



IIT MADRAS RESEARCH CENTRE

CENTRE FOR RESOURCE EFFICIENCY, RECYCLABILITY & CIRCULARITY IN ENERGY TRANSITIONS

CRRET

Annual Report 2025–2026

FUNDED BY
HSBC India

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Annual Report
2025–2026

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– March 2027

PROJECT LOCATION
4th Floor, Bhupat & Jyoti Mehta
Biotech Block-II, IIT Madras



IIT MADRAS RESEARCH CENTRE

CENTRE FOR RESOURCE EFFICIENCY, RECYCLABILITY AND CIRCULARITY IN ENERGY TRANSITION

Funded by **HSBC India**



Annual Report 2025–2026



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Prepared by:

Dr. Sankha Karmakar, Nobika Joy, Dolly Sweetlin and Team CRRET

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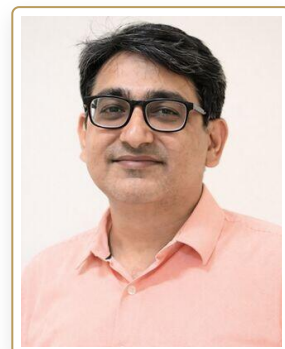
Dr. Hariprasad Narayanan

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FOREWORD

We are delighted to present the Annual Report of the Centre for Resource Efficiency, Recyclability and Circularity in Energy Transitions (CRRET) for the academic year 2025-2026. Established at Indian Institute of Technology Madras, the Centre serves as a hub for research and innovation in circular economy principles. Our work is made possible through the support of HSBC India, whose commitment to sustainable development matches our mission.



In this reporting period, the Centre has achieved significant milestones. We have set up state-of-the-art research laboratories, published high-impact research, and filed key patents. Our educational initiatives and community outreach programs continue to raise awareness about sustainability. We remain dedicated to finding practical solutions to the critical challenges of energy transitions.

I would like to thank our partners at HSBC India, our faculty colleagues, our dedicated research staff, and the administration of IIT Madras. Their support has been crucial to our success. I invite you to read this report and join us in our efforts to build a sustainable and circular future.

Prof. Rajnish Kumar

Lead PI and Head, CRRET
School of Sustainability, IIT Madras

PREFACE

This report highlights the operational milestones and scientific progress achieved by the Centre for Resource Efficiency, Recyclability and Circularity in Energy Transitions (CRRET) during the 2025-2026 period. As co-investigators, we present the collective efforts of our entire research team, spanning CO₂ sequestration, water purification, waste valorization, e-waste recycling, sustainable battery technologies, energy systems policy, and sustainability design.

Over the past year, we have concentrated on setting up advanced research spaces, including the SMART Lab and the REVAMP Lab. These facilities provide critical tools for battery recycling and materials characterization, supporting our core initiatives in converting industrial waste into valuable resources. At the same time, our research extends to analyzing policy frameworks, assessing energy systems, and developing membrane technologies for water purification.

In addition to our scientific and policy research, we have focused on community engagement and education. We developed new academic courses and conducted outreach programs for schools and local stakeholders. These programs are designed to inspire the next generation of scientists and build collaborative networks across sectors.

We are grateful to all our faculty colleagues, project staff, researchers, and students whose hard work is the core of our achievements. We also thank HSBC India and IIT Madras for their support and trust in our vision.



Dr. Sankha Karmakar

Assistant Professor
Chemical Engineering
IIT Madras



Dr. Sreeram K. Kalpathy

Associate Professor
Metallurgical & Materials Eng.
IIT Madras



Dr. Nitin Muralidharan

Assistant Professor
Chemical Engineering
IIT Madras

1. OUR TEAM

Distinguished faculty members leading interdisciplinary research in sustainable resource management, circular economy, and energy transition technologies.

Core PI Faculty

**Prof. Rajnish Kumar****Lead PI & Head**

School of Sustainability, IIT Madras

Research Focus:

CO₂ Sequestration & Water Purification

**Dr. Sankha Karmakar****Assistant Professor**

Chemical Engineering, IIT Madras

Research Focus:

Industrial Waste Valorization & Membrane Tech

**Dr. Sreeram K. Kalpathy****Associate Professor**

Metallurgical & Materials Eng.,
IIT Madras

Research Focus:

E-waste and Plastic Waste Recycling

**Dr. Nitin Muralidharan****Assistant Professor**

Chemical Engineering, IIT Madras

Research Focus:

Battery Recycling & Sustainable Batteries

**Prof. Satyanarayana Seshadri****Head**

The Energy Consortium, IIT Madras

Research Focus:

Energy Systems and Policy

**Dr. Kaushal Jha****Adjunct Faculty**

Dept. of Engineering Design, IIT Madras

Research Focus:

Engineering Design for Sustainability

Affiliated Faculty



Dr. Abhinav S. Raman

Dept. of Chemical Engineering, IIT Madras



Prof. Tiju Thomas

Dept. of Metallurgical and Materials Engineering, IIT Madras



Dr. Khushboo Suman

Dept. of Chemical Engineering, IIT Madras



Dr. Tanushree Parsai

Dept. of Civil Engineering, IIT Madras



Prof. Arshinder Kaur

Dept. of Management Studies, IIT Madras



Dr. Srinivasan S

Dept. of Management Studies, IIT Madras



Dr. R. Ratheesh

Visiting Chair in Urban Mining, MME, IIT Madras



Dr. Himanshu Goyal

Dept. of Chemical Engineering, IIT Madras



Prof. Indumathi M. Nambi

EWRE, Civil Engineering, IIT Madras



Dr. Santosh K. Sahu

Associate Professor, Humanities & Social Sciences, IIT Madras



Dr. Krishna Malakar

Assistant Professor, Humanities & Social Sciences, IIT Madras



Dr. Rahul Muralidharan

Research Specialist, The Energy Consortium, IIT Madras

TEAM PROFILES DIRECTORY



Dolly Sweetlin
Senior Project Manager



Nishant Modi
Research Scientist



Manimegalai
Executive Secretary



Kore Sruthika
Project Engineer



Magesh M V
Project Technician



Nobika Joy G
Project Officer



Vishakha Shankar
Project Officer



Ramitha
Project Officer



K Sravani
Junior Secretary



Viswanathan D
Technical Artist

POST DOCTORAL RESEARCH FELLOWS



Swati
Postdoctoral Fellow



Subramee Sarkar
Postdoctoral Fellow



Venugopal B.
Postdoctoral Fellow



Sateesh Kupusammy
Postdoctoral Fellow



Indumathi I
Postdoctoral Fellow

PRINCIPAL & SENIOR PROJECT SCIENTISTS



Charuta Kulkarni
Principal Scientist



Aswathi
Principal Scientist



K. Shivaraj Kumar
Sr. Project Scientist



E. Carolin Mercy
Sr. Project Scientist



Sonu Yadav
Sr. Project Scientist



Janani B.
Sr. Project Scientist



Kaviraj S.
Sr. Project Scientist



Nithyasree M.
Sr. Project Scientist

PROJECT SCIENTISTS



Athira R. A
Project Scientist



Nalini V.
Project Scientist



Arivazhagan
Project Scientist

PROJECT ASSOCIATES



Abraham S. T.
Project Associate



Avani A. V.
Project Associate



Ganga K.
Project Associate



Santhra K.
Project Associate



Sudharsan
Project Associate



Thilak K.
Project Associate



Kashish F. Wadhvaniya
Project Associate

2. FOCUS FOR THE CENTRE

2.1. Sustainability Focus 2025–2026

Embedding sustainability across operations through recycling, reuse, and waste minimization.

The Centre has prioritized sustainable growth by embedding recycling, reuse, and waste minimization into its operations. Initiatives target three critical categories of material waste: battery waste, e-waste, and solar waste.

Battery Waste

Focus on reducing hazardous disposal and recovering valuable metals from used batteries and packs.

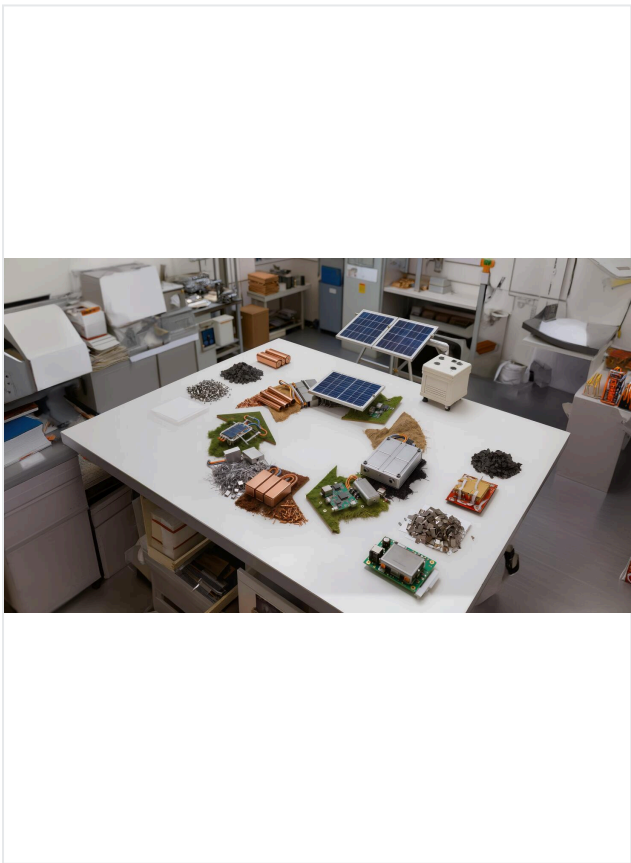
E-Waste

Responsible dismantling and material recovery from discarded devices, circuit boards, and wiring to prevent contamination.

Solar Waste

Innovative recycling methods reclaim glass, silicon, and other components from damaged or end-of-life solar panels.

These efforts collectively minimize process inefficiencies and advance a circular economy model. The Centre’s commitment ensures technological progress aligns with environmental responsibility, reinforcing our role as a leader in sustainable resource management.



3. RESEARCH LABS & WORK SPACE

SMART LAB

Sustainable Materials and Advanced Recycling Technologies

LABORATORY PROFILE

Establishment of the Sustainable Materials and Advanced Recycling Technologies (SMART LAB) as a dedicated research facility, located in the Biotech 2 Building (407). Funded by HSBC India, this facility is part of the Center for Resource Efficiency, Recyclability and Circularity in Energy Transition. It houses a state-of-art pilot line for performing Lithium-Ion Battery (LIB) Recycling R&D. Designed with green and white interiors, it reflects sustainability principles and a clean, organized research environment.

KEY CAPABILITIES

- Multiple fume hoods and safety systems.
- Materials synthesis and characterization.
- Advanced workstations for simulation and data modeling.
- Interdisciplinary collaboration platform.



RESEARCH FOCUS & IMPACT

Development of sustainable materials, advanced recycling technologies, and circular economy solutions. The lab when fully commissioned would house capabilities to generate black mass from spent LIBs, extract valuable critical materials such as (Li, Ni, Co, Mn, Cu, Al, Fe, etc.) and remanufacture battery grade cathode and anode active materials for reuse in freshly assembled Recycled LIBs. It provides a robust platform for interdisciplinary research, innovation, and collaboration in sustainability science, enhancing institutional capacity for high-impact research.



REVAMP LAB

Recycling of E-waste and Valorization of Advanced Materials and Plastics Laboratory

REVAMP LAB PROFILE

Establishment of the Recycling of E-waste and Valorization of Advanced Materials and Plastics (REVAMP) Laboratory as a specialized facility. The focus in the REVAMP lab is on the recycling of printed circuit boards (a part of e-waste) for the extraction of precious metals, circuit metals, plastics, and glass fiber. Clean and organized environment reflecting professional standards in research and technology development.

FOCUS & IMPACT

Focus areas include innovation in PCB recycling and material extraction. Out of every 10 kg of PCBs recycled, the process yields about 5 kg of the resin polymer (which can be projected as plastic), 2 kg of glass, and 3 kg of metals. The lab provides a platform for applied research, industry collaboration, and technology demonstration in e-waste sustainability, strengthening the visibility of the Centre's commitment to resource efficiency.

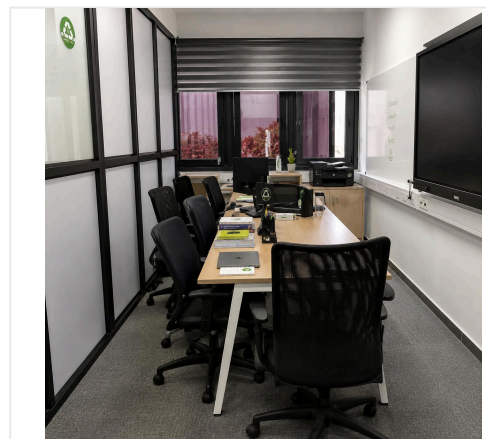


CENTRE'S OFFICE SPACE

Administration and Workspace

FACILITIES & OPERATIONS

Designated office spaces established for internal discussions and collaborative work. Two dedicated workstations provided for focused tasks and small team interactions. Extended office area with multiple aligned workstations supporting group activities and documentation. Organized setup with books, files, and essential office supplies ensuring efficient workflow. Natural lighting and glass partitions create a professional and transparent working environment. Infrastructure reflects institutional commitment to structured operations and effective team coordination. Enhances organizational capacity for planning, reporting, and internal engagement. Strengthens visibility of the Centre's professional environment and operational readiness.



INNOVATION PORTFOLIO

4. Patents

Debromination of End-of-Life Printed Circuit Board

PATENT FILEDPatent Application No: 202541002887 **Indian Patent filed, January 2025****Inventors:** Prof. Sreeram K Kalpathy, Prof. Tiju Thomas, Prof. Ratheesh Ravendran, Dr. K Shivaraj Kumar, Dr. Mississippi M Bhunia

A Device for Extraction and Accumulation of One or More Metal Ions and Method Thereof

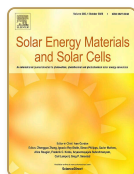
PATENT FILEDPatent Application No: 202541131513 **Indian Patent filed, 2025****Inventors:** Prof. Nitin Muralidharan, Lakshmi Narayana Manickavasagam, Abraham Samuel Thangadurai

A Metal Organic Hybrid Material and Methods Thereof

PATENT FILEDPatent Application No: 202641040498 **Indian Patent filed, March 2026****Inventors:** Prof. Tiju Thomas, Prof. Sreeram K Kalpathy, Anju Thomas

PUBLICATIONS PORTFOLIO

5. Journal Publications



Mississippi M. Bhunia, Santhra Krishnan, and Sreeram K. Kalpathy

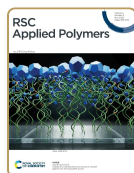
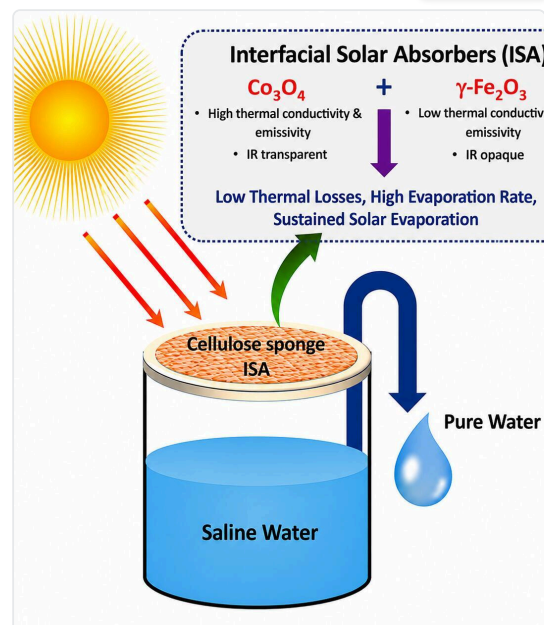
Solar Energy Materials and Solar Cells 297, 114114 (2026)

DOI: [10.1016/j.solmat.2025.114114](https://doi.org/10.1016/j.solmat.2025.114114)

[FULL TEXT](#)



Abstract: Interfacial solar absorbers (ISAs) used for photothermal (PT) desalination typically consist of a PT material and a substrate. Several ISA materials are limited by their optical absorption and thermal losses, as well as substrate pore blockage due to salt accumulation. For example, despite being highly transparent to infrared (IR) radiation, pure Co_3O_4 has restrictions as a PT material due to its high thermal conductivity and emissivity. In contrast, $\gamma\text{-Fe}_2\text{O}_3$, despite low thermal conductivity and emissivity, is often underestimated in its potential as a PT material due to not being transparent to IR radiation. This work attempts to synergize the merits of both materials by developing an ISA with wide absorption window and reduced thermal losses. For this purpose, nanoparticle blends of $\gamma\text{-Fe}_2\text{O}_3$ and Co_3O_4 were deposited on a cellulose-based sponge substrate, and used as an ISA. At an optimum particle loading ratio of 1:1, and upon using saline water with 3.5 wt% NaCl as the test liquid, a PT conversion efficiency of $\sim 77\%$ and evaporation mass flux of $\sim 1.2 \text{ kg/m}^2/\text{h}$ was obtained under simulated solar radiation of 1 sun. These values are respectively $\sim 11\%$ and 45% higher compared to when Co_3O_4 and $\gamma\text{-Fe}_2\text{O}_3$ are used individually. Furthermore, fluctuations in evaporation rates were found to be considerably lesser during 50 cycles of reuse. The water collected post desalination had significantly lesser Na^+ , Mg^{2+} , and K^+ ions. Besides, the negligible salt accumulation within the pores of the substrate even with saline water containing $\sim 10 \text{ wt}\%$ NaCl signifies excellent anti-fouling property of the ISA.

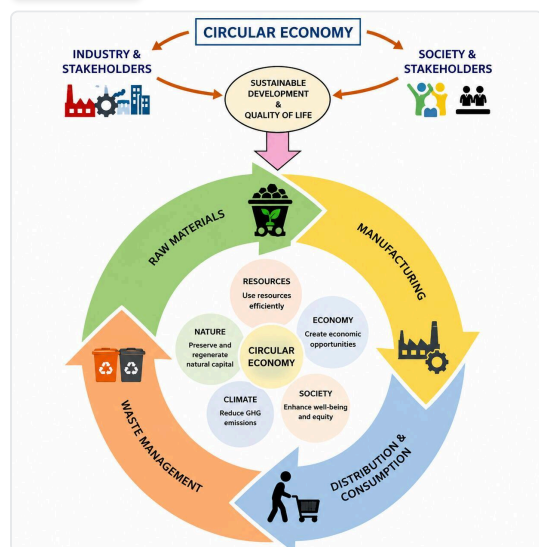


Suvitha S. Kumar, Berly Robert, Sreeram K. Kalpathy, and Tiju Thomas

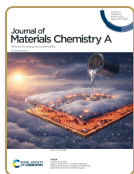
RSC Appl. Polym. 4 (3), 861-891 (2026)

DOI: [10.1039/D5LP00385G](https://doi.org/10.1039/D5LP00385G)

[FULL TEXT](#)



Abstract: Modern industries are experiencing a dual transition: advancing toward sustainability (Industry 5.0) goals while simultaneously embracing Industry 4.0, characterized by Internet of Things (IoT)-driven smartification. This rapid expansion of interconnected devices is occurring in an era where conventional electronics remain fundamentally unsustainable, with persistent challenges in recycling, metal segregation, and circularity. This disconnect necessitates alternative material and fabrication strategies that can enable scalable sensor deployment without exacerbating environmental burdens. In this review, we analyze recent progress (over the last five years) in low-temperature fabricated polymer-driven sensors, focusing on their relevance for sustainable environmental and health monitoring. Advances across different polymer families and fabrication techniques are systematically examined, with evaluation from both sustainability and scalability perspectives. Special emphasis is placed on how these approaches address limitations of conventional high-temperature, resource-intensive processes and their applicability across sectors such as agriculture, pharmaceuticals, textiles, and chemicals. By examining current literature in light of the dual transition, the review identifies recent trends, outlines knowledge gaps, and highlights pathways for integrating polymer-based sensors into large-scale, environmentally responsible technologies.



Berly Robert, Suvitha S. Kumar, Tiju Thomas, and Sreeram K. Kalpathy

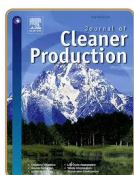
J. Mater. Chem. A 14 (22), 13318-13331 (2026)

DOI: 10.1039/D5TA09015F

[FULL TEXT](#)



Abstract: Industries in both developed and developing countries are under growing pressure to align with sustainable development goals (SDGs) while simultaneously contributing to economic development. Several SDGs inevitably require maintenance of air, water, and soil quality. Industrial effluents typically pollute these natural resources, which in turn need effective monitoring through sensors. Conventionally, sensors have relied largely on semiconductor materials; however, their high cost, manufacturing bottlenecks, availability, and environmental footprint limit their suitability in many low- and middle-income countries. In contrast, polymeric sensors, particularly if derived from recycled plastics, could offer a scalable, customizable, and cost-effective platform. Their inherent flexibility, light weight, and easy fabrication enable seamless integration into Internet of Things (IoT) devices, which would help industries move closer toward decentralized monitoring. Electronic waste (e-waste) could serve as a suitable and valuable source of polymers for sensor materials, given their high diversity and that much of recycled e-waste polymers are incinerated or landfilled. This article unearths new opportunities in the field of urban mining in the form of combining recycled e-waste plastics and IoT-integrated polymer science to advance sustainable and customizable sensor development. It is hoped that these ideas would tremendously strengthen circular economy initiatives, particularly in resource-constrained economies.

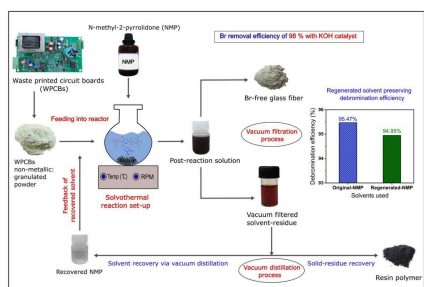


Shivaraj Kumar Kummari, Mississippi M. Bhunia, R. Ratheesh, Tiju Thomas, and Sreeram K. Kalpathy

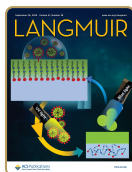
Journal of Cleaner Production 561, 148331 (2026)

DOI: 10.1016/j.jclepro.2026.148331

[FULL TEXT](#)



Abstract: Printed circuit boards (PCBs) contain substantial amounts of brominated epoxy resin (BER), which releases hazardous polybrominated dioxins and furans upon thermal treatment. This makes it difficult to recycle PCBs through conventional smelting processes. This study presents a low temperature ($\sim 100^\circ\text{C}$), atmospheric pressure solvothermal process for near-complete removal of BER, achieving $\sim 98\%$ debromination of the non-metallic fraction (NMF) of waste PCBs (WPCBs). The process uses N-methyl-2-pyrrolidone (NMP) as a solvent, which penetrates the polymer matrix, inducing swelling, depolymerization, and cleavage of brominated bonds. The addition of KOH as a catalyst markedly enhances debromination kinetics through secondary reactions that further degrade the BER into phenolic by-products. The NMP solvent is recovered via vacuum distillation and reused without loss of debromination efficiency, establishing a zero liquid discharge system. The solid residue products post filtration and vacuum distillation consist of glass fiber and Br-free resin polymer, which are potentially reusable for secondary applications. The process is demonstrated to be scalable, and a plausible mechanistic pathway for solvothermal debromination is proposed. Overall, this work offers an environmentally sustainable and energy-efficient strategy for bromine removal from end-of-life PCBs, enabling subsequent recycling, metal recovery, and circular material utilization.



Guguloth Naresh, Roopesh Patali, Ethayaraja Mani, and Sreeram K. Kalpathy

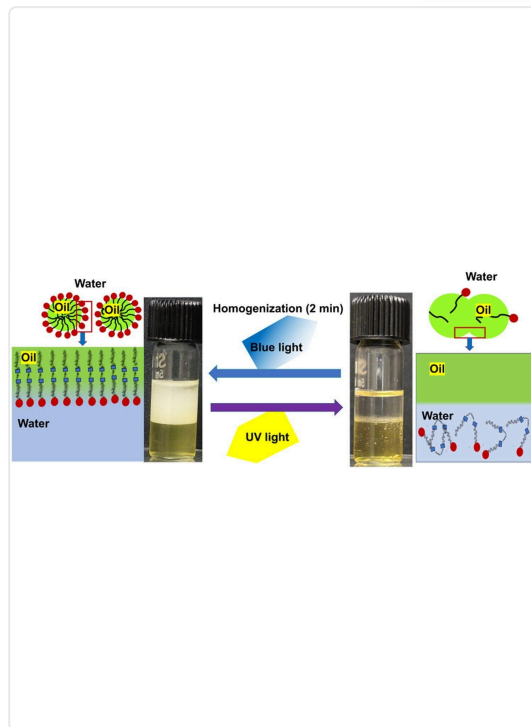
Langmuir 41 (38), 25919-25929 (2025)

DOI: [10.1021/acs.langmuir.5c02356](https://doi.org/10.1021/acs.langmuir.5c02356)

[FULL TEXT](#)



Abstract: Stimuli-induced interfacial destabilization of oil–water emulsions is an attractive approach for emulsion processing, as it typically requires less energy input than conventional bulk manipulation methods. In this work, we demonstrate the photoinduced destabilization and reconstruction of n-decane-in-water emulsions that were rendered highly stable (>45 days) with the help of an azobenzene-containing cetyltrimethylammonium bromide (Azo-CTAB) surfactant. Phase separation was induced easily in Azo-CTAB stabilized emulsions by the illumination of ultraviolet (UV) light, which activates photoisomerization of the Azo-CTAB molecule and would, in turn, affect its interfacial adsorption. A simple analysis based on the size of the dispersed phase droplets shows that phase separation occurs by coalescence of the droplets, following second-order kinetics. The coalescence rate constant is higher by about 5 orders of magnitude when demulsification is induced by UV exposure, compared to those in samples stored under ambient conditions. The degree of phase separation can be controlled by tuning various factors, such as the power intensity of UV light, the addition of an electrolyte, and the addition of a mutually soluble solute. The coalescence rate is faster by about 4–5 times in the presence of an added electrolyte (NaCl). When UV light of low intensity ($\sim 1 \text{ mW cm}^{-2}$) is used, complete demulsification can still be achieved if a small quantity of a volatile liquid such as ethanol is added to the emulsion. More interestingly, we show that the original emulsion can be reconstructed by subsequently illuminating the phase-separated mixture with visible light, thus demonstrating photoswitchability in Azo-CTAB stabilized emulsions. The reversible photoswitchability persists for multiple (5–7) cycles, without any appreciable change in the appearance and size of the dispersed droplets. These results have great significance in applications that require repeated and facile stabilization and destabilization of emulsions, such as oil recovery and wastewater treatment.

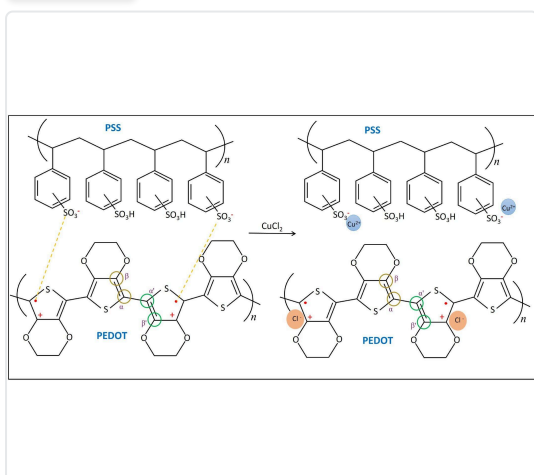


Suvitha S. Kumar, K. V. Vidhya, Tiju Thomas, and Sreeram K. Kalpathy

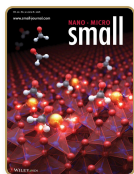
Polymers for Advanced Technologies 36 (11), e70365 (2025)

DOI: [10.1002/pat.70365](https://doi.org/10.1002/pat.70365)

[FULL TEXT](#)



Abstract: Copper is an essential trace element for human health, and a key micronutrient for plants. However, excess of copper can pose risks to environment and human health. Therefore, tools for quantitative detection of copper as well as other heavy metals are useful in various settings. Such tools are crucial for ensuring safe water access and monitoring wastewater treatment. Here, we report the development of a copper (Cu^{2+}) sensor that is capable of operating in aqueous media over a wide concentration window between 1 nM and 8 mM within an error of 10%. The sensor test strip was fabricated by drop casting the polymer poly(3,4-ethylene dioxithiophene)-poly(styrene sulfonate) (PEDOT:PSS) on glass substrate. Subsequently, the PEDOT:PSS test strips were dip coated in Cu^{2+} containing aqueous solution, and analyzed using Fourier transform infrared (FTIR) spectroscopy. The area under relevant portions of the FTIR spectra were computed to arrive at calibration curves, which serve as the basis for sensing. The polymer-metal interaction that facilitates sensing is discussed in light of Pearson's hard soft acid base (HSAB) theory. The results provide a foundation for fabrication of low-cost, targeted detection systems for heavy metal ions over a wide concentration range.



Lakshmi Narayana Manickavasagam, Shivam Dutta, Mega Kar, Ilias Belharouak, and Nitin Muralidharan

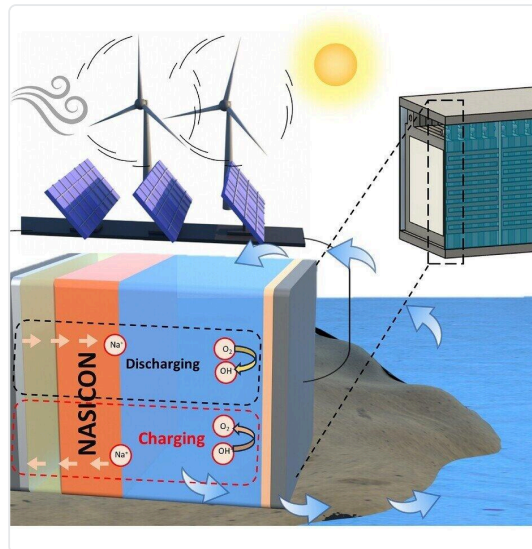
Small, e73939

DOI: [10.1002/smi.73939](https://doi.org/10.1002/smi.73939)

[FULL TEXT](#)



Abstract: Battery Energy Storage Systems (BESS) are required to be safe, cost-effective, and demonstrate long-duration energy storage capabilities and sodium-based rechargeable seawater batteries can be promising candidates for such demanding applications. These batteries are ideal for coastal economies where the use of abundant seawater as cathode materials and their compartmentalized and adaptable design can be redesigned to enable water desalination, CO₂ capture, and several other applications. Moreover, variants of these systems can potentially use metallic sodium with a very high volumetric energy density of $>4 \text{ kWhL}^{-1}$. Our technical assessments reveal that such configurations boast volumetric energy densities ~ 5 times greater than prevalent hydrogen-based storage systems. This comprehensive review compiles and summarizes recent research developments in rechargeable seawater batteries. Moreover, we have also evaluated the potential of prospective deployment of seawater batteries for applications such as behind the meter energy storage systems for EV charging stations. Additionally, we have also evaluated the technical feasibility of these batteries compared to other prevalent long-duration energy storage systems as a potential storage solution for coastal economies. Overall, this review provides a detailed summary, feasibility study, and perspective on the promise of sodium-based rechargeable seawater batteries for BESS applications.



Lakshmi Narayana Manickavasagam, Rohan Murugavel, Anubala Singaravelu Kumar, and Nitin Muralidharan

Batteries & Supercaps, Wiley (Submission under Review)

UNDER REVIEW

EDUCATION & OUTREACH

6. Courses Developed

LIQUID FILM COATING PROCESSES AND QUALITY ASSESSMENT

Instructors:

- **Dr. Siharitha Rowthu**, Faculty,
Materials Engineering Department, IIT Gandhinagar
- **Dr. Sreeram K. Kalpathy**, Faculty,
Metallurgical and Materials Engineering Department, IIT Madras &
Center for Resource Efficiency, Recyclability, and Circularity in Energy Transition,
School of Sustainability, IITM

NPTEL Collaboration, Relevance, and Impact:

This specialized online course has been developed in partnership with the National Programme on Technology Enhanced Learning (NPTEL). The curriculum addresses crucial industrial needs by focusing on the physics and mechanics of liquid film coating processes along with modern quality assessment techniques. By bridging fundamental transport phenomena with practical manufacturing applications, the course delivers high educational relevance for engineering students and industry professionals alike. It is highly impactful because it equips learners with key skills in surface engineering, thin film fabrication, and defect analysis, which are vital for enhancing resource efficiency and scaling up manufacturing in the energy transition sector.

LIQUID FILM COATING PROCESSES AND QUALITY ASSESSMENT

INSTRUCTORS :

Dr. Sriharitha Rowthu, Faculty,
Materials Engineering Department,
IIT Gandhinagar

Dr. Sreeram K. Kalpathy, Faculty,
Metallurgical and Materials Engineering Department,
IIT Madras & Center for Resource Efficiency,
Recyclability, and Circularity in
Energy Transition, School of Sustainability,
IIT Madras



Dates of the Workshop:
21st February, 2026



Last date of Registration:
18th February, 2026



Timings (IST) :
10:00 am to 01:00 pm
02:00 pm to 04:00 pm



Mode of the Workshop:
Online

FOR REGISTRATION CLICK HERE



Fee Structure:

- Students :**
Rs.354 /- (300 + 18% GST)
- Industry Professionals :**
Rs 590 /- (500 + 18% GST)

Intended Audience

- Undergraduate.
- Postgraduate students from Materials Engineering.
- Metallurgical Engineering.
- Chemical Engineering.
- Mechanical Engineering.
- Food Processing.
- Marine Engineering.
- Ceramic Engineering.
- Physics, Chemistry, any other allied discipline.
- Also, professionals working in industries will find this course beneficial.



For any queries :
npotelplus.workshop@npotel.iitm.ac.in

7. PROGRAMMATIC PORTFOLIO

7.1. Industry Partnerships and Engagements

MOU Signing with Bridge Green UpCycle

April 2025

The ceremony, documented officially, symbolized mutual agreement and collaboration, emphasizing shared commitments to sustainability and upcycling. This milestone marks a significant step toward advancing environmental initiatives and reflects a joint dedication to future projects that foster sustainable practices and circular economy principles.



Visit to BGU Hydrometallurgical Plant (Led by Prof. Nitin Muralidharan)

October 2025

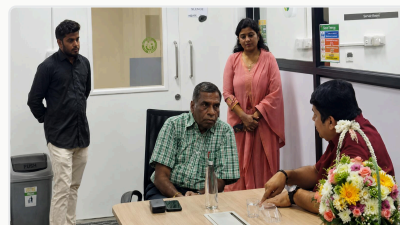


The interaction facilitated meaningful dialogue around operational practices and collaborative opportunities. Notably, discussions focused on strengthening partnerships in hydrometallurgical processes and advancing sustainability-driven initiatives. This engagement contributed to reinforcing industry collaboration, enhancing knowledge exchange, and supporting the development of sustainable and circular technology practices aligned with the Centre's objectives.

Murugappa Group Leadership & Distinguished Visitor Lab Engagements

January 2023 & February 2026

M.M. Murugappan, Executive Chairman of the Murugappa Group, visited the SMART Lab and REVAMP Lab under the theme of industrial engagements. The visit was documented in two frames: one capturing a laboratory discussion with equipment visible, and the other showing a formal conversation at a table with additional participants. The atmosphere reflected structured industrial-academic collaboration, emphasizing the importance of strengthening ties between industry leadership and research facilities. The engagement enhanced institutional visibility and highlighted innovation, while also demonstrating a strong commitment to advancing industrial partnerships and applied research that contribute to sustainable progress and future collaboration.



Visit to SMART and REVAMP Labs

February 2026



Distinguished visitors, including Dr. Sarma, Head of the MME Department, Dr. Ratheesh, Director General of CMET, Dr. Debashish Bhattacharjee, Former Vice President, along with Dr. Sankaran and N.V. Ravikumar, visited the SMART Lab and REVAMP Lab under the theme of industrial engagements. The group engaged in discussions within advanced laboratory settings, with scientific equipment and research posters highlighting the high-tech environment. The interaction reflected professionalism, collaboration, and knowledge exchange, strengthening academic-industrial partnerships and enhancing visibility of institutional research capabilities.

JSW Group Delegation Visit

March 18, 2026

A delegation from JSW Group visited the SMART and REVAMP Labs to understand ongoing research initiatives and explore collaboration opportunities. Led by Prof. Nitin, the group engaged with faculty and researchers, gaining insights into advanced recycling technologies and circular economy approaches. Discussions focused on sustainable materials, industrial recycling, and scalable solutions for energy transition challenges. A formal meeting on March 18, 2026, reinforced institutional visibility, identified opportunities for joint projects, and strengthened academia–industry ties supporting innovation in sustainability and resource efficiency.



Future Editor Workshop with Elsevier

March 2026

IIT Madras, in collaboration with Elsevier, organized the Future Editor Workshop to strengthen India's role in global research publishing. Led by Helen Habernickel, Executive Publisher, Energy, Elsevier, Berlin, the interactive session highlighted India's growing leadership in scholarly publishing. Editors discussed roles, peer review, ethics, inclusion, and commissioning impactful content, while participants explored Elsevier's editorial tools. Journals showcased included Renewable and Sustainable Energy Reviews, Energy Conversion and Management, Journal of Power Sources, Solar Energy Materials and Solar Cells, and Energy and Climate Change, reinforcing India's expanding editorial leadership.



7.2. Capacity Building for Waste Handlers Across Segments

Strengthening public hygiene and recycling supply chains through awareness, training, and direct community outreach.

400+

 WASTE HANDLERS
TRAINED

4

TARGET VERTICALS

25

STUDENTS SELECTED

3

DISTRICTS COVERED

Outreach Segments

7.2.1. Naan Mudhalvan School E-waste Awareness (August 2025): School Children Awareness Program on E-waste management for "Naan Mudhalvan Scheme students" was organized in August 2025 for the top 25 Grade 9 students selected for the program. The objective was to raise awareness among school children on responsible E-waste handling and sustainability. The format featured an interactive seminar with presentations and discussions led by faculty and experts in a formal classroom/seminar setting, fostering structured engagement. A key highlight was that students actively engaged with the session on "Centre for Resource Efficiency and Circularity in Energy Transition". The impact of this initiative was strengthened institutional outreach by promoting circular economy principles among younger audiences, achieving enhanced recognition of the Centre's role in sustainability education and community engagement.



7.2.2. Industrial Segment: Outreach activity was conducted for industrial waste handlers in Chennai at CPCL Industry and the Integral Coach Factory (ICF) area. The participants included industrial workers equipped with safety vests and helmets, ensuring compliance with workplace safety standards. The format featured structured sessions including presentations, panel discussions, and interactive engagement. The objective of these sessions was to raise awareness on safe handling practices, waste management, and environmental responsibility, with facilitators consisting of experts and institutional representatives delivering talks and guidance. This initiative strengthened institutional outreach to industrial sectors, promoting sustainable waste management practices, and enhanced recognition of the Centre's role in advancing resource efficiency and circular economy principles within industry.



7.2.3. Residential Segment: Outreach activity was conducted for residential waste handlers at SBIOA Apartment, Mambakkam, with more than 400 active community members engaged in the program. The audience consisted primarily of residential waste handlers, with strong representation from women participants. The format featured structured sessions including awareness talks, training interactions, and distribution of materials. The objective of this initiative was to strengthen community-level waste management practices and promote sustainable handling of residential waste, aligning with the Centre's four outreach verticals (Community, Industrial, Residential, and Informal waste handlers). This program delivered enhanced awareness and capacity-building among residential waste handlers, fostering responsible environmental practices and reinforcing institutional commitment to sustainability and community engagement through large-scale participation.



7.2.4. Community Segment: Outreach activity was conducted for community waste handlers in Chennai. The participants included Urbaser sanitation workers from Sholinganallur and Valasaravakkam (Greater Chennai Corporation). The format featured structured sessions including awareness talks, panel discussions, and interactive engagement. Activities included a group pledge on responsible waste handling, formal presentations, and interactive discussions. The audience showed a large participation of sanitation workers in orange uniforms, reflecting strong engagement. The objective of these sessions was to strengthen awareness, training, and recognition of sanitation workers' role in maintaining public hygiene. This program delivered enhanced community-level capacity building, promoting sustainable waste management practices and reinforcing institutional commitment to outreach and circular economy principles through direct engagement with frontline workers.



7.2.5. Informal Sector: Outreach activity was conducted for informal waste handlers, focusing on awareness and training. Participants engaged in structured sessions including presentations, demonstrations, and interactive discussions. The activities included group photos with posters, highlighting collective commitment to waste management practices. Demonstrations showcased the handling of electronic waste items such as cables and keyboards to reinforce practical learning, and presentations were delivered on e-waste management supported by visual aids and informational posters. The program witnessed active participation from community members, with both male and female attendees contributing to discussions. The objective of these sessions was to build awareness and capacity among informal waste handlers on sustainable waste practices. This effort strengthened institutional outreach to informal sectors, promoting responsible e-waste handling and circular economy principles while reinforcing the Centre's role in community engagement and sustainability education.



7.3. School Education and Outreach Initiatives

Promoting Green Skill Development and sustainability education at the school and grassroots levels across multiple districts.

7.3.1. Daffodils Concept School (Sindhanoor, Raichur District, Karnataka): Outreach activity on Green Skill Development was conducted at Daffodils Concept School, Sindhanoor, Raichur District, Karnataka, with 70 students, 20 teachers, and community members actively engaged in the program to ensure broad and inclusive participation. Sessions were delivered by facilitators, combining classroom talks, interactive discussions, and practical awareness activities with large student participation and attentive involvement in sustainability-focused learning. Community members, including women participants, actively engaged in training and awareness sessions, reinforcing the importance of skill development in environmental responsibility and sustainable practices. Group photographs and collective participation highlighted strong institutional-community collaboration, which strengthened awareness and capacity building among students and the local community on sustainability skills while enhancing recognition of the Centre's role in promoting green skills and environmental education at the grassroots level.



7.3. School Education and Outreach Initiatives (Continued)

7.3.2. St. Mark's Matriculation School (Selaiyur, Chennai): Outreach activity on Green Skill Development was conducted at St. Mark's Matriculation School, Camp Road Selaiyur, Chennai, with 60 students and 15 teachers actively engaged in the program. Activities included certificate distribution, classroom discussions, and structured awareness sessions, combining group learning, interactive engagement, and formal recognition of student participation to build environmental awareness and sustainability-focused skills among school students. The active involvement of teachers and organizers ensured effective delivery and student participation, which strengthened institutional outreach to the education sector, fostering early adoption of green practices and reinforcing the Centre's role in promoting skill development and sustainability education at the school level.



7.3. School Education and Outreach Initiatives (Continued)

7.3.3. Riverside Public School (Kotagiri): Outreach activity on Green Skill Development was conducted at Riverside Public School, Corsley Road, Kotagiri, with 50 students and 12 teachers actively engaged, supported by educators, organizers, and community members. Activities included classroom sessions, interactive presentations, and group discussions on sustainability-focused skills. Facilitators delivered structured talks supported by visual aids and banners, reinforcing environmental awareness. Students participated in group photos and collective activities, highlighting strong institutional-community collaboration to promote environmental responsibility and skill development among school students. This initiative delivered strengthened awareness and capacity building in sustainability practices at the school level and enhanced recognition of the Centre's role in advancing green skills and environmental education.



7.3. School Education and Outreach Initiatives (Continued)

7.3.4. Christwood School (Ponmar, Chennai): Outreach activity on Green Skill Development was conducted across 4 schools in 3 districts, ensuring wide student participation and regional impact. Hosted at Christwood School, Ponmar, Chennai, 47 students actively joined interactive sessions, demonstrating strong interest in sustainability-focused skill development. Expert speakers delivered talks on green skills, fostering awareness and practical understanding among young learners, while 31 teachers, faculty, coordinators, and institutional representatives actively contributed, highlighting a strong academic-community partnership. The activity involved students and staff across genders, reflecting inclusivity in outreach efforts. Group interactions and collective activities emphasized teamwork, environmental responsibility, and long-term skill building, strengthening ties with local educational institutions. The program's success is documented through photographs showcasing lectures, group discussions, and collective participation, reinforcing transparency and outreach effectiveness.



7.4. Programmatic Engagement: Scaling Circular Pathways

Stakeholders Engagement Meeting — 27 February 2026 at IIT Madras Research Park.

Event Overview: The Stakeholders Engagement Meeting was held on 27 February 2026 at the IIT Madras Research Park, organized by the Centre for Resource Efficiency, Recyclability and Circularity in Energy Transitions. The event drew active participation from academia, industry, and government institutions engaged in sustainability dialogues. Keynote insights from Prof. Manu Santhanam emphasized collaborative innovation for scalable waste management solutions, while government perspectives from Ms. Ganga Dileep C highlighted the Thuimai Mission and systemic challenges in managing diverse waste streams. Prof. Sankha Karmakar outlined the Centre's research focus on plastics, batteries, and solar panels using interdisciplinary approaches. Currently, pilot units process 50 kg/day of battery, plastic, and solar waste, with an expansion planned at the IIT Madras Tarur campus. The innovation focus remains centered on advanced battery recycling technologies, diagnostics, and material recovery to support India's growing energy storage needs.



SESSION I - BATTERY RECYCLING AND ENERGY AUDIT

This session focused on battery recycling, energy auditing, and circular energy systems in the context of India's energy transition. India's electric vehicle market is projected to reach 40% penetration by 2030, requiring nearly one billion battery cells. The Centre's research infrastructure includes the BAT Lab, which supports diagnostics, coin and pouch cell fabrication, and performance evaluation, as well as the SMART Lab, which handles recycling and material recovery at a processing capacity of 50 kg per day. Cathode minerals such as lithium, nickel, and cobalt were highlighted as critical supply chain concerns, with cobalt scarcity identified as a major risk. Hydrometallurgical, pyrometallurgical, and direct recycling methods were discussed as key technological approaches for material recovery. A significant innovation gap was noted in translating academic research into industrial-scale recycling solutions. Emerging tools including artificial intelligence, machine learning, and a proposed battery passport system were highlighted for enabling lifecycle traceability and efficient sorting. The session emphasized that the current export of black mass creates supply chain inefficiencies, and that building domestic recycling capacity is a national priority. It concluded that stronger collaboration between academia, industry, and government is essential for developing sustainable battery ecosystems.



SESSION II - PLASTIC, E-WASTE AND SOLAR WASTE IN INDUSTRY

This session addressed circular economy strategies for plastics, e-waste, and solar panel waste. India is among the world's largest generators of e-waste, with printed circuit boards (PCBs) posing particular complexity due to the presence of both valuable metals and hazardous substances. The informal sector plays a significant role in waste collection but lacks the technological capacity and safety standards required for effective processing. On plastic recycling, the session emphasized chemical recycling approaches and biodegradable alternatives, as well as the need to integrate end-of-life design considerations into product development. IIT Madras is developing zero-discharge debromination processes for safe PCB recycling that minimize secondary pollution. Extended Producer Responsibility was highlighted as a critical policy mechanism for enforcing lifecycle accountability and incentivizing recyclability across industries. Solar panel waste was identified as an emerging challenge that demands proactive recycling infrastructure for composite materials. Audience contributions called for demand-side mandates, decentralized waste parks, and regulatory reforms to expand the use of recycled plastics. The session concluded that achieving circularity in this sector requires an integrated approach combining technological innovation, policy support, economic incentives, and broad multi-sector collaboration.



SESSION III - WASTE TO WEALTH APPROACHES AND SUSTAINX 2026

This session focused on sustainable materials, waste-to-wealth technologies, and circular innovation systems. A central theme was the scaling challenge faced in translating laboratory research into industrial applications, with infrastructure gaps, economic constraints, and regulatory barriers identified as the primary obstacles. Advancements in polymer science and material recovery were presented as promising pathways to improve recyclability and reduce environmental impact. The session also emphasized integrated systems for nutrient and energy recovery from wastewater streams as part of broader resource efficiency strategies. Waste-to-wealth approaches were discussed as mechanisms to convert industrial, electronic, and organic waste into valuable products, including metal recovery and energy generation. Startups were recognized as key drivers of innovation in this space, though participants noted the need for sustained funding, mentorship, and access to pilot-scale infrastructure. Joint research initiatives, pilot projects, and cross-disciplinary partnerships between industry and academia were recommended to accelerate the deployment of circular technologies. Audience interventions highlighted enforcement gaps in Extended Producer Responsibility and Battery Waste Management Rules, with academics encouraged to actively pursue commercialization opportunities. The session concluded that long-term success requires technological innovation supported by coherent policy frameworks, efficient waste segregation systems, and sustained collaboration across sectors.



7.5. Conference and Seminar Presentations

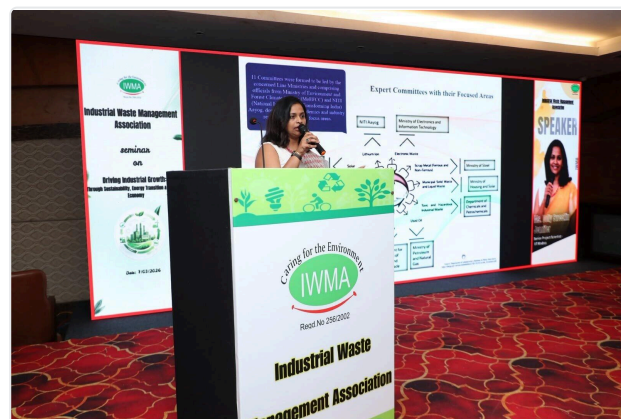
IWMA - CIRCULAR ECONOMY FRAMEWORK

Ms. Dolly, Senior Project Scientist, delivered a session at the Industrial Waste Management Association seminar on the theme "Driving Industrial Growth: Through Sustainability, Energy Transition and Circular Economy." The session presented India's Circular Economy framework, highlighting national policies and implementation pathways for industry stakeholders. Key policy milestones covered included the NITI Aayog's Circular Economy Cell coordinating ten waste streams, Extended Producer Responsibility regulations introduced in 2016 for plastics, e-waste, and hazardous waste, the Vehicle Scrappage Policy of 2021, and EPR provisions for batteries and tyres enacted in 2022. The session also referenced eleven expert committees addressing sectoral action plans for e-waste, battery waste, solar waste, and municipal solid waste. CRRET's priorities for 2025 to 2026 were outlined, encompassing recycling of e-waste, batteries, and solar waste, reducing operational inefficiencies, and enabling growth through technology partnerships and integrated supply chains. Waste-to-wealth initiatives such as GOBAR-Dhan, which supports biogas generation with 67.8% district coverage, and Tamil Nadu's Circular Economy Investment Policy 2026 with over 600 MoUs, were highlighted as key examples of impact. The engagement reinforced the importance of academia-industry collaboration, ESG and BRSR relevance, and future directions in digital traceability and AI-driven recycling.



CHEM-TECHNOVA 2026 (HBTU KANPUR)

On 14 March 2026, Ms. Dolly Sweetlin Jennifer delivered the keynote address at CHEM-TECHNOVA 2026, held at Harcourt Butler Technical University, Kanpur. The presentation shared the vision, initiatives, and impact of the School of Sustainability at IIT Madras in advancing sustainable development and circular economy transitions. The School was positioned as a collaborative platform connecting industry, policymakers, and researchers to co-develop solutions for critical environmental challenges. Key domains emphasized included sustainable energy systems, water security, and circular economy, with a focus on the need for integrated and interdisciplinary approaches. The session showcased the School's strong capacity-building efforts through academic programs, executive education, and government training initiatives that enable large-scale knowledge dissemination. Actionable research was demonstrated through living labs and interdisciplinary projects on methane monitoring, plastic upcycling, wastewater management, and industrial decarbonization. CRRET's role in advancing waste recycling, battery recovery, and circular economy technologies was prominently highlighted. The importance of stakeholder engagement through conferences, workshops, and industry collaborations was stressed as essential for achieving real-world impact and policy influence. The keynote concluded by introducing the Climate and Sustainability Venture Studio as a bridge between research and entrepreneurship for developing scalable climate solutions.



7.6. Competitions and Hackathons Representation

IDEAS TO IMPACT (I2I) CHALLENGE RECOGNITION

Team Eco-solar e-waste recyclers, comprising Monica Kannan, Adithyan T.R., Shivaraj Kumar, and Suvitha S. Kumar, mentored by Prof. Tiju Thomas and Prof. Sreeram K. Kalpathy, was selected among the top 10 teams in the prestigious Ideas to Impact (i2i) Challenge 2024-25. The team's innovative approach to addressing e-waste challenges through sustainable solar-driven recycling solutions reflects strong academic guidance and practical relevance. Their achievement highlights the institution's commitment to fostering student innovation, advancing circular economy principles, and promoting impactful research. This recognition reinforces IIT Madras's leadership in sustainability-oriented initiatives and industry-aligned problem solving.

TEAM NAXUS - GLOBAL SUSTAINABILITY CHALLENGE

Team NaXUS from IIT Madras, led by Lakshmi Narayana Manickavasagam (Doctoral Scholar, Department of Chemical Engineering) with undergraduate teammates from the same department, achieved a significant milestone by being declared Champion of the South Asian Region and selected as a finalist for the Global Sustainability Challenge to be held in Germany. The team's innovation builds on the R&D efforts of the EMERGE Research Group under Prof. Nitin Muralidharan, resulting in the development of a seawater battery that uses energy-dense sodium metal and seawater. This eco-friendly alternative to lithium-ion batteries offers remarkable potential, delivering up to five times volume savings compared to hydrogen-based energy storage solutions. The project was showcased under the banner of the Global Sustainability Challenge, with logos of IIT Madras, GESH IITB, and partner organizations reinforcing institutional visibility. The poster highlighted the team's vision of ethical, scalable, and sustainable energy storage for a renewable-powered future. Team members include Rishabh Singh, Sarthak Niphade, Sarvesh Pasare, Lakshmi Narayana Manickavasagam, and Pramod Mahato. Their achievement reflects India's growing leadership in sustainability research, advancing circular economy principles, and positioning IIT Madras as a hub for innovation in clean energy technologies and global academic-industry collaboration.

KEY MILESTONES & ACCOMPLISHMENTS

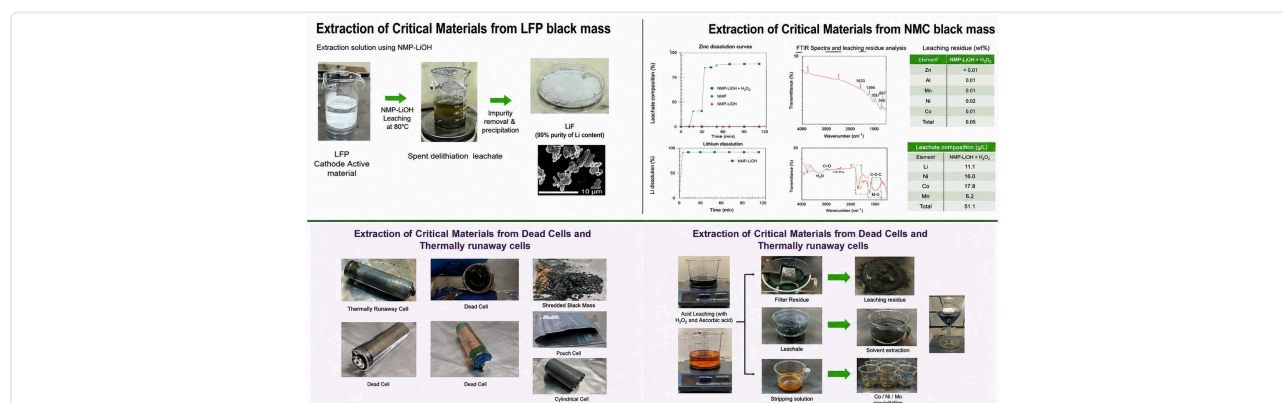
8. Key Accomplishments of the Centre

YEAR	KEY MILESTONES ACHIEVED
FY 24 - 25	Centre's capability established with two labs — Lab 407 (SMART) and Lab 410 (REVAMP). Core equipment purchased and installed (details can be provided as required). Human resources employed and key work delegated, comprising 15 staff and 6 part-time staff. 5 Collaborative R&D projects ongoing, with 6 more projects launched.
FY 25 - 26	10 Kg plastic waste recycling line installed (pending commissioning). New R&D verticals identified in AI and Supply Chain. Round 2 of the collaborative projects was funded. Engaged in the School Awareness Program on E-waste management. Skill development carried out through engagement of the IITM Xpert Housekeeping Team. 400 waste handlers and sanitation workers trained on e-waste management and waste segregation. Workforce development supported through NPTEL free courses and CODE certification. Stakeholder engagement conducted with 25 companies.

9. RESEARCH UPDATES

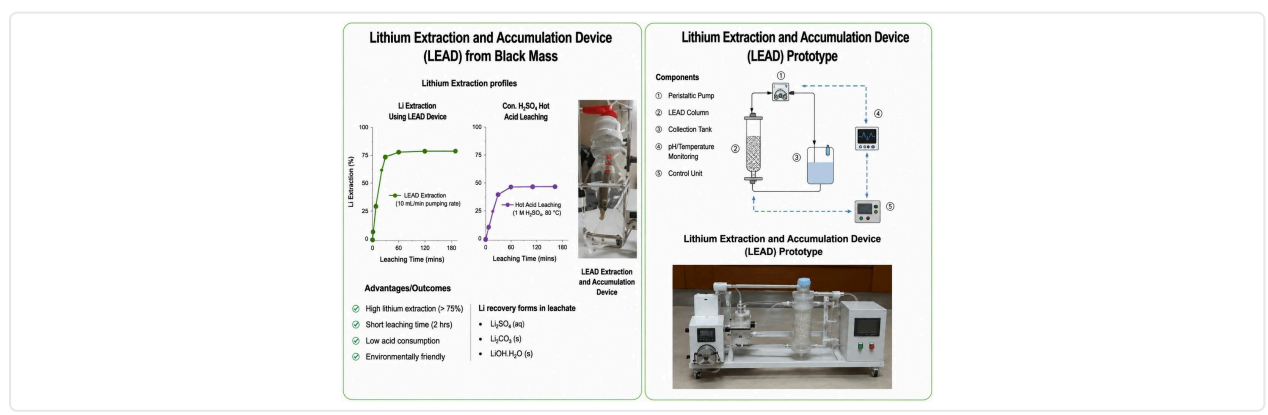
9.1. Battery Recycling Research & Development

Research under this theme focuses on the extraction of critical materials from different types of battery waste streams. Key work includes recovery from LFP black mass, with emphasis on the separation and purification of valuable components. Extraction studies have been extended to NMC black mass, supported by process flowcharts and performance data that demonstrate process efficiency. Laboratory experiments involve filtration setups and material recovery procedures designed to ensure reproducibility of results. A manuscript currently in progress documents the methodologies and findings for academic dissemination. Research also addresses recovery from dead cells, ensuring safe handling and effective material extraction. Thermally runaway cells have been studied to recover usable fractions despite physical damage, contributing to overall waste minimisation. Visual evidence of recovered materials from damaged batteries provides proof-of-concept support for the approaches developed. The outcomes strengthen sustainability efforts by reducing dependence on primary mining for critical materials. Collectively, this work contributes to circular economy goals by enabling the reuse of lithium, cobalt, nickel, and other key elements in the battery supply chain. The findings provide a strong foundation for scaling these processes to industrial-level recycling operations, while also supporting institutional visibility through advanced research in battery waste management. This work aligns with global sustainability goals by conserving finite resources and reducing environmental impact. It demonstrates the technical feasibility of recovering materials from diverse battery waste categories and enhances the broader knowledge base for future recycling innovations and evidence-based policy support.



LEAD PROTOTYPE (LITHIUM EXTRACTION AND ACCUMULATION DEVICE)

This research introduces the Lithium Extraction and Accumulation Device (LEAD) prototype, designed for recovering lithium from battery black mass. Extraction profiles were studied for both LFP and NMC black mass, revealing distinct linear regions of lithium recovery for each material type. LFP black mass demonstrated 1.3 hours of linear extraction, yielding 8.2 mg of lithium deposition, while NMC black mass exhibited 14.8 hours of linear extraction, achieving 19.2 mg. Theoretical lithium recovery was calculated at 9.97 mg, validating the experimental outcomes. Lithium was successfully deposited over copper foil, confirming the proof-of-concept for the device. The prototype design incorporates accumulation, extraction, and cathode compartments separated by a Nafion membrane, and device photographs and diagrams illustrate the operational setup and material recovery process. A patent filing is in progress, strengthening the institution's innovation portfolio and intellectual property capacity. The research supports sustainable resource recovery and circular economy principles, and outcomes reduce dependence on primary mining by enabling efficient lithium recycling from spent batteries. This work aligns with SDG goals on responsible production and clean energy, provides a foundation for industrial-scale lithium recovery technologies, and demonstrates the technical feasibility of targeted extraction from diverse battery waste streams. Collectively, the project enhances institutional visibility through advanced recycling innovation.



9.2. Collaborative R&D Projects (Projects 1–2)

PROJECT 9.2.1

Elements Recovery from E-waste & Debromination of Plastics

PI: Prof. Tiju Thomas **Co-Is:** Dr. Sreeram Kalpathy, Dr. R. Ratheesh

Global e-waste is projected to reach 82 million tonnes by 2030, with printed circuit boards containing approximately 30% metals and 70% non-metallic fractions. Conventional recycling methods release toxic emissions, creating significant environmental and health hazards. This project developed a low-temperature solvothermal debromination process operating between 40 and 200 degrees Celsius at atmospheric pressure, achieving over 75% bromine removal. A zero-liquid-discharge system was demonstrated with solvent recovery and reuse, and potassium hydroxide was identified as the most efficient reagent. Over 90% bromine removal was achieved below 130 degrees Celsius using NMP and DMSO solvents. Catalytic kinetics were established, validating the scientific basis of the process, and closed-loop solvent regeneration was successfully demonstrated. The pilot process flow encompasses depopulation, shredding, granulation, reactor treatment, filtration, solvent recovery, and drying. Outputs include reusable glass fibres, bromine-free resin, and high-purity metal fractions. The pilot operates at a capacity of 10 kg per batch, with a shredder, granulator, cyclone, and dust collector installed. A metal separation unit and a 120-litre reactor are currently under installation to further expand the process capability. A patent has been filed (202541002887), one manuscript has been submitted, and another is ready for submission. The project supports circular economy principles and aligns with SDG 12 and SDG 13 on responsible production and climate action. It contributes to SDG 3 by reducing pollution-related illnesses and deaths, and advances SDG 6 by improving water quality through reduced hazardous chemical discharge.

KEY ACHIEVEMENTS

- >90% bromine removal using KOH with NMP/DMSO.
- Demonstrated closed-loop solvent regeneration.
- Reusable glass fibres, bromine-free resin, and high-purity metal fractions produced.
- Metal separation unit and 120L reactor under installation.
- One manuscript submitted; another ready for submission.

IP: Patent Filed (202541002887)

SDG 3 **SDG 6** **SDG 12** **SDG 13**

PROJECT 9.2.2

Process Flowsheet Simulation of Battery Recycling

PI: Dr. Himanshu Goyal **Co-I:** Dr. Sankha Karmakar

This project spans 2023 to 2026 with funding support of Rs. 10 Lakhs and a utilization rate of 99.5%. The objective focused on developing a battery recycling process flowsheet using ASPEN simulation software, with simulation-based performance evaluation carried out to validate efficiency and scalability. The major outcome achieved is a validated ASPEN simulation model comparable to the IIT Madras framework. All four project milestones have been completed: M1 covering literature review and methodology, M2 covering ASPEN model development, M3 covering model optimization, and M4 covering final report preparation. The work is now ready for techno-economic analysis and scale-up studies. The project contributes to advancing circular economy practices and sustainable technology development, provides a foundation for industrial adoption of battery recycling processes, and strengthens institutional expertise in simulation-based process design. It demonstrates efficient fund utilization and timely milestone completion, aligning with SDG 9 and SDG 12.

MILESTONES (M1–M4)

- M1: Literature review and methodology completed.
- M2: ASPEN model development completed.
- M3: Model optimization completed.
- M4: Final report preparation completed.

Funding: ₹10 Lakhs (99.5% utilized)

SDG 9 **SDG 12**

9.2. Collaborative R&D Projects (Projects 3–4)

PROJECT 9.2.3: BATTERY ECO-AUDIT

PI: Prof. Indumathi M. Nambi **Co-I:** Dr. Nitin Muralidharan

The rapid growth of electric vehicles, electronics, and grid storage is increasing the volume of end-of-life lithium-ion batteries. Recovery of critical minerals such as lithium, cobalt, nickel, and manganese is essential to reduce mining impacts. Hydrometallurgical recycling offers high recovery efficiency, lower temperature operation, and compatibility with diverse battery chemistries, though environmental trade-offs necessitate a life cycle-based eco-audit for balanced assessment. The project objectives include reviewing recycling pathways, collecting pilot-scale datasets, conducting environmental LCA, identifying environmental hotspots, and developing sustainable recommendations. The methodology evaluates electrowinning, chemical precipitation, and solvent extraction routes, and an inventory database has been developed to support life cycle analysis. LCA methods applied include TRACI, BEES+, CED, AWARE, and CML. The project establishes an eco-audit framework for recycling plants and supports low-carbon battery recycling design, enabling evidence-based regulatory decisions and advancing the circular economy for critical materials. Outcomes include environmental database creation and quantified impacts on global warming, energy demand, water scarcity, toxicity, and resource depletion. Sustainability trade-offs have been identified to inform balanced recycling strategies. Milestones achieved include literature review, hydrometallurgical evaluation, process data collection, and inventory development; the life cycle impact assessment milestone is currently ongoing.

KEY MILESTONES

- Literature review and hydrometallurgical evaluation completed.
- Process data collection and inventory development completed.
- Life cycle impact assessment (LCIA) – ongoing.

SDG 12

SDG 13

SDG 7

PROJECT 9.2.4: PRICING & CE INDICATORS

PI: Dr. Santosh K. Sahu **Co-I:** Prof. Rajnish Kumar

This research explores circular economy adoption and its potential to decouple material use from economic growth, with a focus on measuring macro-economic impacts of the circular economy transition and developing sustainability indicators. A sectoral assessment examines economic and environmental trade-offs in the Indian textile industry, and an evaluation of industrial resource efficiency pathways supports sector-specific strategies. Urban resource recovery studies leverage quick-commerce logistics for aluminium can recycling in India, with reverse logistics models developed for urban recycling systems. A national material flow database has been compiled for India covering 1961 to 2008, enabling historical resource consumption analysis, alongside a global comparative dataset for 1978 to 2009 linking material use, GDP, and population trends. Methodological approaches include material flow analysis, circular economy indicators, economic-environmental modelling, policy analysis, and logistics network assessment. Expected outcomes provide evidence on the economic feasibility of the circular economy transition and generate policy insights to link growth, resource use, and sustainability. Milestones achieved include literature synthesis, database compilation, and analytical framework development; the economic modelling milestone is ongoing, with policy interpretation upcoming.

KEY MILESTONES

- Literature synthesis and database compilation completed.
- Analytical framework development completed.
- Economic modelling – ongoing.
- Policy interpretation – upcoming.

SDG 8

SDG 9

SDG 11

SDG 12

SDG 13

9.2. Collaborative R&D Projects (Projects 5–6)

PROJECT 9.2.5

Sustainable Policy Framework for End-of-Life EV Batteries in India

PI: Dr. Krishna Malakar **Co-Is:** Dr. Rahul Muralidharan, Prof. Rajnish Kumar

This project addresses standardisation gaps in battery recycling regulations and Extended Producer Responsibility alignment across EV OEMs, battery producers, and recyclers. Objectives include reviewing regulatory frameworks, conducting stakeholder consultations, identifying EPR gaps, and developing policy recommendations. The methodology involves policy review, stakeholder mapping, semi-structured interviews, and thematic analysis. Key stakeholders engaged include EV OEMs, battery producers, recyclers, and NGOs. Insights highlight standardisation gaps that limit circularity in battery recycling, and EPR targets have been found to be misaligned with actual battery lifetimes, creating compliance challenges. The informal sector has been identified as critical for collection and recycling activities. The project contributes to strengthening regulatory frameworks and advancing circular economy practices, aligning with SDG 7, SDG 9, and SDG 12 on sustainable energy and responsible production. Milestones achieved include policy review, stakeholder mapping, and interview design; the consultations milestone is currently ongoing, with further progress expected.

KEY MILESTONES

- Policy review and stakeholder mapping completed.
- Interview design completed.
- Stakeholder consultations — ongoing.

Funding: ₹3.37L utilized / ₹6.63L remaining

SDG 7

SDG 9

SDG 12

PROJECT 9.2.6

Mapping & Economic Analysis of Reverse Supply Chain of Batteries & PCBs

PI: Prof. Arshinder Kaur **Co-I:** Prof. Rajnish Kumar

This project focuses on mapping and economic analysis of reverse supply chains for batteries and PCBs, led by Dr. Arshinder Kaur, Professor at IIT Madras. The study addresses fragmented reverse supply chains in India dominated by informal actors, involving valuable materials such as lithium, cobalt, nickel, copper, and gold alongside hazardous constituents. Key aims include mapping reverse flows, identifying actors, quantifying costs and revenues, comparing centralised and decentralised logistics, and recommending efficient and sustainable business models. The methodology involves defining scope and boundaries, stakeholder mapping, interviews, field visits, economic data collection, scenario development, sensitivity analysis, and proposing interventions. Expected outcomes include detailed supply chain maps, economic profiles, comparative assessments, and actionable recommendations for policymakers, producers, and recyclers. The project also builds a foundational dataset for lifecycle assessment and investment planning. The research aligns with SDG 9 and SDG 12, contributing to sustainable logistics and responsible waste management. The total budget is Rs. 5 Lakhs, with Rs. 4.56 Lakhs allocated for staff and Rs. 0.44 Lakhs for contingency.

KEY PARAMETERS

- Cost-revenue mapping for supply chain optimisation.
- Centralised vs. decentralised logistics comparison.
- Supply chain maps, economic profiles, and policy recommendations.

Budget: ₹5 Lakhs total (₹4.56L staff + ₹0.44L contingency)

SDG 9

SDG 12

9.2. Collaborative R&D Projects (Projects 7–8)

PROJECT 9.2.7: MSME BEHAVIORAL RESPONSES

PI: Dr. S. Srinivasan **Co-I:** Prof. Rajnish Kumar

This project studies the behavioral responses of MSMEs and SMEs towards Extended Producer Responsibility in lithium battery manufacturing, led by Dr. S. Srinivasan, Associate Professor, IIT Madras. The growth of EVs in India has increased demand for lithium batteries, with MSMEs and SMEs playing a major role in battery-pack assembly. EPR is mandated under India's Battery Waste Management Rules 2022, requiring registration, compliance reporting, and recycling targets; non-compliance risks cancellation of registration, penalties, and restricted market access. Project objectives include evaluating awareness of EPR, compliance behavior, operational changes, managerial mindset shifts, and business model adaptations among these enterprises. The methodology combines surveys, compliance data analysis, interviews, case studies, and on-site observations. Expected outcomes include mapping behavioral responses, insights on awareness and compliance levels, identification of best practices, and recommendations for scalable recycling systems. The project aligns with SDG 8, SDG 9, and SDG 12, supporting decent work, industrial innovation, and responsible manufacturing practices.

KEY PARAMETERS

- EPR awareness, compliance, and operational change assessment.
- Surveys, interviews, case studies, and on-site observations.
- Recommendations for scalable EPR recycling systems.

Budget: ₹6L (₹4.56L staff + ₹1L travel + ₹0.44L contingency)

SDG 8 **SDG 9** **SDG 12**

PROJECT 9.2.8: RECYCLED POLYMER RHEOLOGY

PI: Dr. Khushboo Suman **Co-I:** Dr. Sankha Karmakar

This project tackles global plastic waste by enabling recycled plastics in additive manufacturing, with a focus on rheological characterisation to improve printability and reliability of recycled polymers. The project investigates shear-thinning for smooth extrusion and yield stress for immediate shape retention, and measures viscoelastic properties to balance elasticity and viscosity for structural stability. It examines recovery post-shear (thixotropy) and the rebuild of viscosity after extrusion, and studies curing and gelation kinetics to ensure dimensional stability and mechanical performance. The effects of additives, fillers, and contaminants on melt behaviour are also evaluated. Experimental methods employed include steady shear, stress ramp, oscillatory shear, and recovery tests at elevated temperatures. Outputs include rheological profiles, identification of critical parameters, and development of formulation guidelines, with two peer-reviewed publications targeted as key deliverables. The project advances circular economy goals by reducing plastic waste and enabling sustainable, high-performance 3D printing. It aligns with SDG 9 and SDG 12, promoting innovation in recycling and responsible production. The total budget allocation is Rs. 10 Lakhs, covering consumables, contingencies, and travel.

KEY PARAMETERS

- Shear-thinning, yield stress, and viscoelastic characterisation.
- Thixotropy, curing, and gelation kinetics studies.
- Two peer-reviewed publications targeted.

Budget: ₹10L (consumables, contingencies, travel)

SDG 9 **SDG 12**

9.2. Collaborative R&D Projects (Projects 9–11)

PROJECT 9.2.9

Recovery of Metallic Nanoparticles for Wastewater Remediation

PI: Dr. Tanushree Parsai | **Co-I:** Dr. Sankha Karmakar

Recovery of Metallic Nanoparticles from Spent Battery Waste for use in Wastewater Remediation: This project addresses the environmental hazards and resource depletion associated with spent zinc-based household batteries (Zn-C and Zn-MnO₂). Instead of allowing heavy metals to landfill, this research recovers zinc and manganese as valuable secondary resources. Spent battery waste is processed to synthesize zinc oxide (ZnO) nanoparticles, which exhibit high surface areas and enhanced reactivity. The methodology involves a hydrometallurgical leaching process (using hydrochloric acid) combined with selective solvent extraction (using Cyanex 923) and precipitation to recover high-purity ZnO nanoparticles. These waste-derived nanoparticles are then applied as photocatalysts for domestic and municipal wastewater remediation. Under light exposure, the ZnO nanoparticles act as photocatalysts, generating reactive oxygen species (such as hydroxyl and superoxide radicals) that break down organic contaminants, while their antimicrobial properties help reduce harmful microorganisms. This closed-loop process provides an efficient green chemistry framework that simultaneously tackles battery waste and improves environmental water quality.

KEY PARAMETERS

- Synthesis of ZnO nanoparticles via leaching and solvent extraction (Cyanex 923).
- Photocatalytic degradation of organic pollutants in wastewater.
- Antimicrobial evaluation for municipal and domestic wastewater treatment.

SDG 3

SDG 6

SDG 12

PROJECT 9.2.10

Green Chemistry for Metal Extraction & Polymer Sensors

PI: Prof. Tiju Thomas | **Co-I:** Dr. Sreeram Kalpathy

Green Chemistry approaches for selective extraction of metals from e-waste and polymer based sensors for critical energy transition metals: Deep Eutectic Solvents (DES) have emerged as promising green alternatives to conventional hydrometallurgical reagents for the sustainable recovery of valuable metals from electronic waste (e-waste). Composed of readily available, low-toxicity, and biodegradable components, DES possess unique solvation and complexation capabilities that enable the selective dissolution and separation of critical energy-transition metals such as lithium, cobalt, nickel, manganese, copper, and rare earth elements from complex waste matrices. Their tunable chemical environment allows targeted metal extraction under mild operating conditions, minimizing energy consumption and the generation of hazardous secondary waste. Beyond metal recovery, DES can also be employed in the synthesis and functionalization of advanced polymeric materials for sensing applications. Incorporation of DES-derived recognition sites, ion-imprinted polymers, or conductive polymer composites can lead to highly selective and sensitive sensors capable of detecting trace concentrations of critical metals in environmental, industrial, and recycling streams. The integration of DES-based extraction and polymer-based sensing technologies provides a holistic green chemistry framework for resource recovery, process monitoring, and circular utilization of strategic metals essential for batteries, renewable energy systems, and next-generation clean technologies.

KEY PARAMETERS

- Selective metal extraction (Li, Co, Ni, Mn, Cu, REEs) using DES.
- Synthesis of advanced polymer materials for sensing.
- Mild operating conditions to minimize energy and secondary waste.

SDG 9

SDG 12

SDG 13

9.2. Collaborative R&D Projects (Project 11)

PROJECT 9.2.11

ML-enabled Sorting and Recycling of End-of-Life Batteries
PI: Dr. Abhinav S. Raman | **Co-I:** Dr. Nitin Muralidharan

ML-enabled Sorting and Recycling of End-of-Life Batteries: With global lithium-ion battery (LIB) production capacity projected to reach ~1.3 TWh by 2030 and generate up to 340,000 metric tons of annual waste by 2040, automated recycling is critical. Current sorting processes are hindered by lack of global labeling and highly diverse cathode chemistries (NMC, LFP, NCA, LMO). This project develops a computer-vision-based deep learning classifier to identify battery chemistries. To address data scarcity, transfer learning is applied to a pre-trained ResNet model trained on the ImageNet dataset. The model is fine-tuned with an experimentally curated, labeled (using LabelMe), and augmented dataset of end-of-life battery images. Splitting the dataset into an 80/10/10 ratio, the model targets binary classification (NMC vs. LFP) with >90% accuracy, eventually scaling to multi-class classification for direct integration into automated sorting and recycling systems.

KEY PARAMETERS

- Transfer learning using ResNet (pre-trained on ImageNet) for battery classification.
- Experimental dataset curation, labeling (LabelMe), and data augmentation.
- Targeting >90% accuracy for binary classification (NMC/LFP) and multi-chemistry scaling.
- Fusionstor Workstation: 36-core Intel Xeon, 128GB RAM, NVIDIA RTX 4080 16GB GPU.

Budget: ₹10.40L (₹5.00L equipment, ₹5.15L staff, ₹0.25L contingency)

SDG 7

SDG 9

SDG 12

10. PROGRESS SUMMARY

Key performance metrics and achievements for Year 2 (FY 2025–2026), tracked across outreach, infrastructure, technology development, and academic collaborations.

OUTREACH & COVERAGE

KEY PERFORMANCE INDICATOR	Q1 Apr– Jun '25	Q2 Jul–Sep '25	Q3 Oct– Dec '25	Q4 Jan– Mar '26
Total no. of direct beneficiaries	NA	—	250	400
Total no. of indirect beneficiaries	NA	—	2000	3000
Total no. of state covered	1	—	1	2
Total no. of district covered	1	—	3	5
Total no. of block covered	1	—	5	7
Total no. of center covered	NA	—	5	5

BATTERY RECYCLING LABORATORY SETUP

KEY PERFORMANCE INDICATOR	Q1 Apr– Jun '25	Q2 Jul–Sep '25	Q3 Oct– Dec '25	Q4 Jan– Mar '26
Space identified for the lab (Yes/No)	Yes	Yes	Yes	Yes
No. of rooms/centres under the lab	2	2	2	2
No. of equipment/machinery procured and installed at the lab	NA	1	6	10
No. of equipment/machinery installed for R&D and pilot testing	NA	12	14	31
No. of experts/people utilising the lab	14	18	22	32

TECHNOLOGY DEVELOPMENT & SCALE-UP

KEY PERFORMANCE INDICATOR	Q1 Apr– Jun '25	Q2 Jul–Sep '25	Q3 Oct– Dec '25	Q4 Jan– Mar '26
No. of existing technologies considered for the assessment	1	2	2	3
No. of Life Cycle Assessment (LCA) reports completed for the existing technologies	—	—	—	—
No. of recycling technologies progressed from TRL 3-4 to TRL 5-6	—	—	—	2
No. of technologies transitioned from lab-scale to pilot-scale	—	1	1	3
No. of pilot lines established for scale-up demonstrations	—	1	1	3
No. of pilot-scale demonstrations conducted (~100 kg batches)	—	—	1	1
No. of recycling companies engaged for pilot testing	—	1	1	4

VALIDATION & STAKEHOLDER ENGAGEMENT

KEY PERFORMANCE INDICATOR	Q1 Apr– Jun '25	Q2 Jul–Sep '25	Q3 Oct– Dec '25	Q4 Jan– Mar '26
No. of exhibitions and product demonstrations conducted	—	—	—	1
No. of stakeholders (industry, academia, policymakers) engaged	—	1	—	1
No. of training sessions conducted for industry or academic partners	—	1	—	1
No. of industry partnerships established for technology validation	—	—	1	3
No. of field trials initiated for new recycling technologies	—	—	—	—
No. of research papers published on new recycling approaches	—	2	3	5
No. of workshops and seminars conducted for knowledge sharing	—	1	1	2
No. of participants attending workshops/seminars	—	25	30	60
No. of technological developments showcased at national/international forums	—	—	6	10

CURRICULUM & MANPOWER DEVELOPMENT

KEY PERFORMANCE INDICATOR	Q1 Apr– Jun '25	Q2 Jul–Sep '25	Q3 Oct– Dec '25	Q4 Jan– Mar '26
No. of new R&D verticals initiated for waste recycling	—	3	3	3
No. of research studies initiated in emerging waste recycling techniques	—	11	11	12
No. of new elective courses introduced at IIT Madras	—	—	—	—
No. of NPTEL certification courses developed and launched	—	—	1	1
No. of students enrolled in NPTEL courses	—	—	—	—
No. of industry-academic collaborations for skill-building initiatives	—	—	2	4
No. of students enrolled in battery recycling certification programs	—	—	—	230
No. of industry personnel trained through workshops	—	—	—	45
No. of internships offered to undergraduate (NIT) students	—	—	7	10
No. of students transitioning to higher education (M.Tech/PhD) in sustainability fields	—	—	—	4

RECYCLING APPROACHES & PILOT DEMONSTRATIONS

KEY PERFORMANCE INDICATOR	Q1 Apr– Jun '25	Q2 Jul–Sep '25	Q3 Oct– Dec '25	Q4 Jan– Mar '26
Battery Recycling				
Total quantity of battery waste processed per quarter (kg)	—	—	10	20
Total no. of QR-code enabled sorting tests conducted	—	—	10000	10000
Total no. of battery chemistries identified and sorted	—	2	2	2
Yield of black mass recovered (kg)	—	—	5	10
Metal recovery efficiency (%) from hydrometallurgical process	—	—	>95%	>95%
Total no. of direct recycling trials conducted	—	—	3	3
Solar Panel Recycling				
No. of solar panels dismantled and processed	—	—	—	1
Yield of recovered glass, silicon, and metal components (kg)	—	—	—	2
No. of chemical extraction tests performed	—	—	—	0
Efficiency (%) of resource recovery from panels (percentage)	—	—	—	0
Plastic Waste Recycling & Valorization				
Amount of plastic waste recovered from e-waste (kg)	—	—	20	20
Number of new processes tested for flame retardant removal	—	—	2	2
Yield (in %, Output/Input) of the process developed for metallic and plastic waste recovery from e-waste	—	—	—	85

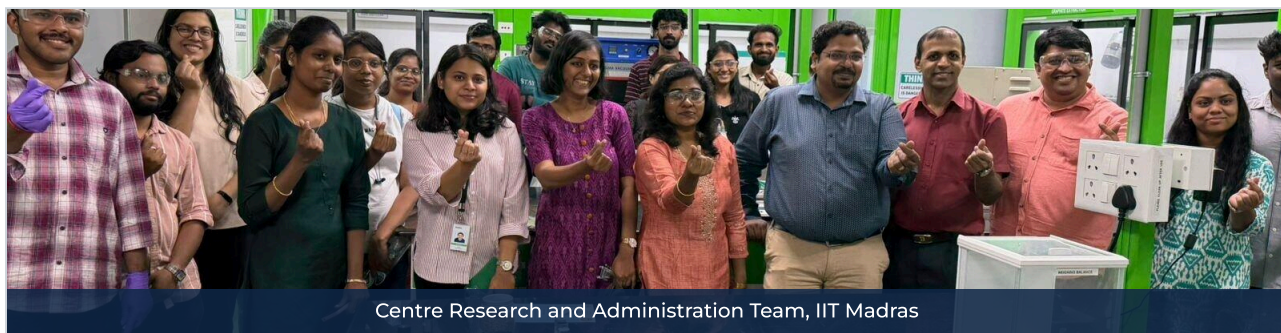
11. ACKNOWLEDGEMENT

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We are especially thankful to our industry partners, government bodies, and institutional collaborators for their valuable engagement and support in strengthening research translation and sustainable technology development. Their continued collaboration has enabled impactful progress in areas such as battery recycling, e-waste management, plastics sustainability, and circular economy research.

We also acknowledge the contributions of our research staff, project scientists, associates, technical teams, and administrative members whose dedication ensures the successful execution of the Centre's activities. Special appreciation is extended to community partners, schools, waste-handling workers, and stakeholders who actively participated in the outreach and awareness programs organized during the year.

Finally, we express our gratitude to the funding agencies and institutional leadership whose continued support enables the Centre to pursue innovative solutions for sustainable resource management and energy transition.



Centre Research and Administration Team, IIT Madras

IIT MADRAS RESEARCH CENTRE

Centre for Resource Efficiency, Recyclability & Circularity in Energy Transitions (CRRET)



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ABOUT THE CENTRE FOR RESOURCE EFFICIENCY, RECYCLABILITY & CIRCULARITY IN ENERGY TRANSITIONS (CRRET)

The global transition from fossil-based energy systems to renewable and low-carbon alternatives is essential to achieving climate and net-zero goals. However, this shift is also generating a rapidly growing volume of end-of-life waste from renewable energy infrastructure such as lithium-ion batteries, solar photovoltaic panels, and associated electronic components. If not managed responsibly, this waste threatens to undermine the environmental benefits of clean energy. The Centre for Circularity in Energy Transitions, supported through a CSR-led philanthropic initiative of HSBC India, was established to address this critical challenge. The Centre is dedicated to embedding circular economy principles into energy transitions by ensuring efficient recovery, reuse, and valorisation of materials across the entire lifecycle of energy technologies. Working across all verticals of circularity, the Centre integrates fundamental research, translational innovation, pilot-scale demonstration, policy engagement, and capacity building. Its focus spans metallic, non-metallic, and plastic waste streams from batteries, solar panels, and energy-related electronics, with particular emphasis on difficult-to-recycle polymers that are often overlooked. Collaboration is central to the Centre's approach. By bringing together academia, industry, policymakers, start-ups, and global research partners, the Centre develops scalable, sustainable solutions aligned with key United Nations Sustainable Development Goals, including Responsible Consumption and Production, Affordable and Clean Energy, and Climate Action. By reimagining waste as a resource and circularity as a design principle, the Centre for Circularity in Energy Transitions aims to ensure that the clean energy transition is not only low-carbon, but also resource-efficient, resilient, and enduring.



CENTRE FOR RESOURCE EFFICIENCY, RECYCLABILITY & CIRCULARITY IN ENERGY TRANSITIONS (CRRET)

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