NANYANG TECHNOLOGICAL UNIVERSITY SINGAPORE

E-waste Recycling

NTU-Singapore CEA Alliance for Research in the Circular Economy (SCARCE)

Prof. Madhavi Srinivasan (NTU)
Dr. Jean-Christophe Gabriel (CEA)

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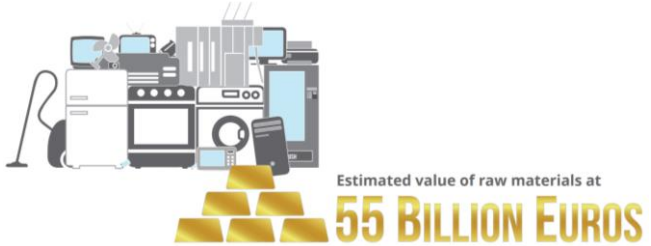
E Waste

Worldwide 45 million tonnes of e-waste was generated in 2016

≈ 4500 Eiffel towers

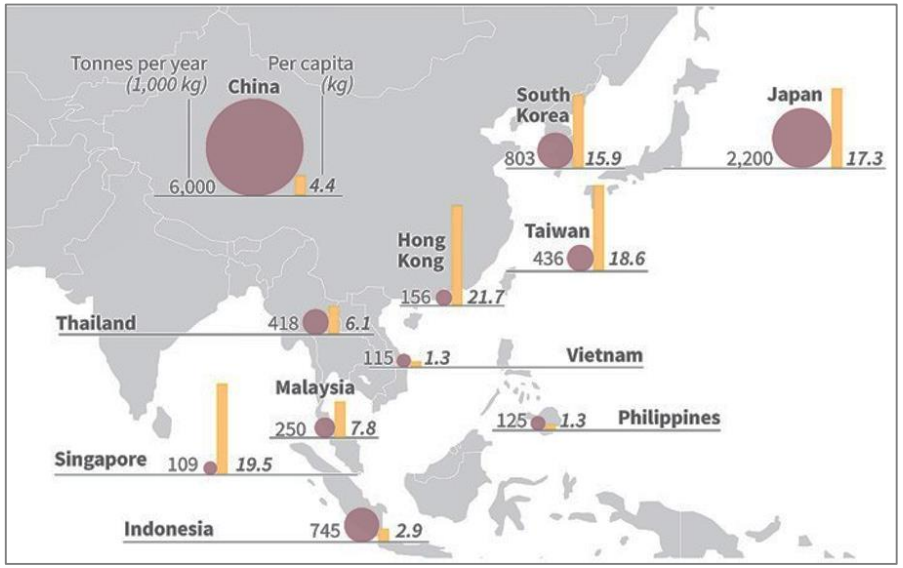
E-waste contains **toxic** elements, such as Pb, Cd, Hg, etc, poses health, environmental hazards

15-20% are recycled or “downcycled”



Up to *60 elements from the periodic table* can be found in complex e-waste along with plastics and many of them are technically recoverable.

E-waste in Asia



- In Singapore generates 60,000 tonnes of e-waste per year (NEA).
- Second largest producer of e-waste in this region 19.5 kg per person e-waste

Source : UNU-VIE Sustainable Cycles Programme/Japan Ministry of Environment

NTU Singapore – CEA Alliance for Research in Circular Economy (SCARCE)

- SCARCE aims to develop innovative, solutions for the recycling and recovery of resources from electrical and electronic waste (e-waste)

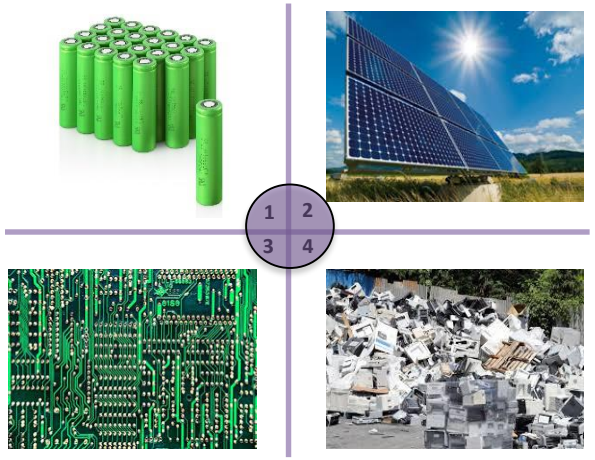
- SCARCE will focus on four research thrusts :

  Thrust 1: Recycling of advanced lithium ion batteries

  Thrust 2: Recycling of silicon solar panels

  Thrust 3: Recycling and recovery of valuable metals from printed circuit boards

  Thrust 4: Recycling and treatment of plastic part from e-waste



10 (NTU) + 12 (CEA)+ 30 (Researchers)
3 years

SCARCE Project Scope

Sorting, ,mechanical process, hydrometallurgy, separation, detoxification, materials reuse processes etc.

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RT 1: Recycling of Lithium ion Batteries

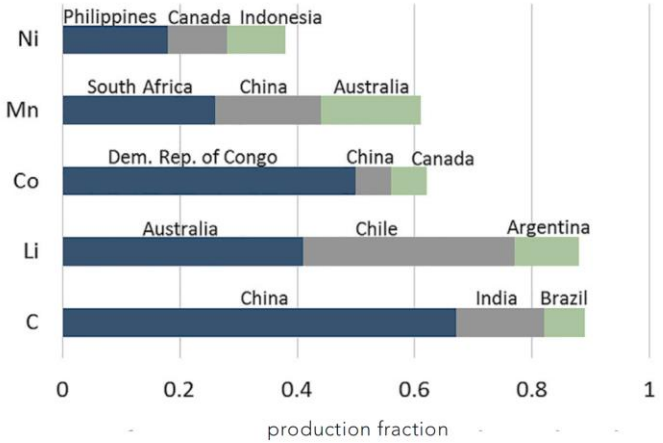
Madhavi Srinivasan (NTU), Dalton Tay (NTU)
Daniel Meyer (CEA), Andreas Brambilla (CEA)

Why Recycle Lithium ion Batteries (LIB)?

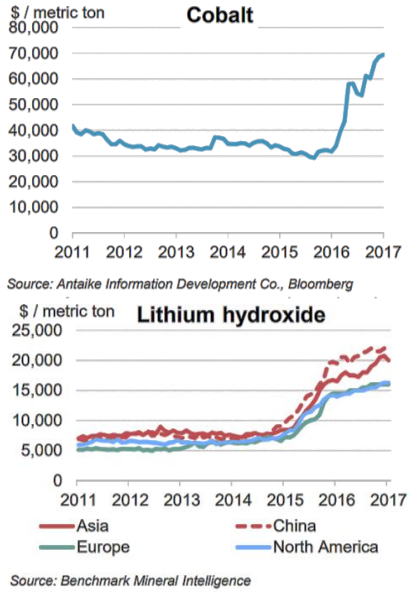
Environmental Concern

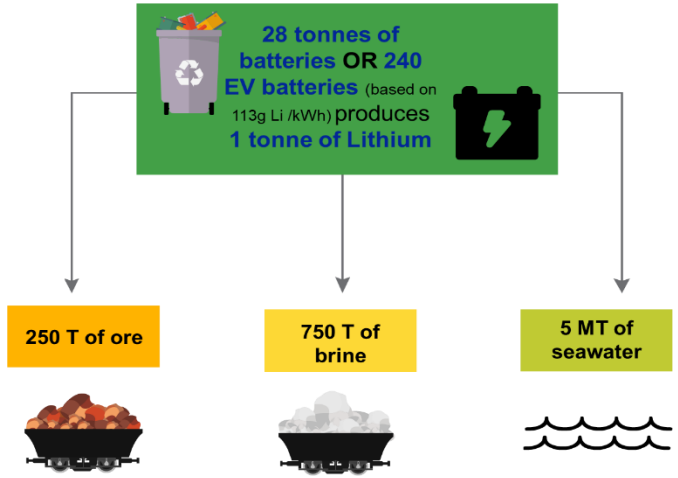
- Toxic Heavy metals like Co, Ni, and Mn would contaminate soil and water
- Corrosive hazardous gas such as hydrogen fluoride (HF), CO, CO_2, etc

Resource Recovery



Resources Policy 51 (2017) 100–106

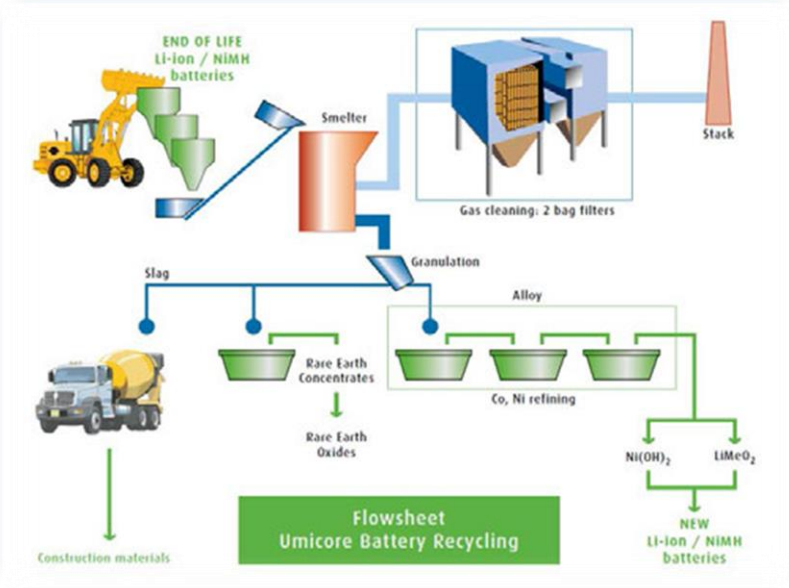


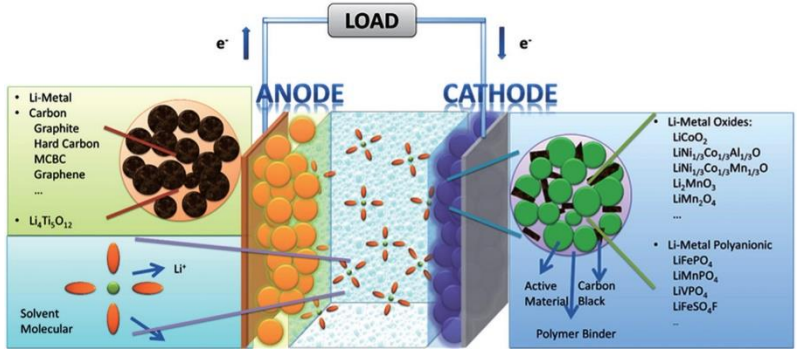


Joule 1, 229–243, October 11, 2017

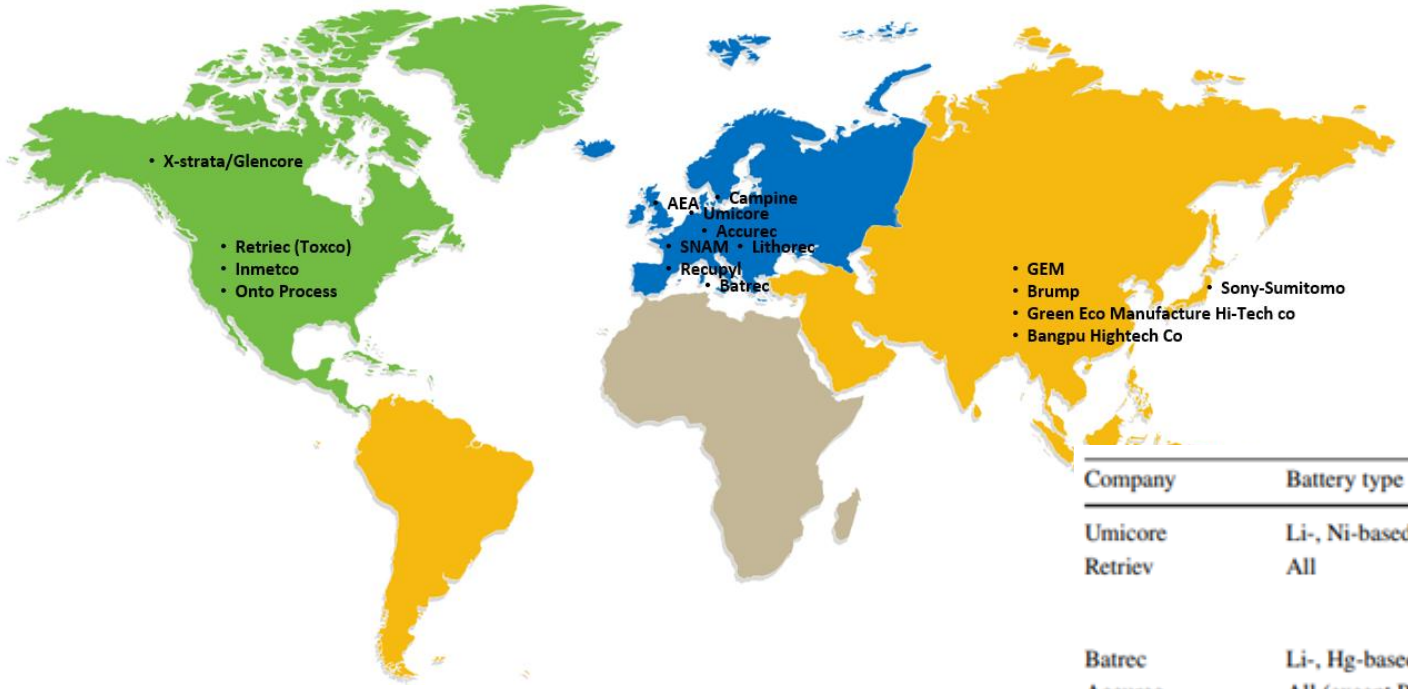
State of art LIB recycling

- Commercial Smelting: Pyrometallurgy, same as other batteries (**Discharge - Shred – Melt – Recover)**
- High-Temperature required, **Li, Co, Ni, go to slag,** recovered @ **high $ and energy costs**
- Environmental gas emissions HF, Dioxin etc.



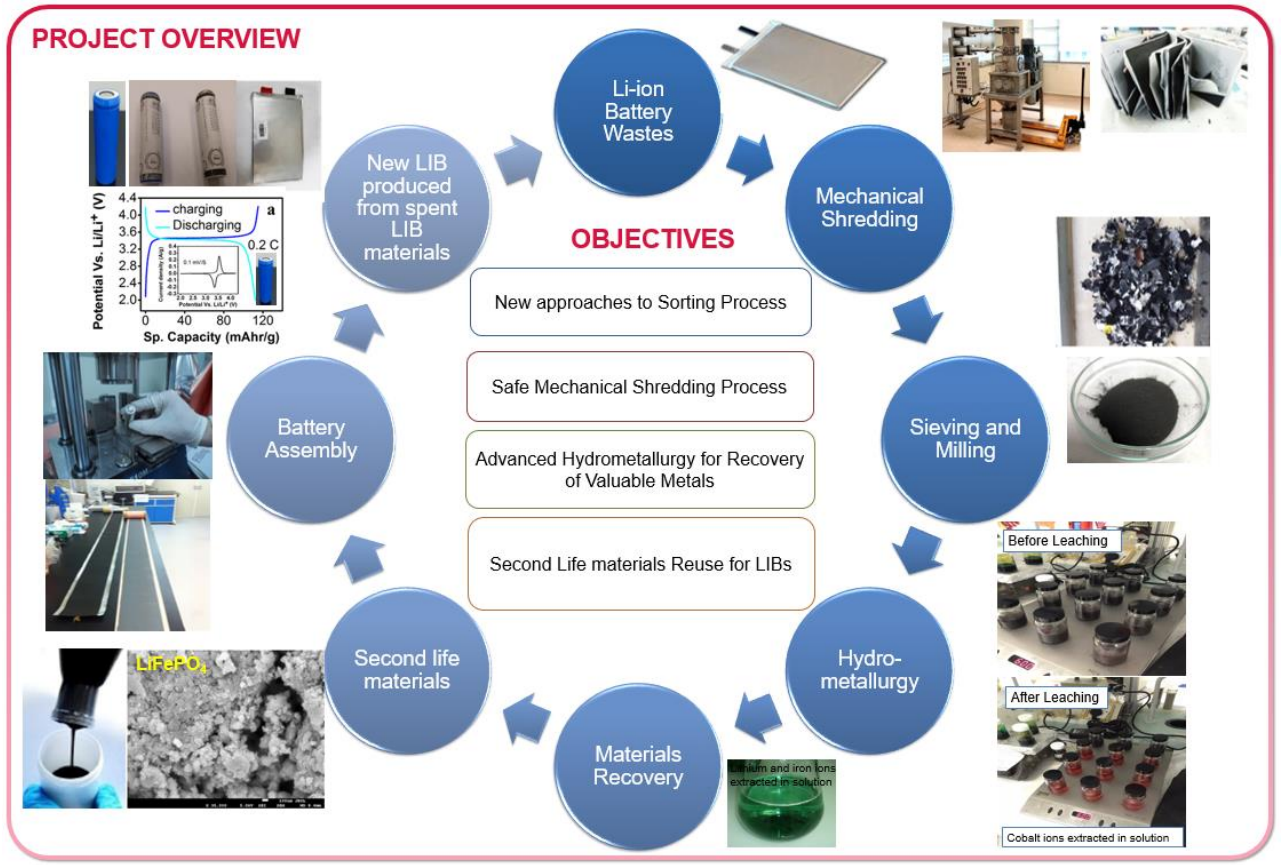


LIB Batteries Recycling Industries



Company	Battery type	Methods
Umicore	Li-, Ni-based	Pyrometallurgy and hydrometallurgy
Retriev	All	Pyrometallurgy (Ni-based) Hydrometallurgy (Li-based) Mechanical process (Pb-acid)
Batrec	Li-, Hg-based	Pyrometallurgy
Accurec	All (except Pb and Hg)	Pyrometallurgy
SNAM	Li-, Ni-based	Pyrometallurgy
Inmetco	Li-, Ni-based	Pyrometallurgy
Recupyl	Li-, Zn-based	Hydrometallurgy
Sony & Sumitomo	All	Pyrometallurgy
Xstrata	Li-, Ni-based	Pyrometallurgy and hydrometallurgy
GEM	Li-, Ni-based	Hydrometallurgy
Brunp	Li-, Ni-based	Hydrometallurgy

Lithium ion batteries (LIB) Recycling process at SCARCE

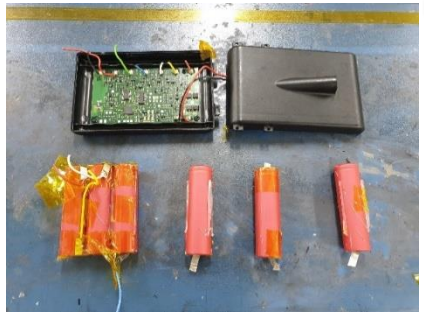


Circular economy process for lithium ion batteries established at NTU

- New (LIB) from waste used LIB
- Overall high recycling rate (>90%)
- >80% extraction of constituent elements in LIB demonstrated
- Second life reuse of materials demonstrated

Lithium ion batteries shredding

- ✓ Set up a mechanical battery shredder in the SCARCE lab which can shred 10kg/h of various form factor of lithium ion batteries.
- ✓ We have collected over 1000 batteries packs/cells in NTU. Ongoing demonstration of using NTU as test bed for battery recycling.

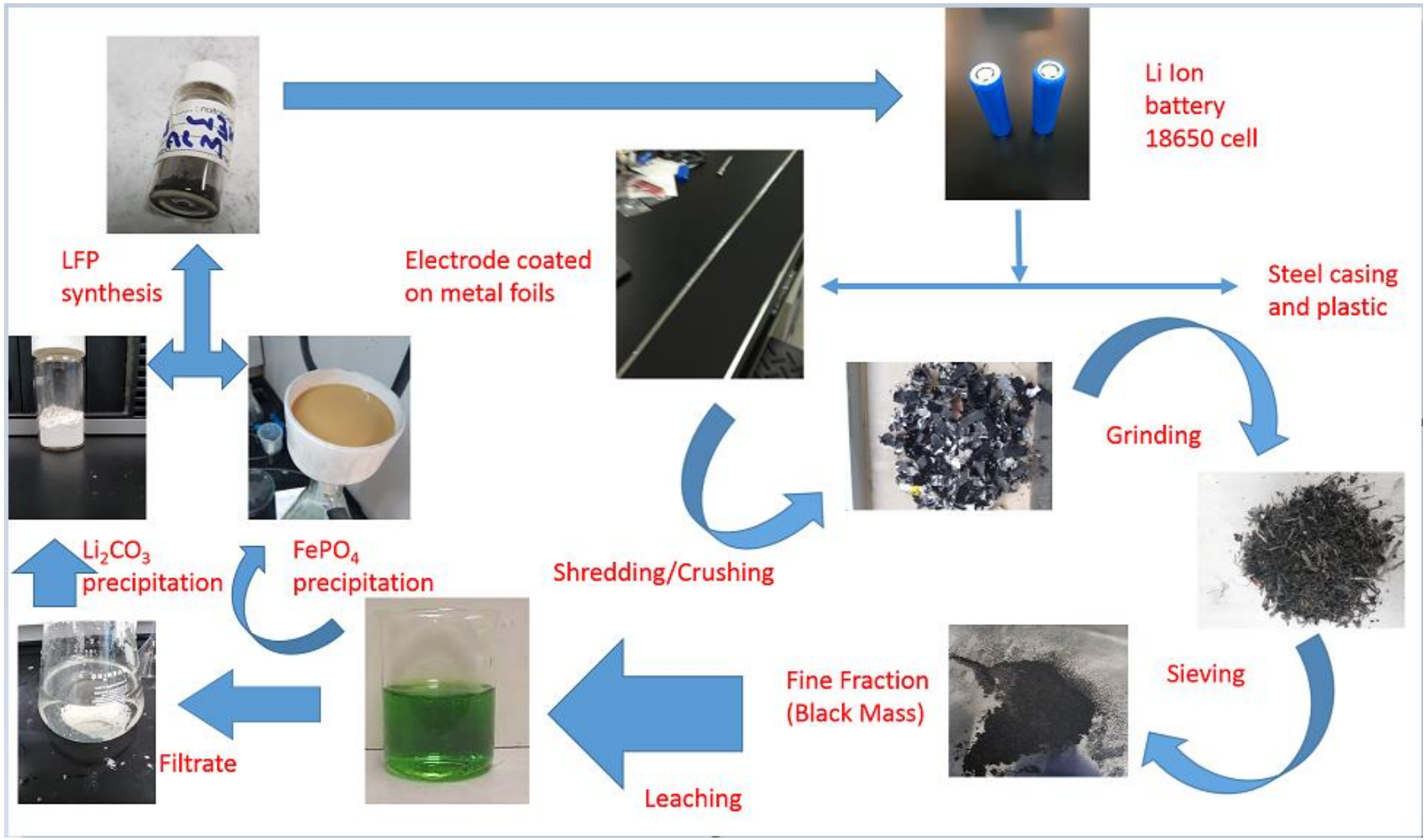


Used batteries collected at NTU

Mechanical Shredder for batteries (10kg/h)

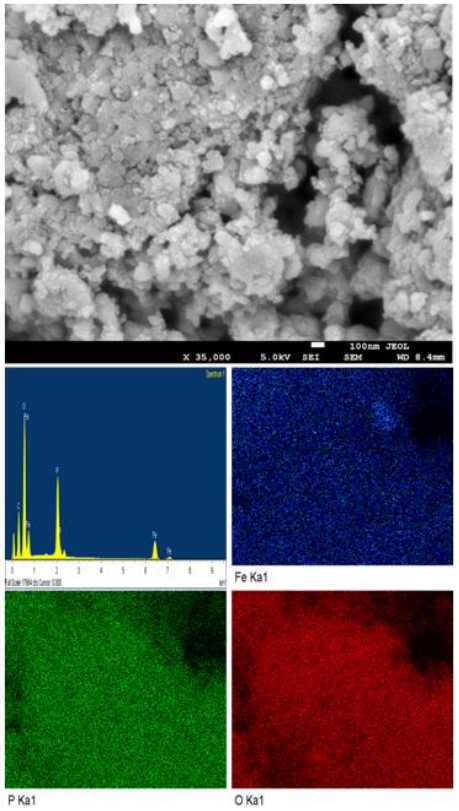
Shredded batteries

Re-use of materials from old spent lithium ion batteries

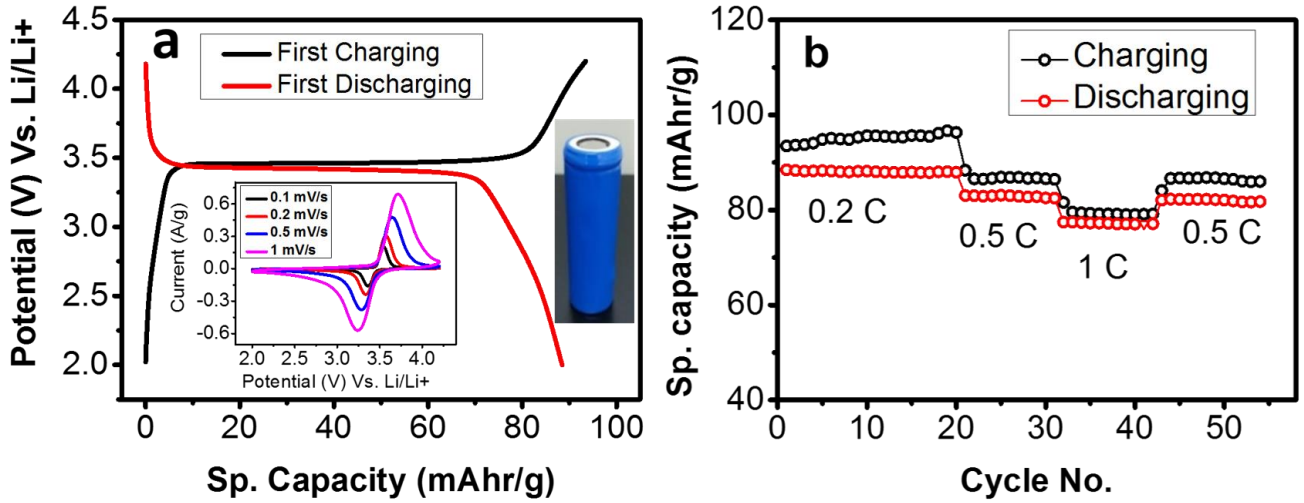


Journal of Hazardous Materials 399 (2020) 123068

New batteries made from elements extracted from old batteries



SEM, EDS and elemental mapping of as synthesized LFP



Electrochemical properties of as synthesized LFP, a) Charge discharge curve at 0.2 C current, (inset CV curve) b) cycling at different C.

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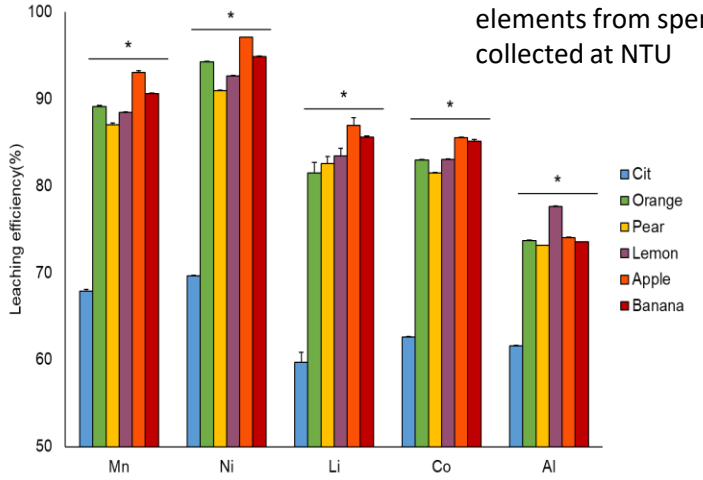
Fruit Waste to treat battery Waste (WTW) approach

Orange Peel waste

Food waste

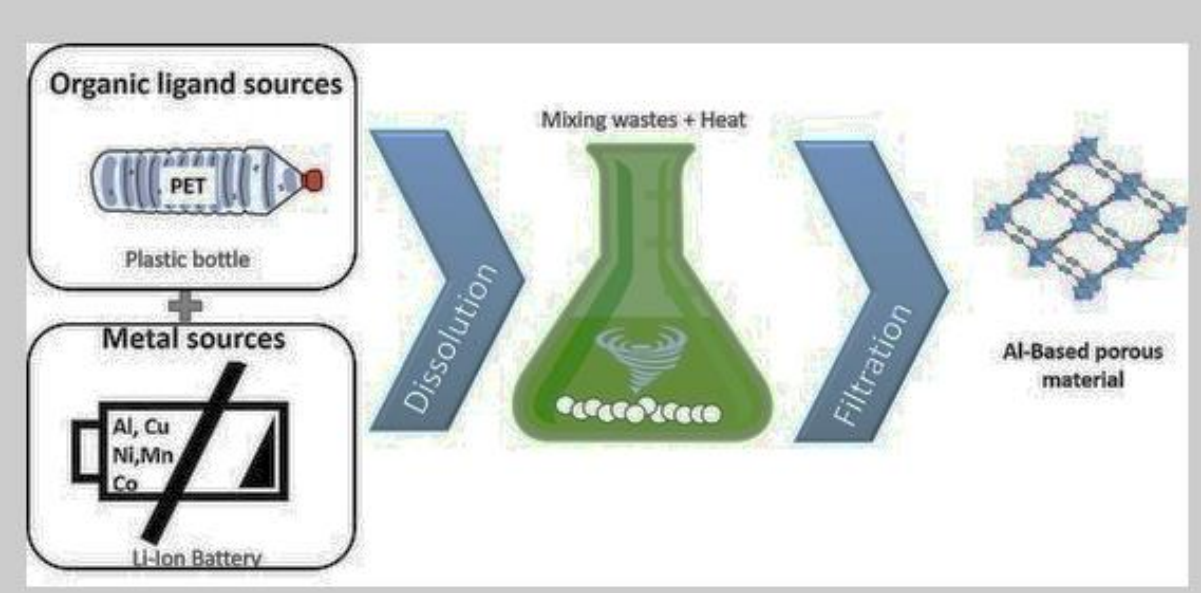
Fruit waste from NTU canteen used to leach out elements from spent LIB collected at NTU

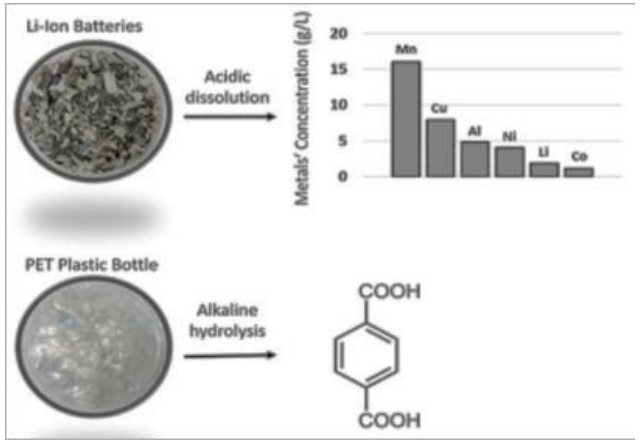


'*Repurposing of Fruit Peel Waste as a Green Reductant for Recycling of Spent Lithium-Ion Batteries*' published in *Environmental Science & Technology* 2020 54 (15), 9681-9692, Madhavi, Dalton et al, DOI: 10.1021/acs.est.0c02873

Recycle plastic bottles and Li-ion battery waste in one process

Simple method to recycle plastic-bottle and Li-ion-battery waste in one process by forming valuable coordination polymers (metal–organic frameworks, MOFs).

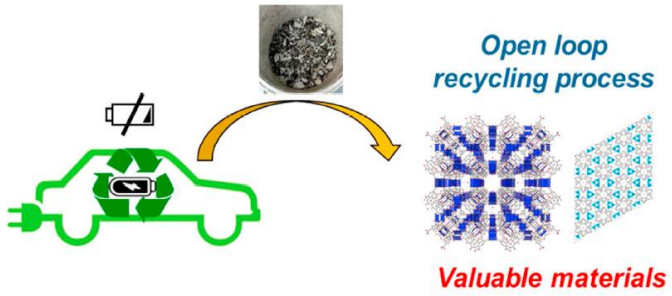


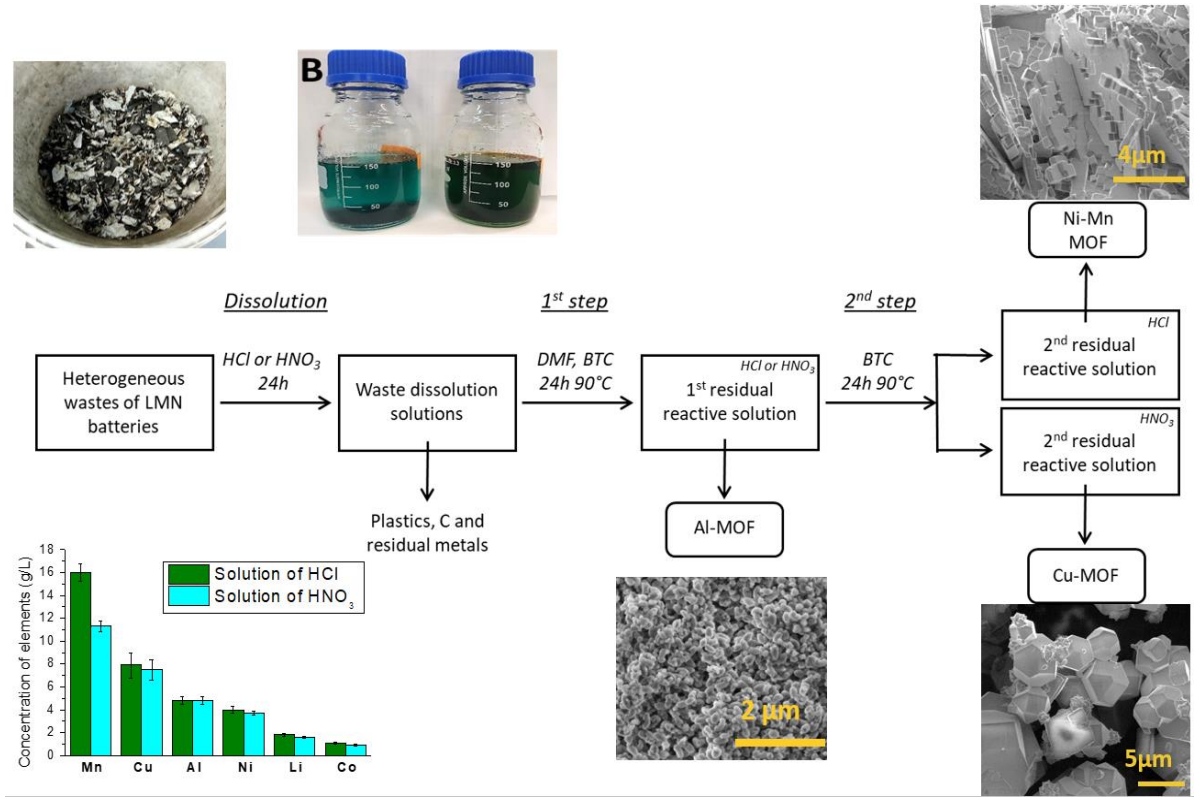


Poly(ethylene terephthalate) from plastic bottles was depolymerized to produce an organic ligand source (terephthalate), and Li-ion batteries were dissolved as a source of metals. By mixing both dissolution solutions together, selective precipitation of an Al-based MOF, known as MIL-53 in the literature, was observed

Materials 2020, 13, 441; doi:10.3390/ma13020441

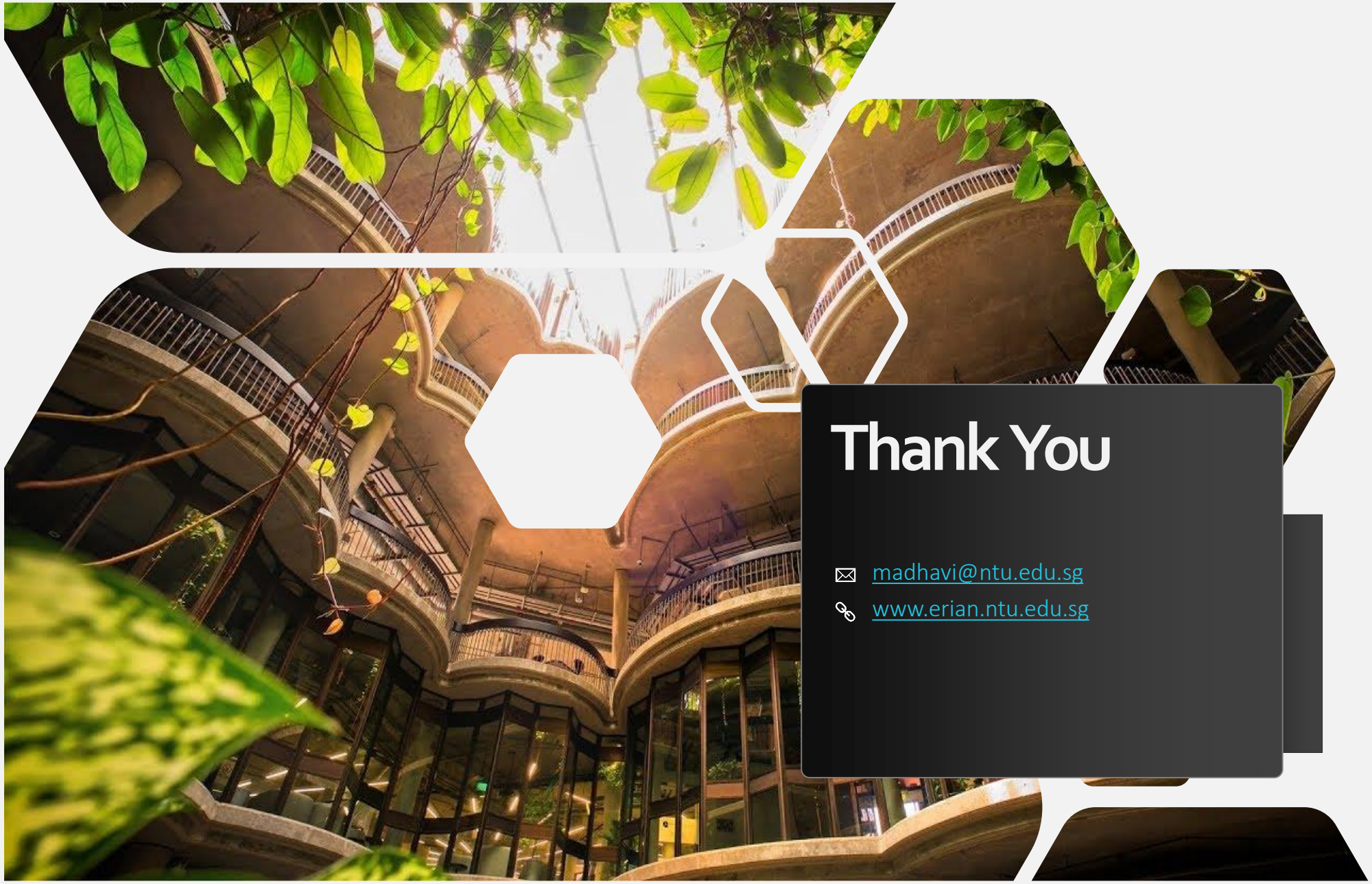
LIB Waste to high value metal organic frameworks





This method shows promising results at the lab scale (15 g of wastes can be converted in 10 g of MOFs) and opens interesting perspectives for the scaled-up production of MOFs.

Journal of Hazardous Materials 385 (2020) 121603



Thank You

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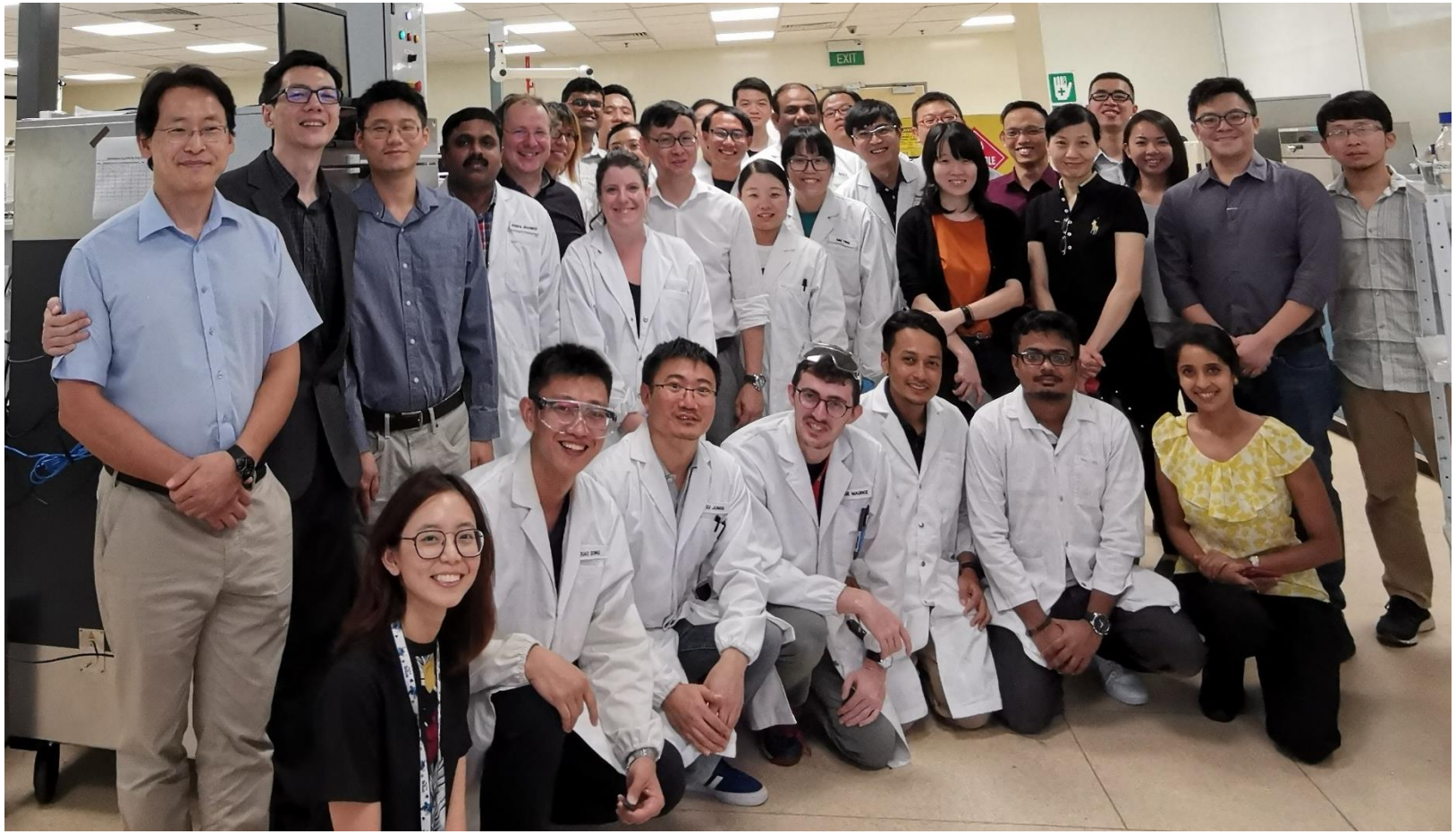

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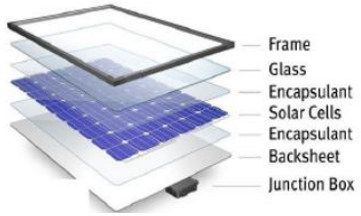
RT2: Recycling of silicon solar panels

EOL silicon solar panels



PV panel component

Possible application of recycled materials

- Present techniques only recycle glass, aluminium, copper and steel fractions of the solar cells
- However this results in low value retrieval, and critical materials, such as silver and antimony, as well as the silicon are typically not valorized. New techniques for value recovery is needed

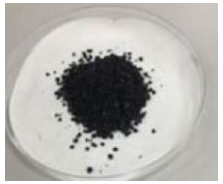
RT3: Recycling and recovery of valuable metals from printed circuit boards (PCBs)

Wasted PCB → Environmental friendly hydrometallurgy → High purity metal recovery

To develop novel recovery processes from PCBs via advanced sorting, mechanical separation and environment-friendly hydrometallurgy techniques.

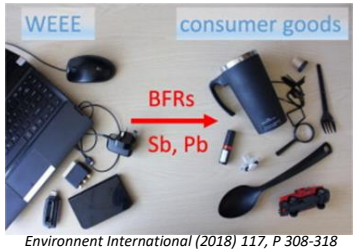
RT4: Recycling and treatment of plastic parts from e-waste

E-waste plastics



Sorted and grinded component

Possible application of detoxified plastic



Environnent International (2018) 117, P 308-318

To develop novel processes for segregation, detoxification and recycling of plastic parts from e-waste at environment-friendly conditions, and develop possible reuse applications for the recovered materials.