	Cobalt
EV	Electric vehicle
R&D	Research and Development
CapEx	Capital expenditure
OpEx	Operational expenditure
kW/h	Kilowatt per hour
GW/h	Giga watt per hour
FY	Financial year

1. Introduction and Objectives

The use of lithium ion batteries (LIBs) in India is expected to increase in the near future.The market value of LIB in India is expected to increase from the current 1.89bn US $ is expected to 4.84bn US $ The main reason for this will be the use of Electric Vehicles, which use LIBs as the main power source. LIBs are also widely used in portable electronic devices (e.g. mobile phones and laptops).

LIBs have an expected lifespan of 3-5 years. Over the next few years, an increasingly large waste stream of LIBS is expected. LIBs contain toxic and flammable components, as well as valuable metals such as Li, Ni and Co. For these reasons, there are benefits to recycling used LIBs, instead of disposal in landfills.

There are two issues associated with the disposal of lithium ion batteries in landfills:

(i) Lithium ion batteries contain flammable and toxic components, and the risks of disposing LIBs in landfills are possible explosions or contamination of soil and groundwater. It poses serious threats to workers directly engaged in the recycling process and also to the local population.

(ii) India does not have a source of lithium and currently imports batteries. Any attempt to set up local LIB manufacturing will require the import of lithium.

Both of these issues depict the importance of a cost-effective and environmentally suitable process for the recycling of lithium ion batteries India, which needs to be developed before the billions of dollars market gets captured by foreign investors.

In terms of power produced, cumulative lithium-ion battery market size is estimated to increase from 2.9 GWh in 2018 to reach about 800 GWh by 2030. At present, about 65% of lithium-ion batteries are used in the telecom sector, data centers, street lights, and other small consumer applications, while the remaining 35% market is held by the electric vehicles segment. However, by 2030, the share of electric vehicles is expected to be about 80% on the pretext of a government push towards electric mobility. So with growth in EV the battery market will also grow . The electric vehicle boom in the global market would also have a similar impact on the lithium-ion batteries growth in the Indian market in the next ten years.

The increase in volume of lithium-ion batteries would, in turn, lead to a rise of ‘spent’ batteries in our ecosystem which if left untreated would become a health and environmental hazard. Also, the precious metals comprising these batteries would be lost forever. Earlier the batteries were treated by different mechanical and metallurgical processes, making a heavy toll on the environment, however the process which we will be proposing will be more economically viable eco friendly and.

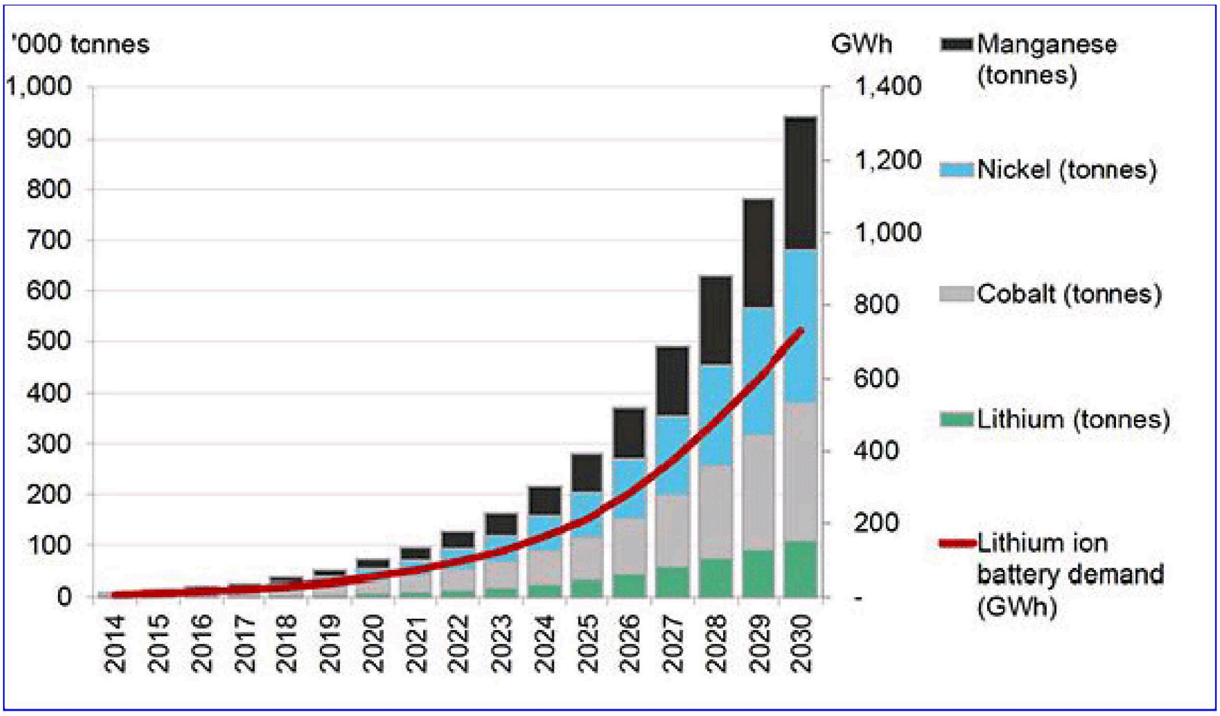


Fig1: Graph depicting increasing trend in usage of Lithium Batteries

1.1 Global Recycling Scenario

No.	Company	Location	Material Recycled	Capacity (tonnes/year)
1	Sony and Sumitomo Metals	Japan	Li-ion only	150
2	Dowa Eco-System Co. Ltd.	Japan	All Lithium Batteries	1 000
3	Toxco	Canada	All Lithium Batteries	4 500
4	Umicore	Belgium	Li-ion only	7 000
5	Batrec AG	Switzerland	Li-ion only	200
6	Recupyl	France	All Lithium Batteries	110
7	SNAM	France	Li-ion only	300
8	Xstrata	Canada	All Lithium Batteries	7 000
9	Inmetco	USA	All Lithium Batteries	6 000
10	JX Nippon Mining & Metals Co.	Japan	Unknown	5 000
11	Chemetall	Germany	Unknown	5 000
12	Accurec	Germany	Unknown	6 000
13	Stiftung Gemeinsames	Germany	Unknown	340
14	G&P Batteries	UK	Li-ion only	145
15	SARP	France	Li-ion only	200
16	Revatech	Belgium	Li-ion only	3 000
17	Shenzhen Green Eco-manufacturer Hi-Tech Co.	China	Li-ion only	20 000
18	Fuoshan Bangpu Ni/Co High-Tech Co.	China	Li-ion only	3 600
19	TES-AMM	Singapore	Li-ion only	1 200
20	BDT	USA	All Lithium Batteries	350
21	Metal-Tech Ltd	Israel	All Lithium Batteries	
22	Akkuser Ltd	Finland	All Lithium Batteries	4000
			Total	**70 595**

Fig2: Country wise recycling of Lithium ion batteries.

As recommended, we have studied the country wise recycling process to understand how different countries attempt to recycle before formulating our process

1.2 Approach

Now the problem being discussed, we reveal our innovative approach to tackle the problem. So basically we are proposing a new recycling method which will incorporate discarded lithium ion batteries and will produce new batteries to be used instantly. After studying the global recycling approaches, we inferred that most of the countries follow the Recupyl process to treat LIBs. The process is able to treat 320 tonnes per annum of lithium batteries, including primary and secondary battery types and employs a combination of physical and chemical treatment steps. However this process was discovered in 1993 and since then it has undergone very few changes to meet sustainability goals and have a lot of disadvantages which takes a toll on human health as well as causes air and water pollution. Further drawbacks of this process and improvements made by our intervention at industry level are discussed in the Discussion section along with process design.

Before moving to Theoretical aspects let's discuss the FAQs regarding LIBs.

Q. It is evident that we need to recycle LIB’s but why only LIB’s. Why don't we use other sources of power.

Ans. To reduce the demand on conventional sources of fuel (diesel & petrol) other alternatives are being generated such as enhanced solar energy harnessing techniques and biodiesel but the problem is that solar energy can’t be used as a constant source whereas biodiesel still uses 80% diesel in blend. Plus we can’t use them in mobile phones and laptops. Hence we need a constant power source with compact size and that’s where rechargeable batteries come into play.

Unlike the Zn-Cd batteries used in remotes, watches, LIBs are rechargeable. What makes them special is the High Charge Density , Low maintenance cost and a long life span of 3-5 years. The Ionization energy of Lithium is very less and therefore can lose an electron very easily facilitating a quick recharging and discharging process

These are the reasons why we prefer Lithium ion batteries over other sources of power.

2. Theoretical and Conceptual Aspects of the Problem Selected

The theoretical aspects of the problem selected is first to understand and analyze the existing process of Lithium-ion battery recycling and finding the flaws in it which can be later improved by incorporating the recycling process designed by us in this project.

As the government is aiming to ensure that at least 15% of the vehicles in the country are electric by 2030, this will also mean an increase in the consumption of lithium-ion batteries--rechargeable batteries used in a number of industries, including automotive and consumer electronics which in turn will lead to subsequent rise in the number of spent batteries. If the spent LIBs are not taken care of responsibly they can adversely affect the environment and health of the surroundings. Apart from environmental and social effects, dumping of spent batteries is also a lost economic opportunity.

The life of an EV battery ranges between six and eight years and needs replacement when its capacity starts falling below 80%. A lithium-ion battery can perform between 500 and over 10,000 cycles of charging and discharging, said a report on recycling of lithium-ion batteries by JMK Research and Analytics, a research analytics firm. The batteries retired from electric vehicles could still retain 70% to 80% of their initial capacity upon recycling.

EV batteries can be managed in two ways: first they can be repurposed for secondary applications; second they can be sent for recycling directly and metals can be recovered from them using technology. Our purpose is to incorporate a more efficient LIB recycling process, than the existing recycling processes (eg- Recupyl process, pyrometallurgical processes, etc.), that can increase the scale of recycling and reduce the cost of recycling LIB which inturn will help us in proper management and reduce the open dumpings of spent Lithium-ion batteries and to reduce the diseases caused by it.

Since India is deprived of lithium reserves and other raw materials required for LIB, thus we import LIB to fulfill our needs. Recycling, recovery and repurposing of LIBs will not only reduce the adverse effects on health and environment, but can also create a circular economy and reduce dependence on resources and materials used to make these batteries.

3. Methodology

- Clear Village Description and also description of Bengaluru

We have chosen our field site to be a village, Mavallipura which is located about 15 Kilometer away from Bengaluru. About 100 acres of land in and around the village are used for dumping for a long time and almost 70% E- Waste generated from Bengaluru is dumped here. This village is heavily affected by Landfills, toxic waste treatment, uncontrolled dump sites, Land acquisition conflicts. It is the closest village to Bengaluru which has a waste facility. The reasons for choosing the same are described below.

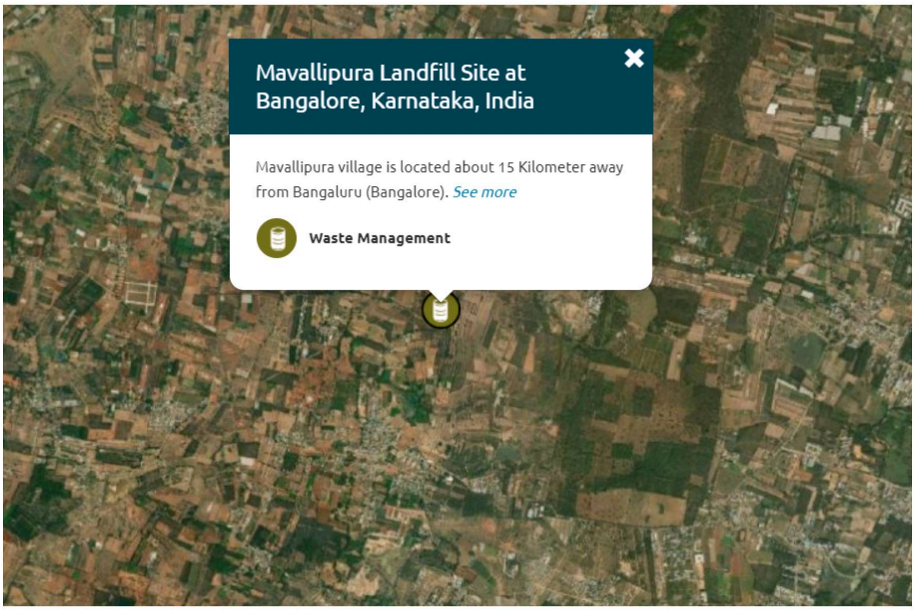


Fig3- Satellite Image of Mavallipura Village

About Mavallipura

According to Census 2011 information the location code or village code of Mavallipura village is 612871. Mavallipura village is located in North Tehsil of Bengaluru district in Karnataka, India. It is situated 12km away from sub-district headquarter Bangalore North and 15 km away from district headquarter Bengaluru.

The total geographical area of the village is 303.17 hectares. Mavallipura has a total population of 1,000 people. There are about 218 houses in Mavallipura village. As per 2019 stats, Mavallipura village comes under Yelahanka assembly & Chikballapur parliamentary constituency.

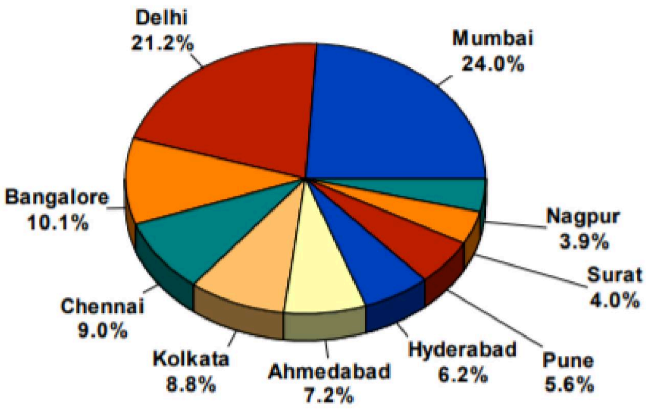


Fig-4: City wise E-waste Generation in India(Tonnes/year)

Reasons for choosing Bengaluru : The reason to choose a site near Bengaluru is that among all the IT Hubs of India, Bengaluru generates the maximum amount of e-waste (Fig4) . As per an estimate there are over 1.2 crore electronic devices in the city having LIB as the main power source. That much LIB's we are expected to receive out of them which will be very crucial for the project . Also, the number of Automobile companies dealing with Lithium-ion Batteries is greater in Bengaluru than in any IT Hub of India. Battery manufacturing companies such as Panasonic, Duracell have their headquarters. R&D wing and manufacturing units in the city. So it will be very easy to obtain expert advice . For the same reasons there are over 50+ EV startups by engineers like us that are concentrated in Bengaluru only. Tesla too have announced its unit in Bengaluru hence going by the same flow we have chosen our field site very close to the city

Methods of Data Collection:

Primary Data Collection -

Since physical movements are restricted, we were entirely dependent on online mode for data collection. The method implemented was the Interview Schedule of Focus Group. This was conducted via video conferencing platforms (E-Survey) such as Google Meet, WebEx meet, Zoom etc.

Questionnaire - Our team members conducted a questionnaire with Dr. Amit Kumar Malik , former director of Energy Club at MIT, USA via video conferencing platform google meet. His expertise in Lithium ion batteries helped us to improvise the thermodynamical aspects of the model which in turn enhanced the industrial scalability of our designed process. Mr. Yash Sakaria, a resident of Mavallipura was virtually interviewed regarding the conditions of village Mavallipura.

Surveys - We conducted a survey with 47 Electronic vehicle startups in Bengaluru. The survey was based on the difficulties faced in disposing lithium ion batteries, average life of a lithium ion battery, etc.

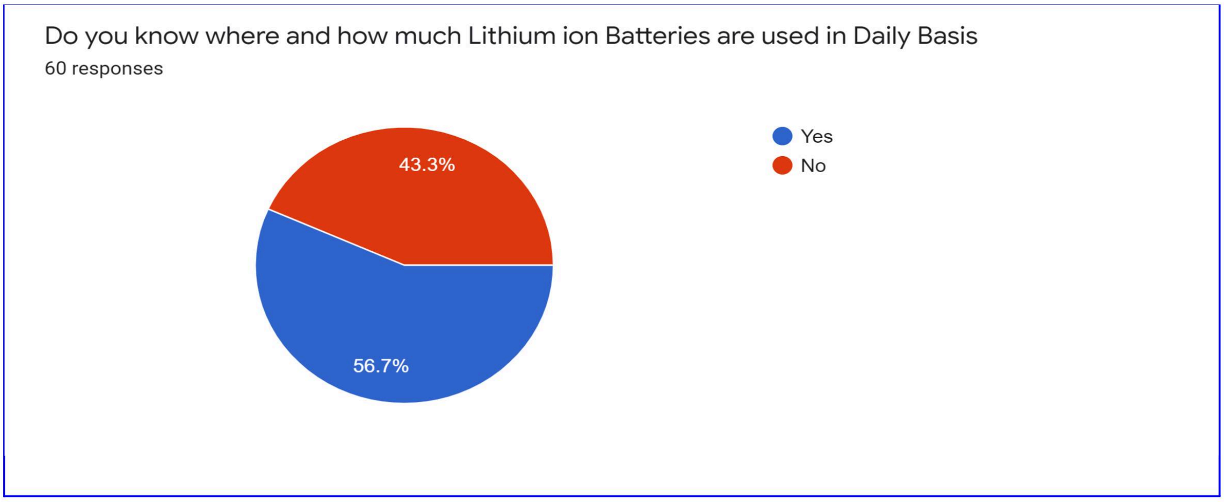
Focus Groups - We gathered information regarding the designed process and the existing processes for recycling lithium-ion batteries from 2 PhD scholars from Monash University and chemical engineering professors from IIT Ropar currently pursuing research on lithium ion batteries. Apart from this we also contacted **eBikeGO**, a startup which has emerged as a premier lithium ion battery recycling startup in India and **Econili Battery, Inc.** an eminent battery recycling company located in Malaysia via email.

Secondary Data collection -

For the statistical and data analysis we employed government and media reports which provided information regarding various issues such as incidents occurring due to dumping of lithium ion batteries, cost of importing lithium and information on other related issues. Research publications and journals which include findings of various research scholars were also included to get an insight of different steps involved in our process which enabled us to make necessary amendments.

● Analysis of Collected data

Following are the observations and quantitative analysis of the data collected via google forms survey conducted among the people of Mavallipura village.



FigA1: Analysis of data collected

1. First inference which can be drawn that people are unaware of the primary cause of all the sufferings. More than 50% of the people didn't know about LIB's and all those who knew were from working backgrounds such as Mechanic, Mobile repairs etc.
2. From figure 2 it can be concluded that every villager's health has been affected in one or another way. Further inputs from Mr. Sakaria revealed that these health complications were not sudden but it was slow and it gradually affected the health over a period of 10-15 years. During our second year course of Organic & Biochemistry , we were taught that such exposures over a long period of time can cause genetic mutations in individuals which can affect their offsrpings as well.

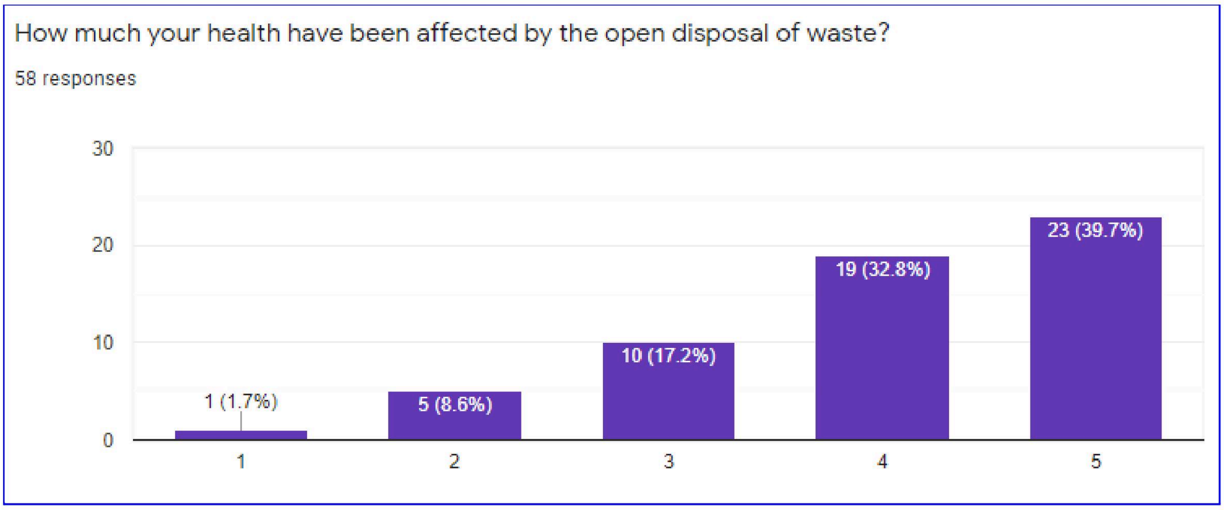
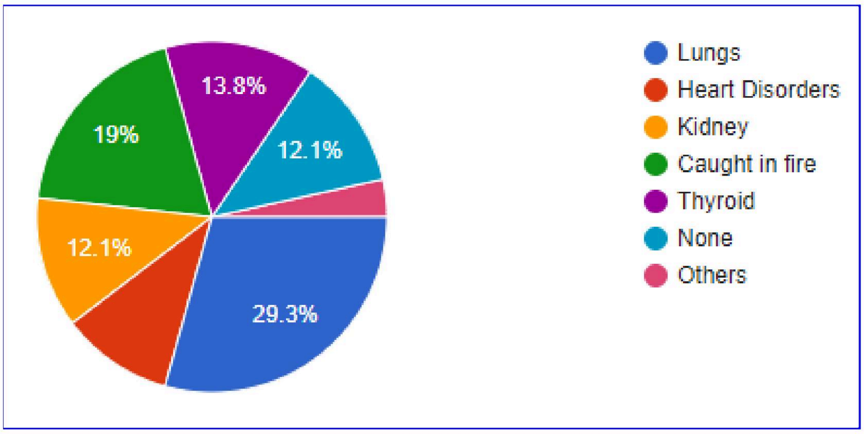


Fig A2: Analysis of data collected 2.

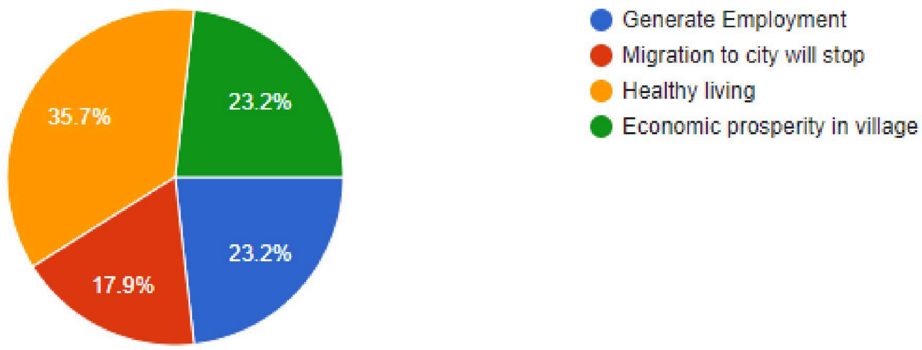


FigA3: Health issues

3. The following pie- chart shows the type of diseases which the people of the village have generated. About 30& of the people have respiratory disorders pertaining to lungs. A significant proportion of the populations also showed signs of heart and kidney related malfunctioning. While 19% of the people were caught in fire incidents. Since a lot of people are unemployed so the most common job is to work at the waste facility

Acc. to you how will the establishment of a new recycling plant will help the village?

56 responses



FigA4: Analysis of collected data

4. The above pie chart substantiates the demand of a proper Recycling process. People of the village have related themselves to the problems and from the data it can be inferred that we will be able to affect the life of the majority of people with our process.

Do you feel there is a urgent need to develop a process that will reduce the open dumping?

57 responses

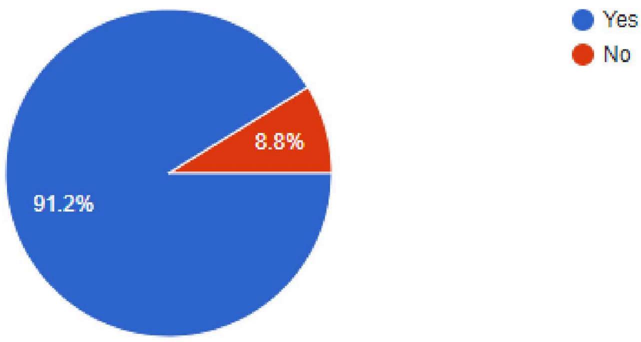


Fig A5: The need of process to reduce open dumping

3. Findings

Upon discussing the conditions of the village with Mr. Yash Sakaria, we discovered that the environmental impacts of dumping LIB are severe. According to reports, the elements present in LIBs are toxic to the extent that even a single LIB can pollute an entire water aquifer. The irresponsible dumping of LIB polluted the local lake and groundwater, resulting in kidney failure, cancer, and a range of illnesses. Also, the reactions among the elements lead to explosions which in turn lead to fire. As stated by the villagers the fires lead to burning of the garbage which produced toxic and foul fumes .

Further, a survey involving 47 EV startups and recyclers was conducted to estimate the amount of E-waste which is recycled per annum. This can be used to figure out what fraction of LIB waste generated reaches the recycling plants. Below is a table depicting the amount of e-waste received at respective recycling plants.

Sr.no.	Authorised(Expert Areas)	Quantity (metric ton per annum)
1	Ash Recyclers, Hoskote, Bangalore	120
2	Newport Computer Services (India)Private Limited, Bommasandra, Bangalore	500
3	EWaRDD & Co., Bommanahalli, Bangalore	600
4	E-R3 Solutions Pvt. Ltd., Peenya, Bangalore	140
5	Ash Recyclers, Thimmaiah Road, Bangalore	120
6	E-Parisara Pvt. Ltd., Nelamangala, Bangalore	1800
7	Surface Chem Finishers, Bangalore	600Kg/annum

Table-1 : Amount of e-waste received at each recycler

Another major issue is the lack of lithium reserves in India which leads to high cost of import of raw materials required for LIB. About 58% of the world's lithium reserves are in Chile and about 43% of rare earth mineral reserves are in China, as a result our country is forced to import lithium-ion batteries to meet the requirements. In 2019-20, India imported 450 million units of lithium batteries (used in a range of electrical equipment, products and EVs) valued at Rs 6,600 crore ($929.26 million), as informed by Union Minister of Science and Technology and Earth Sciences, Harsh Vardhan in Lok Sabha on February 7, 2020.

Profit estimates for lithium-ion battery imports

Margins can range from 8% to 40%, depending on the variant and usage

Cost ($/Unit)*	0.80
Freight & Insuarnce($/Unit)**	0.12
CIF ($/Unit)	0.92
CIF (Rs./Unit))***	58.51
BD (10%)	5.85
CIF + BD	64.36
Cess (3%)	1.93
CIF+BD+Cess	66.29
IGST (28%)	18.56
Final Cost	84.86
Selling price in India #	94.00
Profit	9.14
Profit Margin	9.72

Lithium-ion battery with 2000 mAh storage capacity, size: 18650; HS Code: 85076000; **Freight and insurance cost from Shenzhen, China to JNPT, Mumbai; Minimum order quantity (MOQ): 2,000 units;*Assuming USDINR at 63.60; # Wholesale Price (TDB Intelligence Unit); Note: Profitability ignores brand equity*

Important disclaimer: *Profitability has been calculated based on time-bound indicative prices (prevalent during the third week of August 2017). Prices may vary during a different time period, resulting in profit fluctuation. Factors like brand value, supply chain-related costs like warehousing and logistics, administrative costs, sales and advertising costs, etc., have not been included in the cost of procurement. Margins have been calculated considering government policies (announcements, notifications, etc.) as on August 20, 2017. Risk factors and currency fluctuations have to be considered while importing. Calculations have been provided for informational purposes only; The Dollar Business takes no responsibility for any loss resulting from investments in the said commodity/product. Though all efforts have been made to ensure the accuracy of the content stated herewith, the same should not be considered a statement of law or used for any legal purposes. Prior permission is required before calculations stated herein are published or quoted in a third party web or print property.*

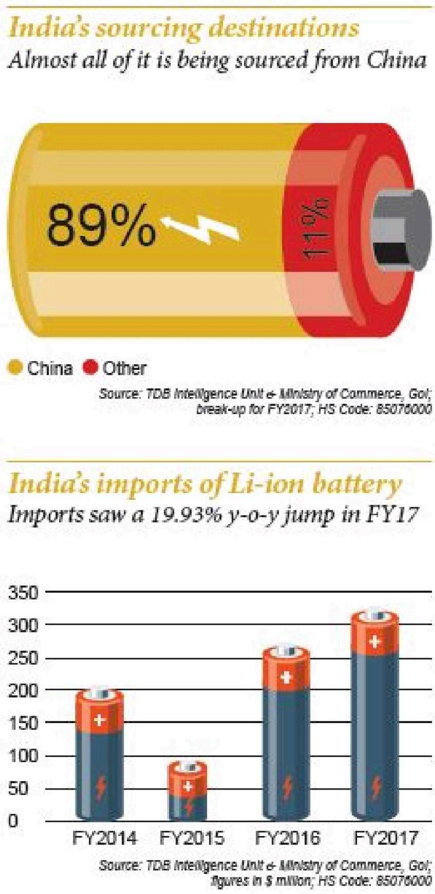


Fig5: Infographic depicting techno-economical aspects of Lithium batteries

Further, EV sales in FY 20 was nearly 246,000 units — Cars -3,400, three-wheeler (E-Rickshaws) – 90,000, two-wheelers – 152,000 and Buses – 600. Nearly 60-70 per cent cost of E-vehicle is its most common rechargeable battery (Lithium Battery), and India is fully dependent on China for the importation of Lithium Batteries, either for cellphone, wristwatch, toys, and vehicles or any electronic, which runs on Lithium batteries Units. And these numbers are expected to grow by 30 per cent till the end of 2021.

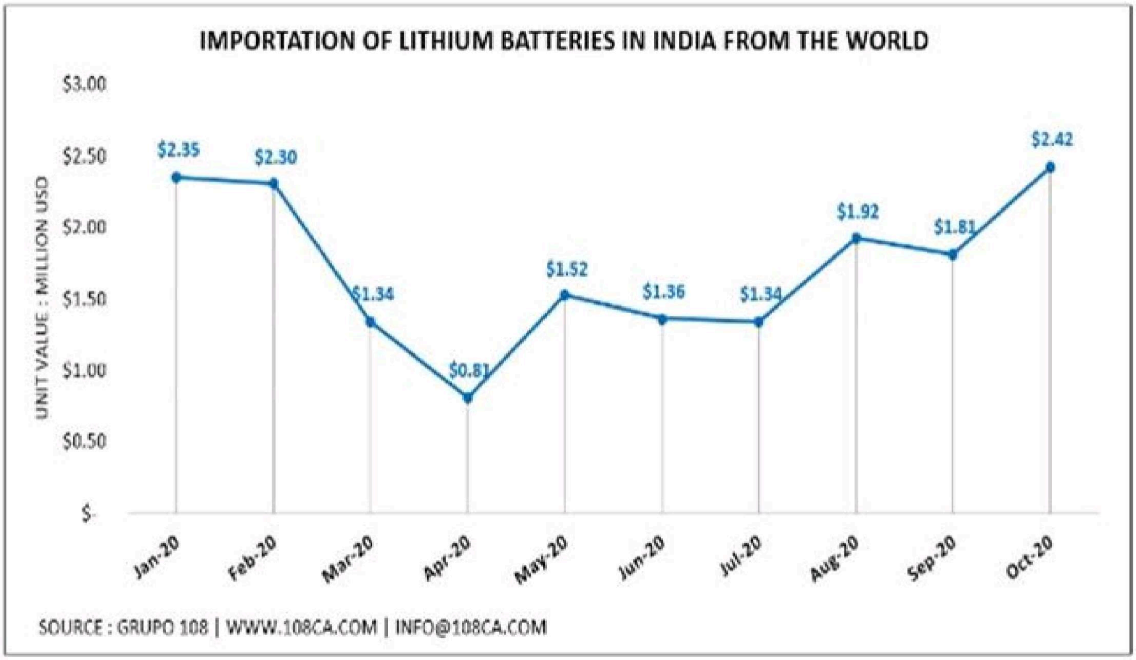


Fig 6: Graphical representation of Importation of LIB from January to October in FY 2020

Lithium Carbonate and Lithium Oxide & Hydroxide which are a part of lithium ion batteries (discussed in the Exploratory design) are also imported by India to meet the requirements of batteries and also manufacturing of special glass, frits for ceramics and enamels, etc. India imported nearly USD6.54 million valued Lithium Carbonate and USD10.38 million valued Lithium Oxide and Hydroxide in 2020 (Jan-2020 to Oct 2020).

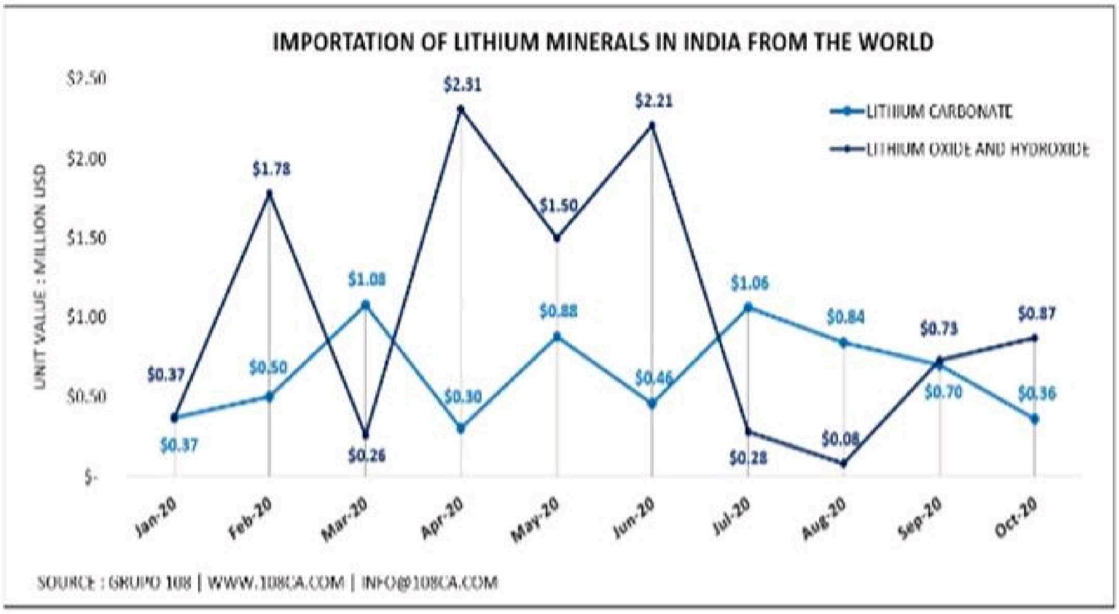


Fig7 : Importation of Lithium Carbonate and Lithium Oxide and Hydroxide from Jan to Oct in FY 2020

From the above available data we can conclude that recycling lithium-ion batteries is essential. As recycling will reduce the cost of production of LIBs as raw materials are already available. Further, the process we are using for recycling lithium-ion batteries is much more efficient, cost effective and cheaper than the existing processes which will make lithium-ion batteries more affordable. Hence reducing the cost of electronic appliances and automotives which use LIB.

Econili Battery, Inc. which is an established and an eminent battery recycling company located in Malaysia was contacted regarding the CapEx and OpEx required to develop a recycling plant. This provided us a rough estimate about the Capital and operational expenditure involved. For estimating the optimum CapEx and OpEx required in India, we contacted **eBikeGO,** a premier lithium ion battery recycling startup in India. Some publications were also used for the purpose of evaluating the CapEx and OpEx required to establish a LIB recycling plant in India. We tired estimating the cost of plant based on certain assumptions which are depicted in the table below -

Plant capacity (GWh)	50
Total land area (acre)*	500
Equipment cost (INR crore)*	25350
Manpower*	6500
Debt : Equity	70:30
Loan repayment period (year)	10
Life of the plant (years)	20
Construction period (months)	36

Table-2 : Assumptions *Source : www.tesla.com

Q. How can our techno-economical intervention help in reducing the cost ?

As per the information received from e-Bike Go the price of battery rom Tesla giga factory will be around US $ 150KW/h but if we are able to build a giant facility of 50GWh(Table 2) based on our designed process, we will be able to reduce the price from 150 to 100 US$ 100KW/h . So if an average plants functions on average 13 hours a day ,we will be able to save

US $ (150-100) X 13 = US $ 650

Furthermore our designed process generates 0.5 tonnes of Graphite per day which is not in the case with any existing process (in discussion part) . This will increase our savings upto

0.5 tonnes X Cost of graphite per tonnes in US$(1000) = 500 US $ per day.

Total savings per day = 650 + 500 = 1150 US $ = appx. INR 85,000

CAPITAL COST SUMMARY | Date to which estimate applies: Mid-2020

Job title: Lithium Recovery from Recycled Li-Batteries | Location: TBD | Capacity: 1,000 kg/hr | By Noah Dunlap

Cost Index Type: CE Plant Cost Index Cost Index Value: 599.5 | Date 4/14/2020

Equipment Identification	Number	Capacity or Size Specifications	Purchased Equipment Cost Year 2004	Purchased Equipment Cost Target Year*	Bare Module Factor, F_{BM}	Base Bare Module Cost, C_{BM}	Material Factor, F_M	Pressure or other Factors, F_p	Actual Bare Module Factor, F_{BM}	Bare Module Cost, C_{BM}	Total
Auxilliary Facilities	N/A										
Total Auxilliary Facilities											
Crushers, Mills, Grinders											
Crusher	C1	0.277 kg/sec, carbon steel	16000	23980	2.1	50358	1	1	2.1	50358	
Total Crushers, Mills, Grinders						50358					50358
Heat Exchangers											
Heat Exchanger	HEX1	265.64 m2, carbon steel, hairpin multitube 10 barg	25000	37468.8	3.2	119900	1	1	3.2	119900	
Heat Exchanger	HEX2	1004.43 m2, carbon steel, hairpin multitube 10 barg	60000	89925	3.2	287760	1	1	3.2	287760	
Heat Exchanger	HEX3	629.29 m2, carbon steel, hairpin multitube 10 barg	42000	62947.5	3.2	201432	1	1	3.2	201432	
Total Heat Exchangers						609092					609092
(Other items as taken from the equipment list)	N/A										
Process Vessels											
Reactor	R1	1 m ID x 12.05 m vertical, carbon steel	25000	37468.8	3.2	119900	1	1	3.2	119900	
Reactor	R2	1.5 m ID x 8.97 m vertical, carbon steel	28000	41965	3.2	134288	1	1	3.2	134288	
Neutralizer	N1	1.5 m ID x 7.47 m vertical, carbon steel	23000	34471.3	3.2	110308	1	1	3.2	110308	
Neutralizer	N2	1.5 m ID x 8.07 m vertical, carbon steel	26000	38967.5	3.2	124696	1	1	3.2	124696	
Evaporator	E1	1 m ID x 10.57 m vertical, carbon steel	23000	34471.3	3.2	110308	1	1	3.2	110308	
Evaporator	E2	4 m ID x 24.55 m vertical, carbon steel	140000	209825	3.2	671440	1	1	3.2	671440	
Tower Total						1270940					1270940
Filters											
Filter	F1	1.43 kg/s, carbon steel	190000	284763	2	569525	1	1	2	569525	
Filter	F2	2.09 kg/s, carbon steel	210000	314738	2	629475	1	1	2	629475	
Filter	F3	1.92 kg/s, carbon steel	200000	299750	2	599500	1	1	2	599500	
Filter	F4	1.96 kg/s, carbon steel	200000	299750	2	599500	1	1	2	599500	
Filter	F5	0.26 kg/s, carbon steel	110000	164863	2	329725	1	1	2	329725	
Total Pumps						2727725					2727725
Storage Vessels											
LV-Separator	S1	8.89 m3, carbon steel, vertical bullet tank, 0-10 barg	12000	17985	2.1	37768.5	1	1	2.1	37768.5	
LV-Separator	S2	0.19 m3, carbon steel, vertical bullet tank, 0-10 barg	3000	4496.25	2.1	9442.125	1	1	2.1	9442.13	
LV-Separator	S3	13.51 m3, carbon steel, vertical bullet tank, 0-10 barg	28000	41965	2.1	88126.5	1	1	2.1	88126.5	
Total Storage Vessels						135337.13					135337.125
Total bare module cost				Base materials, $C_{TBM} = \Sigma C_{BM} =$		$4,793,452		Actual materials, $C_{TBM} = \Sigma C_{BM} =$			$4,793,452
Contingency and fee										$C_C + C_F = C_{TBM} \times 0.18 =$	$862,821
Total module cost										$C_{TM} =$	$5,656,274
Auxiliary (offsite) Facilities										$C_{TBM} \times 0.30 =$	$1,696,882
Grass Roots capital										$C_{GR} =$	$7,353,156

Fig-8 : Capital Expenditure Summary for LIB recycling Plant

We can conclude from the above shown figure that the total grassroots capital required for the proposed layout is around $7,353,156 for a LIB recycling plant to establish. These figures are depicting the CapEx for the existing recycling processes.

5. Discussion

Open disposal of LIBs have both direct and indirect effects on health. Workers directly engaged in waste disposal have suffered serious health injuries mainly due to fire mishaps. LIBs contain flammable and toxic components, and the risks of disposing of LIBs in landfills are possible explosions. Below attached are the statistics of reported fires at LIBs recycling facility in the USA. We were unable to obtain similar data for the waste plant at Mavallipura facility because no one kept the official record but as per information received by Mr. Sakaria, a local resident, in the past 12 months there were about 20 + fire incidents with around 45 injuries.

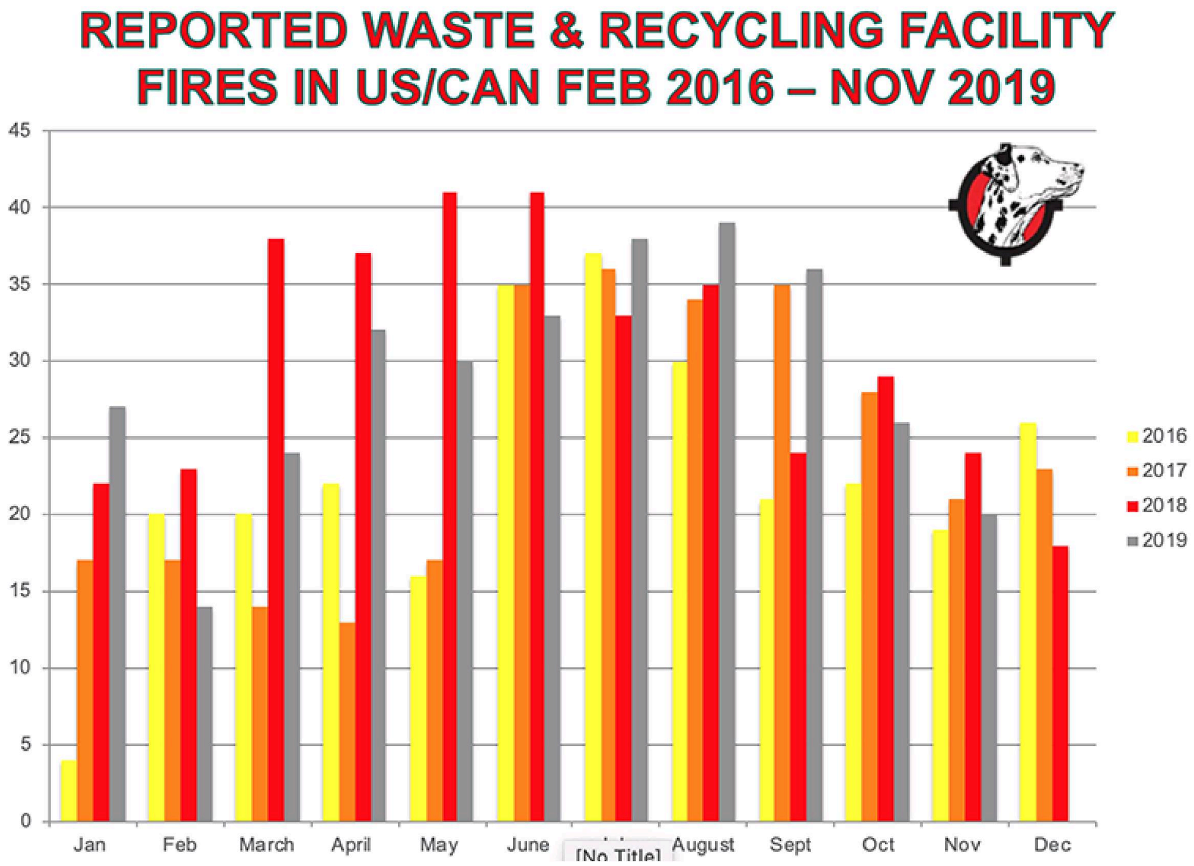


Fig9: Reported fire incidents in waste facilities in US/Canada from Feb2016- Nov 2019

Lithium-ion batteries, if not decomposed properly can be inhaled and may irritate the lungs, higher exposures may cause a build up of a fluid in the lungs (pulmonary edema), a medical emergency. Also, it may affect the thyroid gland, kidney and the heart function and can also cause seizures and coma. Similar inputs have been received from Mr. Sakaria when interrogated about community health. Long term exposures to hazardous fumes have resulted in overall poor health of the village. There has been a surge in Lung and kidney related diseases in the past and that's the reason why people have started migrating and the population has reduced.

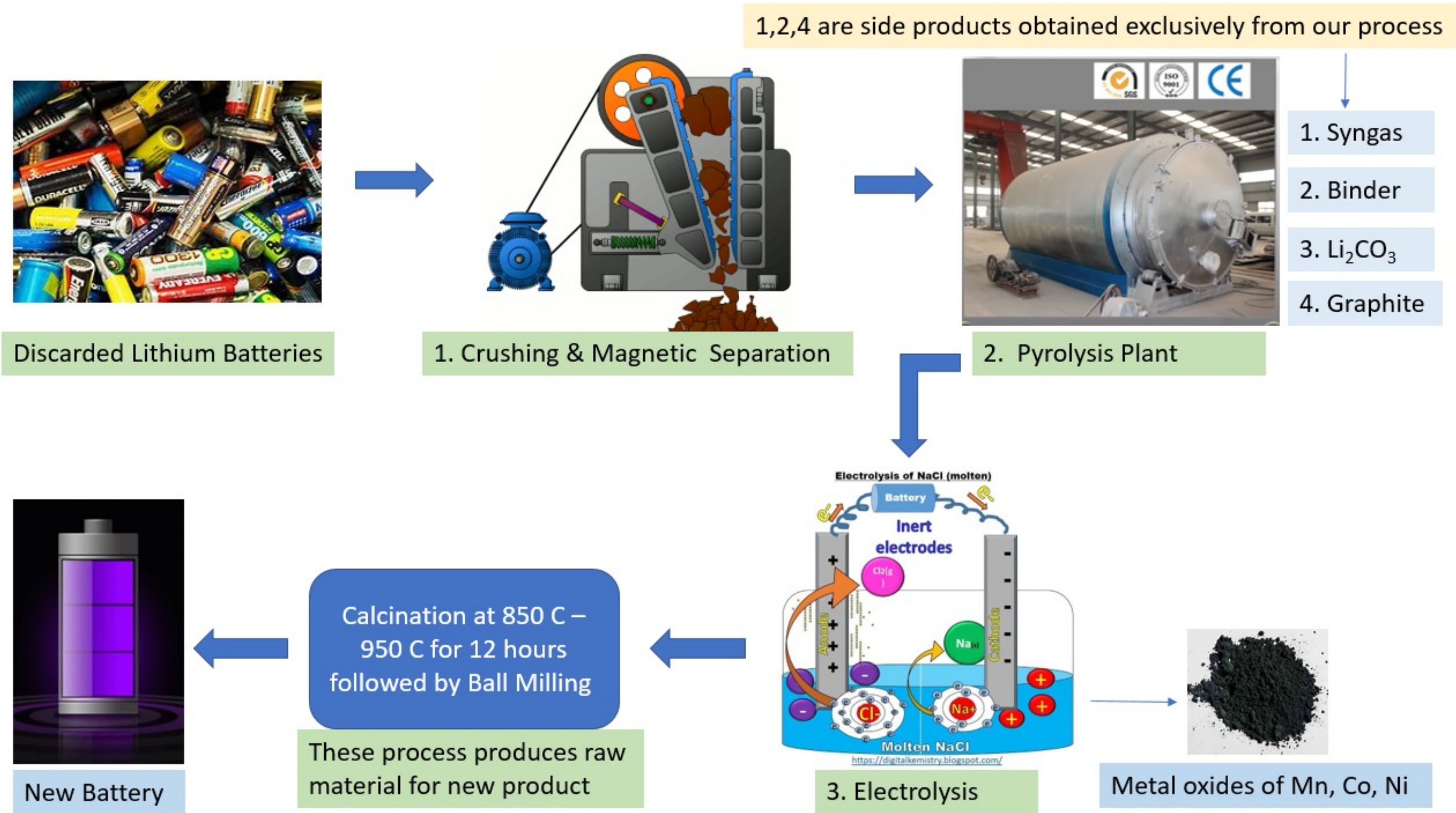
These problems have persisted not only in Mavallipura but in every recycling facility. The problem arises because the LIBs reach the recycling waste mixed with other bio and non biodegradable waste. One might argue that we can separate the LIB from rest of waste. Yes, we can do that. But what after that? Due to lack of proper and effective recycling techniques, the LIB's will again be disposed of openly. If LIB's are sent to the recycling facility, again there will be a lot of issues.

1. First one is that currently India doesn't have any authorized LIB recycling unit.
2. Even if there is one to be established, the current process (Recupyl) requires a lot of input. The operational expenditure (OpEx) shown above is very high plus it requires a lot of chemicals on a daily basis and still produces harmful gases.

These are the real problems which substantiates the demand of an eco-friendly contemporary process in terms of social data collected. While coming to economic aspects, we have discussed the overall impact on India's economy. However as obvious it is, It will also help the affected local area to bloom. A lot of unskilled labour is required to establish a plant as well as to run it. It will not also help to generate employment in villages but also will bring economic prosperity in the region.

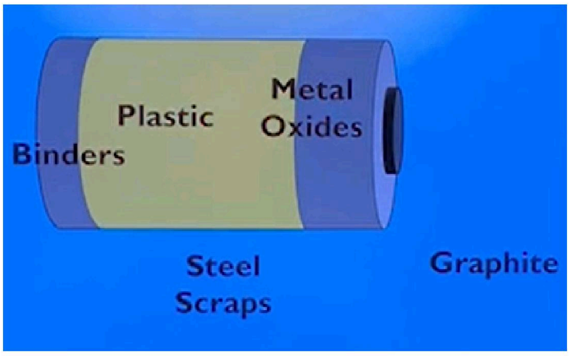
Engineering problem : To develop an innovative LIB recycling process, first of its kind in the country, to incorporate discarded batteries which will not only prevent fire mishaps but will also improve the living conditions of people living in nearby villages to waste disposal sites. Recycling processes will involve the establishment of a plant for various processes involved and will generate employment opportunities in the village.

Below is the model of our designed process


1,2,4 are side products obtained exclusively from our process
Discarded Lithium Batteries
1. Crushing & Magnetic Separation
2. Pyrolysis Plant
1. Syngas
2. Binder
3. Li_2CO_3
4. Graphite
Electrolysis of NaCl (molten)
Battery
Inert electrodes
Anode
Cathode
Molten NaCl
https://digitalkemistry.blogspot.com/
3. Electrolysis
Metal oxides of Mn, Co, Ni
Calcination at 850 C – 950 C for 12 hours followed by Ball Milling
These process produces raw material for new product
New Battery

Proposed process from scratch to end stage

First step of the process is primary component separation of the discarded LIBs. This step is common to all the processes and includes processes such as crushing & magnetic separation because a battery is enclosed in multiple layers of plastic & steel covering. Besides recovering valuable material, our main objective is to obtain lithium (as Li_2CO_3, Lithium Carbonate, because at room temperature Lithium exists in its carbonate form).



Component	Composition (Mass %)
$LiCoO_2$	27.5
Steel/Ni	24.5
Cu/Al	14.5
Carbon	16
Electrolyte	3.5
Polymer	14

Fig10 : Structure of a Lithium ion battery **Table3: Typical composition of a LIB**

Q. Now the question arises what are the roles played in crushing and magnetic separation and how do these processes function ?

Ans. Basically the crusher crushes the LIBs into a powdered mixture. Since our interest is in recovery of Li_2CO_3 , Carbon graphite along with valuable battery materials, the used electrolyte, steel and polymer coating (plastic covering) needs to be separated from the mixture as the new batteries have to be filled with fresh electrolytes and new covering . After this the crushed powder is sent to the Magnetic separator which separates the magnetic materials such as Steel, Al, Ni, LiCoO2 from the non magnetic ones such as the Polymer covering and other unwanted impurities. After removing the unwanted components , now the picture is ready to be treated in the Pyrolysis plant

The second step of the process is different from the existing Recupyl process because we treat our mixture through a pyrolysis plant whereas in Recupyl the powder is fed to a hydrometallurgical process, consisting of hydrolysis, leaching and precipitation steps. For leaching purposes a lot of chemicals are used to precipitate such as H_2SO_4, NaOH, LiOH adding to OpEx.

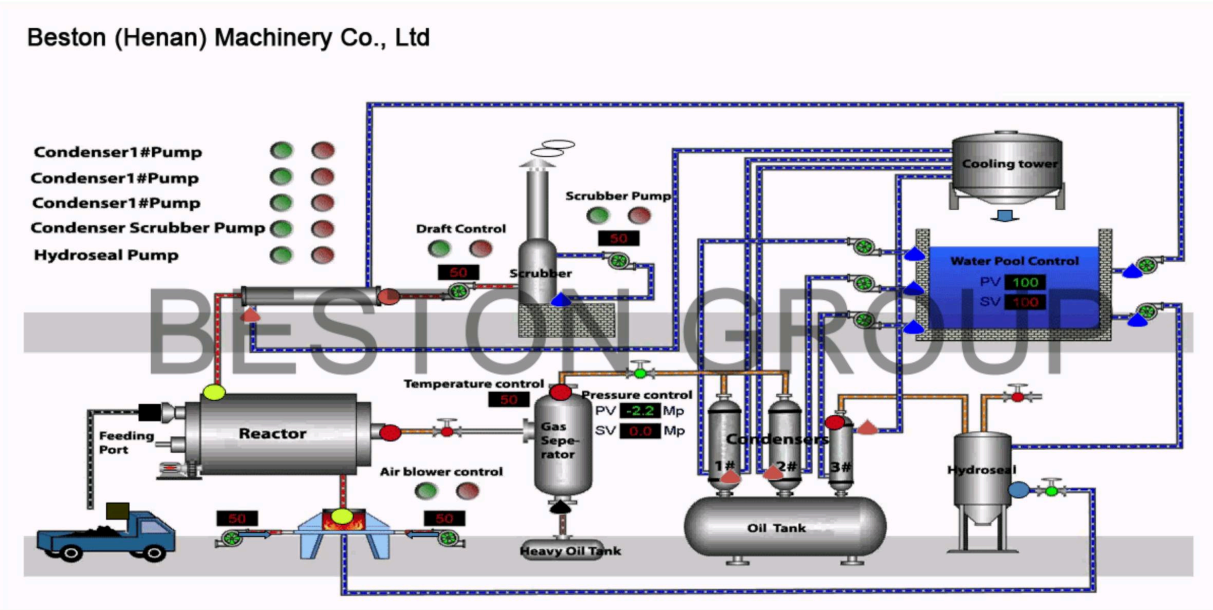


Fig11: Working of a pyrolysis plant

Q. What difference has the pyrolysis plant made? What are the advantages of this part over recupyl process ?

Ans. A Pyrolysis plant has complex working, however for our process we need to work only for a few aspects. Pyrolysis is a type of chemical breakdown process which occurs at high temperature in absence of oxygen. Reason for choosing this over hydrometallurgical process of recupyl is that in recupyl due to leaching , a significant amount of graphite 0.5 tonnes gets leached out hence an major economic drawback. Cost and importance of graphite have been discussed earlier in techno economical aspects. Besides that pyrolysis plants have a lot of advantages over hydrometallurgical processes . Some of them are listed here:

1. It reduces the water pollution as no chemical is used. However recupyl process demands a variety of chemicals in the hydrometallurgical process which are then dumped in rivers harming aquatic life as well..
2. It is simple, inexpensive technology or processing a large variety of feedstock at once. It reduces waste going to landfill and greenhouse gases simultaneously.
3. It creates new jobs for the low income section of society based on quantities of waste generated in the region which in turn provide public health benefits through waste clean up.

Third step: In the recupyl process lithium is recovered as Li_2CO_3 and cobalt is recovered as Cobalt hydroxide after leaching and precipitation steps. However instead of hydrolysis we are proposing electrolysis. The advantages of our method is that apart from getting Lithium and Cobalt products we will be able to recover most of the valuable materials such as Mn, Co and Ni as oxides which was not in the case with the Recupyl process.

Now with Lithium and all valuable materials recovered , the raw materials will be Clacinated at 850^0C followed by Ball milling . Calcination is used to concentrate Li2CO3 while obtained graphite is processed through ball milling because bill milling enhances the charge absorption properties of graphite. Now we have recovered all possible things from a discarded LIB and we are good to go to produce a new battery out of this.

6. Conclusion

Due to absence of a well formulated and advanced recycling process, all Lithium ion batteries are disposed of in open. As LIB's contain toxic and flammable components , it poses a threat not only to people working in waste recycling facilities but also to people living nearby. The current processes as discussed are out of date. They require more economic input and provide less output and also produce hazardous fumes and chemicals in water bodies.

6.1 Engineering Problem

So to deal with these problems we have devised a new process in the hope that this process will be able to cater the recycling demand nationwide. Given the platform of an IIT we're planning to make it big and will directly contact the concerned govt. authorities to incorporate this approach in waste treatment facilities. However for that we need to have early phase test results to claim our theoretical results. We require heavy machinery such as crushers, magnetic separators, a pyrolysis plant and other equipment for processes discussed above; it is only possible with the intervention of industry. So we are in talks with Econlib, Malaysia if they can test our process because India doesn't have the required machinery for primary phase testing.

6.2 Capstone project plans

1. Till we reach our final year we expect to receive the primary phase test data from and based on the theoretical result, we will try to further improve efficiency of the process. However it is a time dependent process.
2. For the time being we are designing the process to elevate the output from 50 GW/hr to 100 GW/hr. Although even Tesla has announced to establish a plant of capacity 50GW/hr but the Indian govt. has set up the target to unexpected 150 GW/hr. However we are planning to increase the output as much as possible.
3. We will further try to reduce the cost by improving the pyrolysis plant or by looking for alternatives because CAPEX of this plant is slightly high.

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Annexure: Questionnaire

Survey Based -

Q1. How much e-waste is collected by you on a daily basis ?

Q2. What are the difficulties faced in disposing the spent LIBs ?

Q3. What percentage of lithium-ion battery waste constitutes the e-waste ?

Q4. What is the transportation cost of transporting LIB from different locations to the recycling plant ?

Q5. What are the working conditions in LIB recycling plants ?

Q6. Besides toxic fumes and fires, what are other harmful effects of open dumping of spent LIBs ?

Q7. What impact can recycling have on the cost of LIBs ?

Q8. What is the average life of a Lithium ion battery ?

Q9. What are the commonly used processes for recycling LIBs ?

Research Based -

Q1. What are the advantages of using pyrolysis instead of hydrometallurgical processes ?

Q2. How can we improve the efficiency of pyrolysis processes ?

Q3. What is the cost of operating a pyrolysis plant on a daily basis ?

Q4. What are the benefits of using electrolysis over hydrolysis in the recovery of metals ?

Q5. What exactly happens in the crushing and magnetic separation step of the LIB recycling process ?

Q6. Does the process proposed by us for recycling have the potential to replace existing recycling processes ?

Q7. What further improvements can be made in the process of recycling proposed by us to make it more efficient and eco-friendly ?