IIT Bombay Research Hub for Green Energy and Sustainability

REPORT

Seminar on

Battery Recycling, Reuse and Repurpose

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Indian Institute of Technology Bombay

3rd October 2024 | VMCC, IIT BOMBAY

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Seminar on Battery Reuse, Repurpose and Recycling

Introduction:

IIT Bombay Research Hub for Green Energy and Sustainability along with the Department of Metallurgical Engineering and Materials Science, IIT Bombay conducted a one-day seminar on 'Battery Reuse, Repurpose & Recycling' on Oct 3rd, 2024, at VMCC IITB (Lecture Hall 21). The objective of the seminar was to explore and discuss innovative strategies and technologies for the reuse, repurpose, and recycling of spent Li-ion batteries and to identify challenges that academic researchers can take up.

The convenor of this seminar, Prof. Jayasree Biswas, holds an M.Tech degree from IIT Bombay and a Ph.D. from McMaster University, Canada. She has also been a postdoctoral fellow and researcher at Aalto University, Finland. Her primary research interests lie in metal recycling from secondary resources. The co-convenors are Prof. Kaushal Jha from the School of Sustainability, IIT Madras, and Prof. Pankaj Jhunja, an adjunct faculty member at IIT Bombay and former head of Sustainability, Tata Passenger Electric Mobility & Tata Motors Passenger Vehicles, TATA. The seminar was organized by the IIT Bombay Green Energy Sustainability Hub in collaboration with the Department of Metallurgical Engineering and Materials Science, IIT Bombay, jointly organized with the Material Recycling Association of India (MRAI), IIT Madras School of Sustainability and endorsed by the Battery Research Society of India, Rocky Mountain Institute (RMI) and the office of Principal Scientific Advisor (PSA), Government of India. This event was the first and the kick-off event of a series that is planned on the Circular Economy as a larger topic with other one covering elements of solar PV recycling, ewaste recycling etc. Special thanks to the sustainability partners of the day: Exigo Recycling Pvt. Ltd. and Gravita India Ltd., as well as the co-sponsors, Lohum Cleantech Pvt. Ltd. and Evergreen Recycle Karo India Pvt. Ltd.

Given the nation's ambitious electrification initiatives and the critical importance of mitigating material and environmental impacts, this seminar provided a crucial platform for discussions between industry, academia and regulatory members on battery reuse, repurposing, and recycling research topics and challenges. The event agenda and the selected topics were aligned with the recent Electric Vehicle (EV) R&D roadmap of India released by the PSA office recently. The event included speakers & guests from MeitY, CPCB, PSA's office, recycling industries, faculties from NTNU, IITM, IISER, and IITB.

Summary of key points:

The demand for Li-ion batteries is growing rapidly mainly due to ambitious electrification goal in the transportation sector to achieve the net zero emission targets. The global demand for Li-ion batteries, including e-mobility, energy storage and consumer electronics sector, is expected to increase from about 700 GWh in 2022 to around 4.7 TWh by 2030 as per recent report by McKinsey & Company and this will require huge volume of critical raw materials. The average lifespan of batteries being short, this will generate tonnes of waste batteries, improper disposal of which may lead to release of toxic and hazardous chemicals. Therefore, battery circularity: recycling as well as reusing and repurposing, becomes crucial to minimize waste, reduce environmental impact and maximize resource efficiency by keeping materials, components, and products in use for as long as possible.

Before recycling, an ecosystem for reusing and repurposing of the batteries is important for proper utilization of resources by extending the life of batteries. For example, end of life batteries from electric vehicles can be reused in storage related applications. The need for development of a robust battery testing system to predict the remaining life and a battery Aadhar system, which can acquire information related to battery manufacturer, localization, material composition, durability, performance etc., was emphasized.

The recycling of spent lithium-ion batteries, which cannot be reused or repurposed, is essential for material circularity. Spent Li-ion batteries contain valuable metals such as Li, Co, Ni, Cu etc. in significant quantities. In current practices, spent Li-ion batteries are typically pretreated through various steps such as discharging, dismantling, crushing, separating to separate the black mass, which is the most valuable mass fraction, and this black mass is treated through metallurgical (pyro/hydro) routes to extract the battery materials. The major highlights of the discussion were need for an economical and sustainable recycling process, an automated battery waste management system for collection, sorting etc., process models for optimization of the extraction processes.

Overview of Seminar

The inaugural session was started by a brief overview on the objective of the seminar by Prof. Jayasree Biswas, convener of the seminar. Thereafter, the role of IIT Bombay specifically the Green Energy and Sustainability Hub and the Department of Metallurgical Engineering and Materials Science on 'Battery Circularity' was covered by Prof. Sanjay Mahajani, Professor-incharge of Green Energy and Sustainability Hub, Prof. Rajib Dusane, acting Head of Metallurgical Engineering and Materials Science and Prof. Shireesh Kedare, Director, IIT Bombay. The **chief guest** of the event, **Dr. Sandip Chatterjee,** SERI, Ex-Sr. Director, Ministry of Electronics & Information Technology (MeitY) pointed out the need for design for sustainability, focused on Extended Producer Responsibility (EPR), and urged the need to develop an affordable recycling process for resource recovery from secondary resources to increase material recovery, decrease energy and reagent consumption to make it more power efficient, decrease the emission of flue gases and waste water. **Dr. Preeti Banzal**, Office of the Principal Scientific Adviser, Govt. of India elaborated on the EVmobility R&D roadmap for India and pointed out that research and development in battery circularity is imperative due to heterogeneity in its chemistry, shape, size, supply chain challenges different recycling approaches and safety risks. **Mr. Vijay Prakash Yadav,** Scientist & Director, CPCB gave an overview of battery waste management policy driving circularity which applies to all types of batteries except those used in war and space. Nearly 2800 producers have registered in the central pollution control board and 276 recyclers have registered on the state pollution control board portal.

Mr. B. K. Soni, Director, MRAI represented the Material Recycling Association of India (MRAI), the apex organization of India dealing with recycling and recyclable commodities such as metals (both ferrous and non-ferrous), plastic, paper, e-waste, tyre, rubber, glass, automobile, ELV, building and construction, and water. He appealed to IITB researchers to develop sustainable and affordable technologies for recycling electronic and battery waste and refining the end product.

Prof. Kaushal Jha represented the School of Sustainability, IIT Madras and touched upon the ongoing research activities of the hub.

This was followed by a session on the subject overview where **Prof. Pankaj Jhunja** discussed the reuse and repurpose aspect of batteries. The 5R principle for managing the end-of-life (EoL) lithium-ion batteries (LIBs) involves Refurbishment, Reuse, Repurposing, Remanufacturing, and Recycling. There is a need to create mechanisms to allow the EoL batteries to enter into second, third or fourth life applications before being recycled to increase the impact of EVs on consumers. This should be driven as an imperative to maximise the asset utilisation considering both the growing need for Battery capacity in India as well as the critical mineral security situation. This will also help make the business case of EV's better if the cost of batteries from EV End of life can be used for 2nd life applications. He indicated that the impact of Circularity could be anywhere in the range of 15% to 20% reduction of total cost of ownership across the lifetime of the battery with planned interventions from design to use phase.

Nitin Gupta, CEO of Attero Recycling stressed the path towards self-reliance on critical minerals for battery circularity. Demand for critical minerals surged in 2023, with lithium up 30% and nickel, cobalt, graphite, and rare earth elements rising 8-15% (https://www.iea.org/topics/critical-minerals). Clean energy applications have become the primary driver of this growth. Critical minerals are in high demand for electric vehicle batteries, which require up to 200 kg each. The battery sector drives 70% of global cobalt demand and also relies on aluminum, copper, lithium, nickel, and rare earths (https://sulkurl.com/zr). Achieving self-reliance in critical minerals is vital for sustainable battery production, especially within a circular economy. With supply chains dominated by a few countries, battery circularity offers a solution. Recycling and reuse strategies reduce reliance on raw imports and lower the environmental impact of mining. Recovering materials like lithium, cobalt, and nickel from recycled batteries strengthens the battery industry and conserves resources. Embracing circularity also supports clean energy transitions, boosts energy security, and creates jobs in recycling and green technologies, making it key to both sustainability and self-reliance. Today Attero has roughly around 45 granted global patents on various recycling technologies developed by them in India. Attero is also the only battery recycling company in the world to generate carbon credits on waste recycled because the amount of energy involved in their processes to extract say pure lithium carbonate, pure copper, and pure aluminum is significantly lower than the amount of energy involved in extracting these metals from either a virgin mine or any other secondary source of this material. It extracts more than twenty plus metals, including gold, silver, tin, copper, aluminum, lithium, carbonate, graphite, nickel, manganese and a few rare earth metals like neodymium from magnets. Globally Attero boosts of extracting >98% of pure battery-grade lithium carbonate, nickel, manganese, and graphite from EoL LIBs. From a geopolitical perspective, China dominates the supply of critical battery metals, providing over 90% of the world's battery-grade lithium carbonate, hydroxide, and graphite although they are not mined in China. Relying heavily on other countries for these vital resources can make a nation vulnerable to price fluctuations or supply cuts, affecting energy security and industrial progress. So, there is a need to be self-reliant in critical minerals ensuring long-term stability, environmental sustainability, and national economic strength.

Dr. Parveen Kumar, Exigo Recycling Pvt Ltd discussed key battery chemistries and raw material component cost, critical minerals in India, various incentives/subsidy on battery/ cells manufacturing, and gave an overview of battery recycling. Annual capacity addition of LIB for automotive applications is going to increase from 2.3 GWh in FY2021 to 1048 GWh by FY2030 as the total sale of EVs is estimated to increase from 1.1 million in FY2021 to 17.8 million by 2030 (JMK research analytics). So, there is a need to recover the metallic values from EoL LIBs to reduce the demand-supply gap for critical metals which are mostly imported as of now. Exigo Recycling Pvt. Ltd. is a key player in India's lithium-ion battery recycling sector. The company focuses on sustainable solutions for managing electronic waste, including the recycling of lithium-ion batteries. They aim to recover valuable materials like lithium, cobalt, and nickel through environmentally friendly processes. Exigo Recycling helps reduce the environmental impact of battery disposal, minimizes reliance on raw mineral imports, and supports the circular economy by reintroducing recycled materials into the production chain. Their work contributes to India's e-mobility and green energy goals. It is in the process of developing a sustainable pyrometallurgical method for the recovery of battery-grade material from EoL LIBs in India.

There are at least fifteen research groups at IIT Bombay working on different aspects of batteries. The research group of **Prof. Amartya Mukhopadhyay from the Department of Metallurgical Engineering and Materials Science, IITB** works on the battery chemistries, electrochemistry aspect of LIBs, cell life prediction, solid electrolyte, solid-state batteries besides sodium-ion batteries.

Prof. Srinivas Seethamraju from Energy Science and Engineering, IITB focused on selective recycling of valuable elements present in LIBs. He discussed the various cell components of LIBs, combining both hydro- and pyrometallurgical processes in the recovery route, pre-treatment of LIBs by copyrolysis of cathode black mass using waste polypropylene as reductant, magnetic separation to separate different oxides present in the LIB chemistry, followed by water leaching to recover lithium carbonate. He also aims to do economic analysis calculations for sustainable recycling.

Prof. Jayasree Biswas from the Department of Metallurgical Engineering and Materials Science, IITB elaborated on the selective extraction of metals from LCO-rich black mass (containing nearly 4% lithium, 27% cobalt, rest graphite) by combining both pyro- and hydrometallurgy. One such approach involved sulfation roasting using SO_2 and O_2 in a controlled environment at around 500, 600, and 700°C based on the thermodynamic stability of different phases stable at the working temperature and gas atmosphere. This led to the formation of lithium sulfate, a water-soluble phase, which can be subjected to water leaching to recover nearly 99% lithium (Biswas et al., 2023). The remaining elements were precipitated as oxides. The Ni-Co alloy recovered in this recycling process was used as feed material for nickel refining.

Prof. Sulalit Bandyopadhyay from the Department of Chemical Engineering, Norwegian University of Science and Technology (NTNU) Norway gave an overview of research carried out at NTNU in the battery circularity field. His research team aims to develop simple, low-energy hydrometallurgical recycling processes that are robust enough to handle diverse battery compositions. These flowsheets focus on recovering target metals, side products, and regenerating chemical reagents while minimizing energy, chemical, and water use. They aim to create recycling solutions that can compete with natural resource mining in terms of cost, sustainability, and environmental impact.

The **first technical session** after the networking lunch gave an overview of **reuse and repurpose practices** followed in the LIB industries.

Darshan Virupaksha from Nunam mentioned about the cost of not reusing batteries which includes both economic losses and significant environmental impacts from the production of new batteries, such as resource depletion and carbon emissions. Challenges in reusing batteries involve thermal management and vibration resistance, which affect their longevity and safety. Structuring battery specifications for reuse requires standardization of components, clear labelling modular design to enable easier repurposing. Ensuring safety during battery dismantling involves protocols for handling hazardous materials, protection against electrical discharge, and proper tools for disassembly.

Shubham Mishra, the founder of BatteryOk Technologies discussed about highly accelerate testing of batteries. EVs catch fire due to internal/external short-circuit, over charging and discharging, exposure to high temperature, and mechanical abuse. To avoid the EV fire mishaps, his group developed EV Doctor, an advanced AI based battery diagnostics to monitor the battery health. EV Doctor takes just a few minutes to analyze whether the battery can deliver the claimed performance and reliability. Based on the available charging data points, the scan determines the voltage profile and DCIR of the battery. It predicts the crucial parameters of the battery such as battery health, risk levels, SoC, AH etc. using state space battery models and ML algorithms. These results later will be leveraged during QC, service, and repair. Right from manufacturing to recycling, EV Doctor is a versatile battery diagnostic solution that helps during manufacturing, dispatch, service, repair, repurposing or recycling and takes care of all touchpoints.

Rahul Lamba, the co-founder and CEO of The Energy Company elaborated data-driven solutions for battery circularity, thus paving the way for a sustainable EV ecosystem by introducing the Battery Aadhar. Battery Aadhaar contains crucial information about the battery's components, health, capacity and usage. A Battery's Aadhaar provides information at a cellular level, allowing for tracking, monitoring, recording performance and service information, managing accountability for failures, easy access of the battery over marketplace, and the development of custom applications across the entire value chain which helps drastically improve the chances of getting a worthy second life, helping reduce unnecessary wastage and recycling. It uses FlexiTwin, an inhouse data-driven tool.

Panel discussion was moderated by Prof. Pankaj Jhunja, IITB with D Virupaksha, Nunam; S Mishra, Battery OK; R Lamba, The Energy Company; Dr. Yashodhan, JSW Energy; and Dr. K Jha, IITM as panellists. It discussed:

- need to do more impactful research in the battery management sector.
- need to address topics outlined in the E-mobility R&D roadmap for India.
- Implementing AI for battery diagnostics, life cycle management, thus increasing the life of batteries and helping in reuse and recycle.

The **second technical session** gave an **overview of recycling practices** followed in the LIB industries.

This started with the talk of **Santosh Kumar, founder of Li-Circle** which gave an outline of the pretreatment practices of batteries. Li-circle focuses on the circular economy for lithium-ion batteries, aiming to recover rare earth metals through urban mining. Santosh and his team at Li-circle develop sustainable strategies, circular business models, and innovative approaches to battery recycling and waste management. Their goal is to drive positive change in the battery industry by promoting sustainable practices and creating a more sustainable and eco-friendlier world. He highlighted the need to develop an automated process to recover both cathode and anode material as well as collect the electrolyte in the recovery step.

Prof. V. Aravindan from IISER Tirupati enlightened the participants and delegates about graphite recycling from spent LIBs. He discussed about the importance of graphite recovery from spent LIB. His group used recovered graphite (RG) from spent LIBs as an additive with excellent electrochemical performance, replacing commercial conductive additives and prepared TiO_2@RG and TiO_2@AB through planetary milling in various compositions and tested their performance in half-cell setups versus lithium. They have successfully fabricated a hybrid lithium-ion capacitor by pairing TiO_2@RG as the negative electrode and commercial activated carbon (AC) as the positive electrode (Jyothilakshmi et al., 2024). He also focused on the production of graphene from the exfoliated recovered graphite from spent LIBs (Divya et al., 2022). .

Dr. Pankaj Choubey, Head R&D, Evergreen RecycleKaro illustrated the critical metal recovery from the complex composition of black masses. Evergreen RecycleKaro recovers Ni, Co, Cu, Li, and graphite from the LIB blackmass. It also recovers Cu, Ni, Mn, Co, Au, Ag, Pt, Pd, Rh, Ru, Ir, In, Ta, Nd etc. from electronic waste. It follows hydrometallurgical route to recover valuable metals from blackmass. Lithium of 99.7% purity and cobalt of 99.5% purity are obtained. Lithium is recovered as lithium carbonate and cobalt as cobalt sulfate with more than 90% recovery efficiency. They plan to focus on the recovery of graphite, LiCoO2 and electrolyte before any chemical treatment and manufacture battery-grade precursor materials for reuse in new LIBs.

Dr. Chidambaram Mandan from Lohum discussed economical and environmentally friendly recycling methods with high outputs. LOHUM aims to become the world's largest producer of sustainable Liion battery raw materials and critical materials through recycling, repurposing, and low-carbon refining. It operates a lithium extraction plant, an aluminum-copper-iron recovery facility, a battery dismantling unit, and a battery reassembly facility. Lohum has also indigenously recycled catalytic converters using hydrometallurgy with minimal energy. The company extracts rare earth metals like Nd, Pr, La, Ce etc. from end-of-life devices and achieved a 98% black mass recovery from any battery material. Their technology produces Li, Co, and Ni salts with over 99.90% purity and operates as a zero-waste process.

Panel discussion was moderated by Prof. Jayasree Biswas, IITB with Dr. P Choubey, Evergreen Recyclekaro; Prof. V Aravindan, IISER Tirupati; S Kumar, Li-Circle; and Dr. Chidambaram Mandan, Lohum as panelists. It discussed following topics:

- Closing the loop of the recycling process where no waste is generated. Wastewater is cleaned and regenerated by evaporation and condensation system and reused.

- Recovered Graphite from recycling of LIB blackmass has less than 100 ppb impurity so that its performance as a battery-grade material is unaffected.
- Academia-industry collaboration is welcomed for the development of battery-grade precursor materials from the recovered blackmass and for improving the quality of yield of the product, leading to reduction in cost manufacturing.
- Both academia and industry are in a win-win situation once a technology developed by academia through an industry-funded collaboration is shared with the industry.

The seminar concluded with the Sponsor's videos and short talks.

Conclusions:

The intention of this seminar was to increase awareness regarding the issue of battery waste and to provide assistance to the scientific community, policy makers, and other stakeholders in identifying areas where improvements can be made to achieve a more environment-friendly and efficient reuse and recycling process. Conventional recycling technologies may not be sufficient to meet the future needs of the industry due to environmental degradation, high costs, and inefficiency. There is a need to transfer the lab-scale recycling process for battery waste management to a pilot-scale and further to a large scale operation to achieve a low-carbon economy by

I. a rational selection of the category of waste to be recycled
II. designing viable energy-efficient and effective recycling techniques for desirable end-product recovery
III. assessing the economic and energy costs implemented in every step of the recycling process
IV. establishing efficiency, % yield, % purity, industrial compatibility of the recovered product, and
V. harmless exposure to human and environment.

In this regard both academia and industry need to work together in the research and development of reuse, repurpose and recycling of EoL batteries and bring out impactful outcomes which addresses the issue of sustainable battery circularity. There is need for economical, environment-friendly and sustainable technologies to tackle the problem of critical and valuable metal recovery for fabricating battery-grade precursors which can be used to develop new batteries. This would help close the loop of circular economy leading to waste minimization and resource recovery from secondary resources.

Perspectives and Recommendations:

- Develop good reuse, refurbishment practices and spread awareness on giving away/collecting batteries after they are of no use to their owners.
- Develop models using AI tools to assist the collection of spent batteries.
- Need for separation of individual solid metals with high purity.
- Need for completely automated process (from feeding till packaging).
- Thermal treatment for ultimate value recovery.
- Optimization of process parameters involved in froth flotation for recovery of graphite before the pyro- and hydrometallurgical treatment of LIB black mass.

- Need to develop a flowsheet to recover all components of EoL LIBs, including the electrolyte.
- Develop sustainable practices to recover battery-grade materials from the EoL LIBs and test their applications.

IIT Bombay Research Hub for Green Energy and Sustainability

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