THE FARADAY INSTITUTION ReLiB

REUSE & RECYCLING OF LITHIUM ION BATTERIES

Recycling of Li-ion batteries: Life cycle assessment approach

WS3

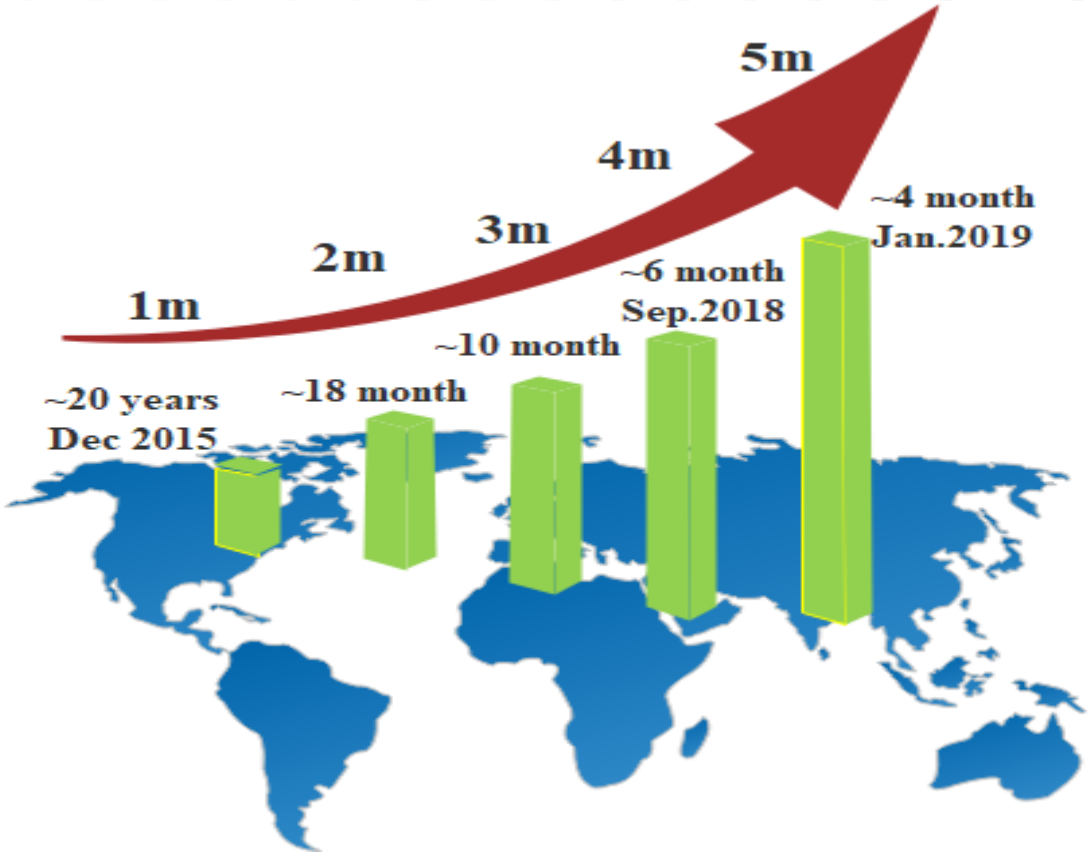
04/09/2019

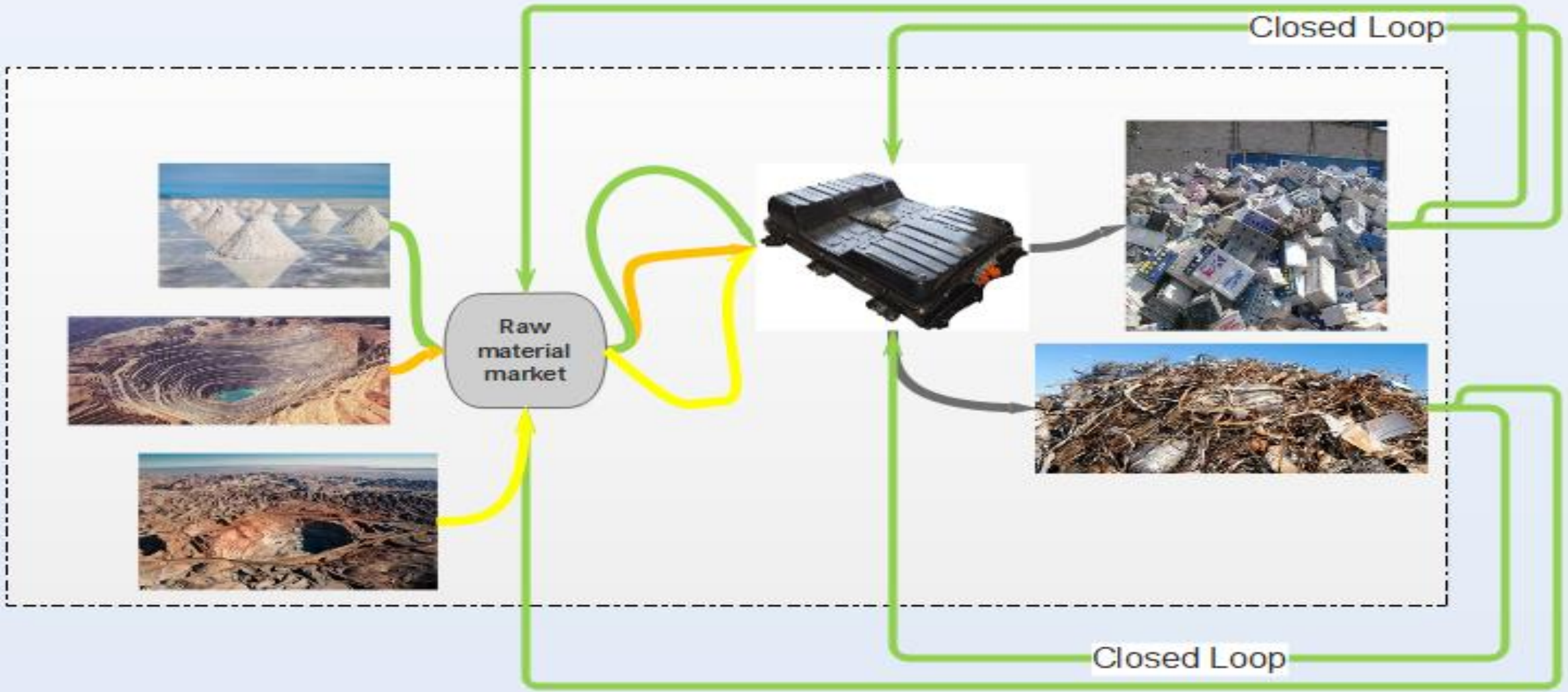
Dr. Mohammad Ali Rajaeifar, Dr. Oliver Heidrich

Decarbonization of transport sector: Electrification and EVs

-The rapid adoption of EVs has caused LiB prices to fall in recent years.
-At least five millions are on roads in 2019.

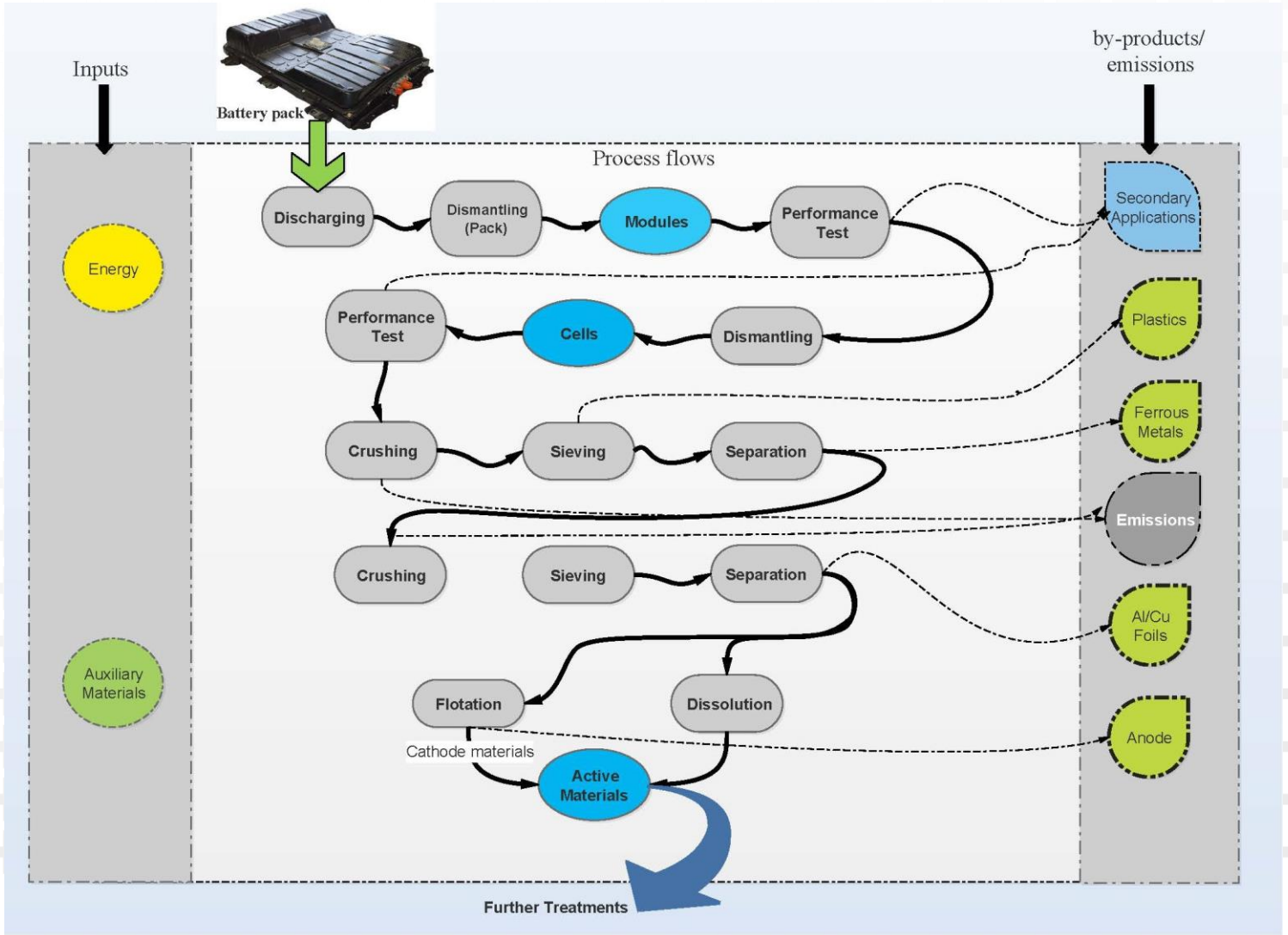
General Motors EV1 in 1996
Image source: Wikipedia

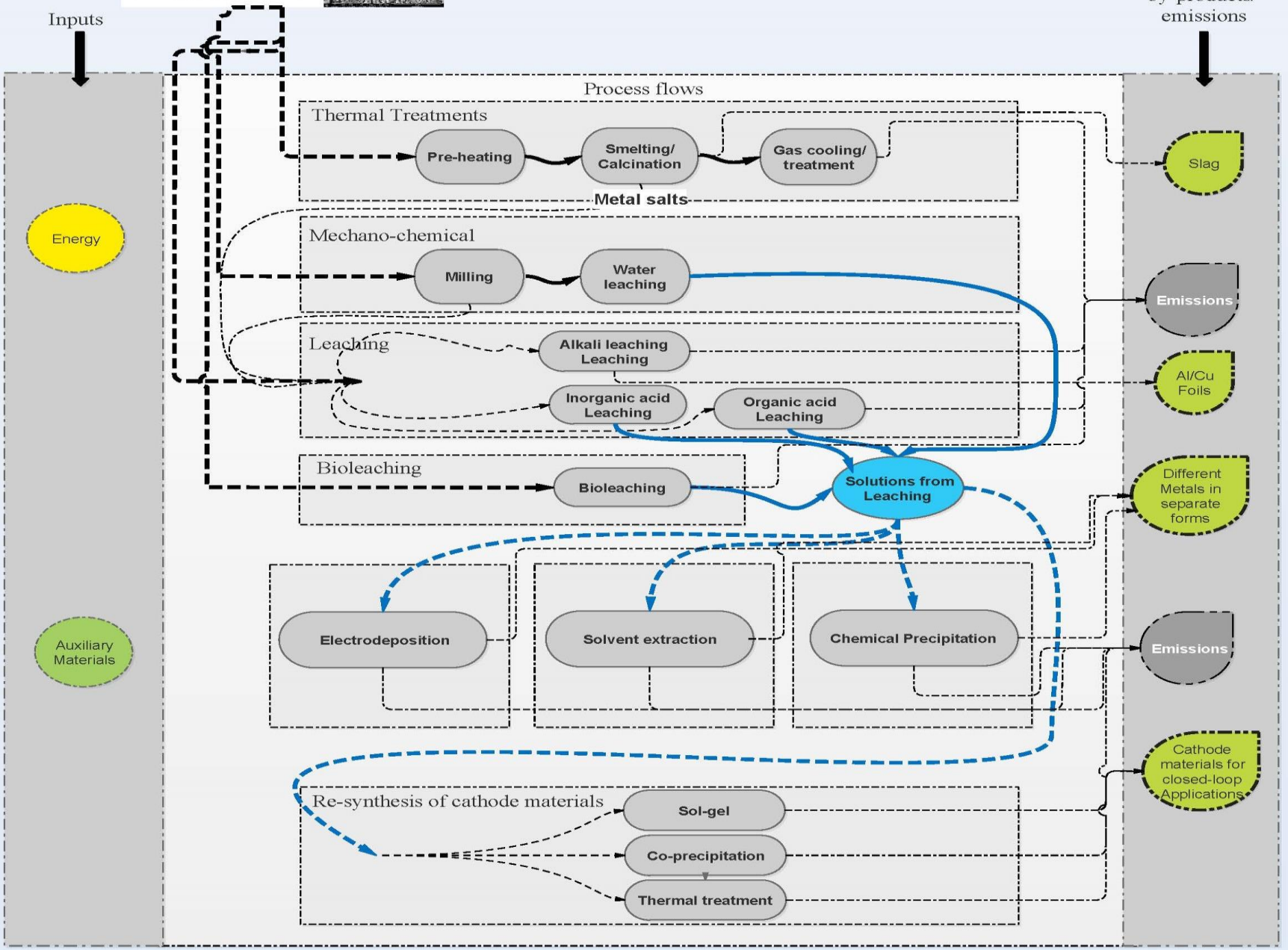


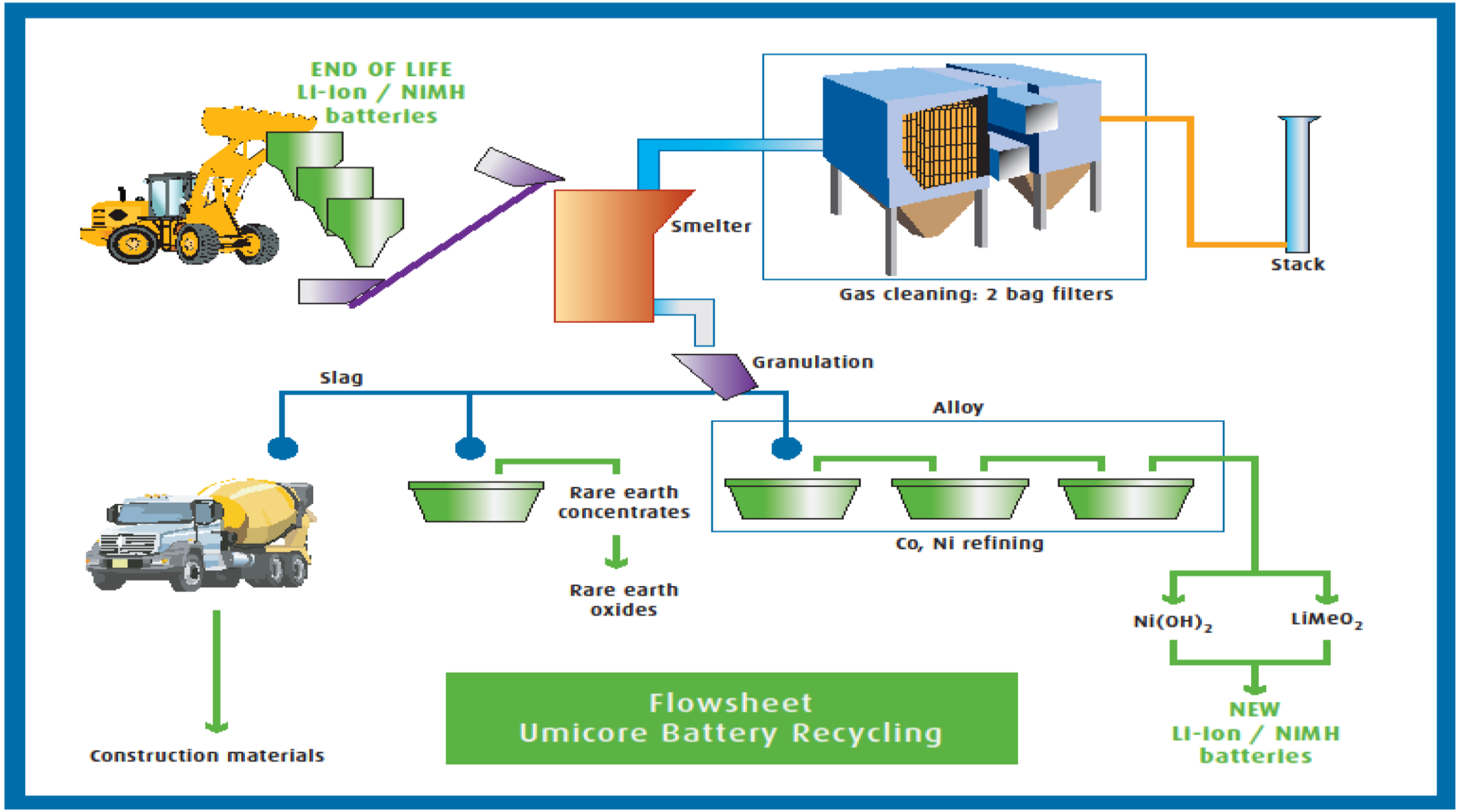

Closed Loop
Raw material market
Closed Loop

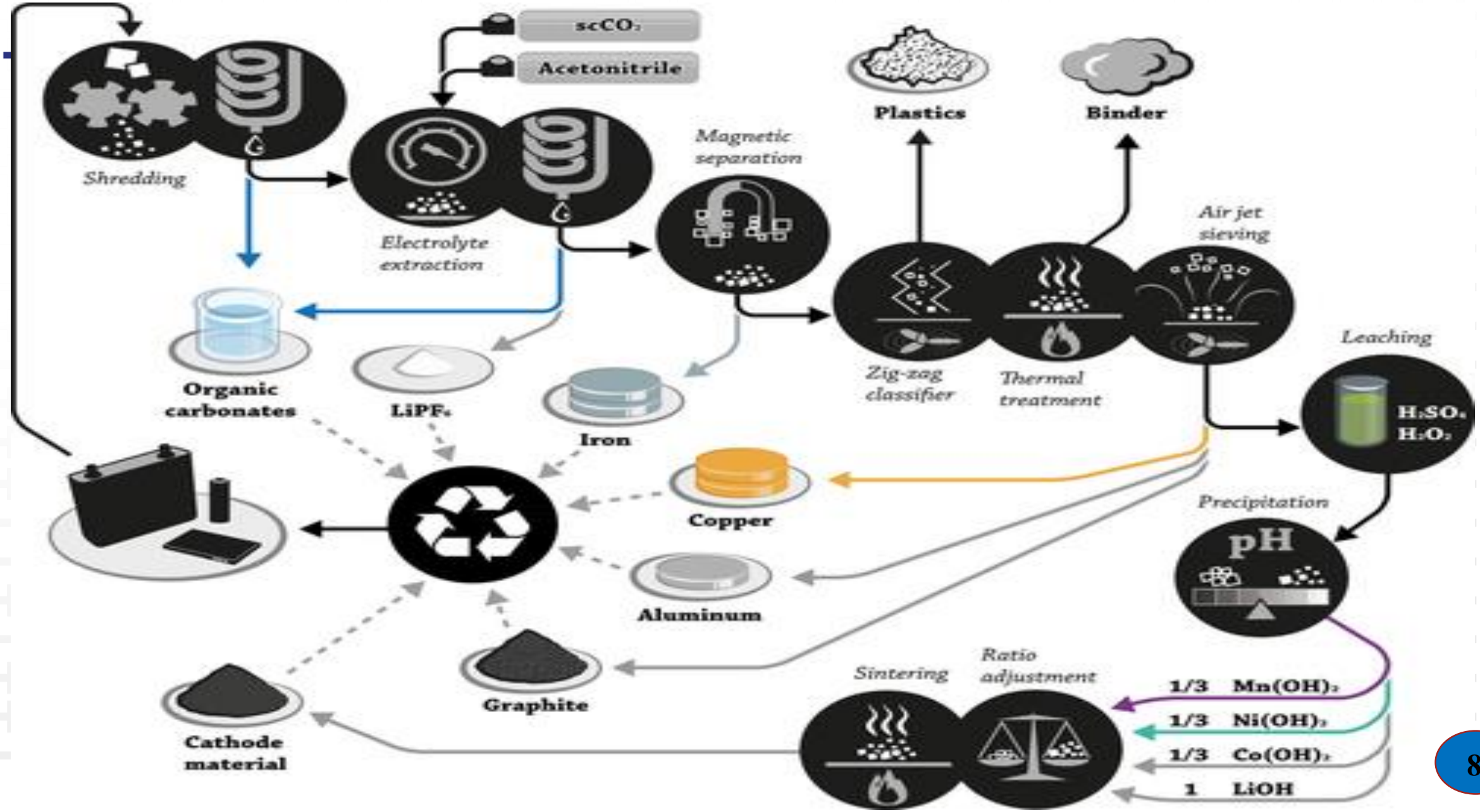
A complicated Task

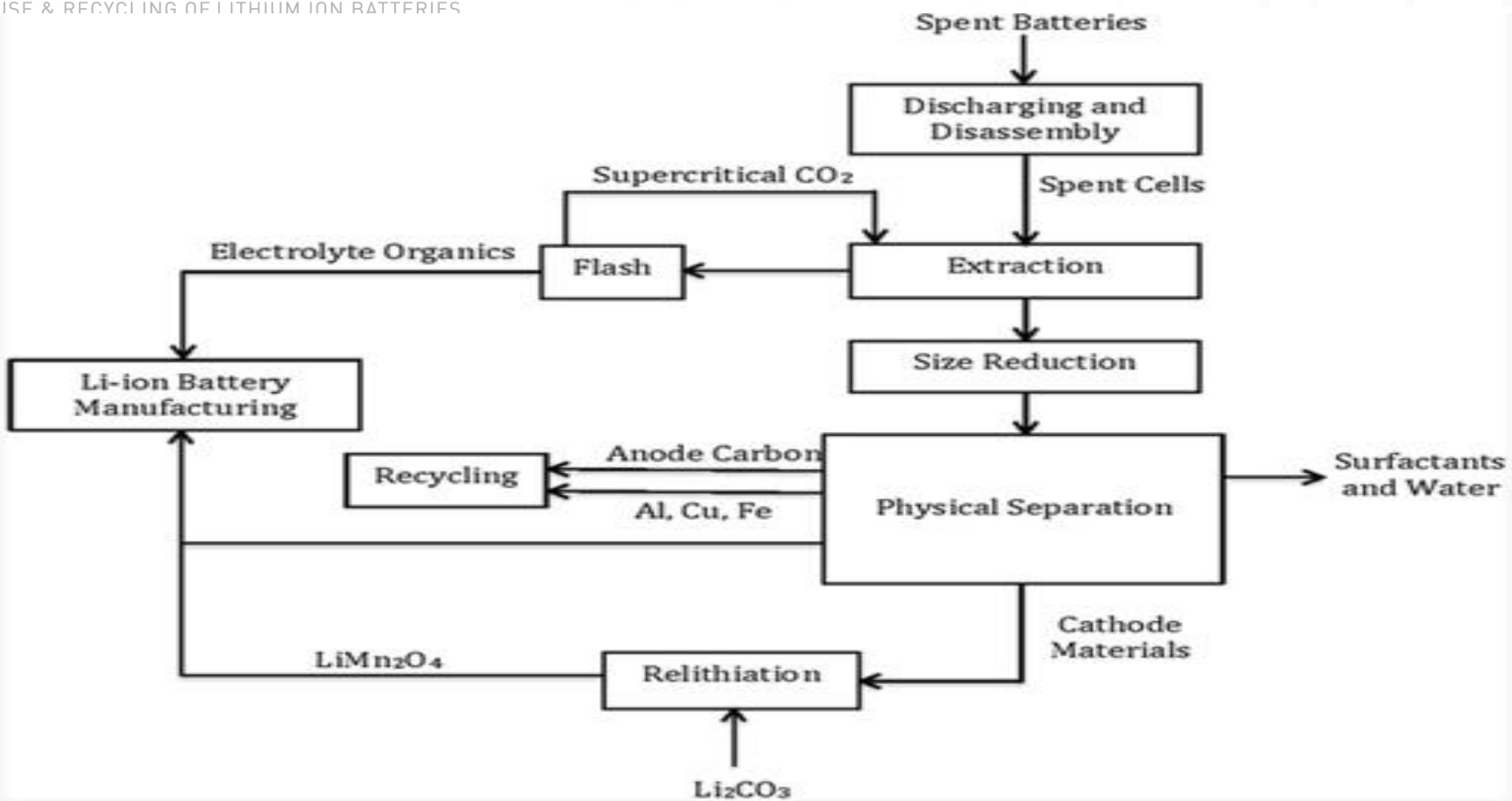
- Different battery chemistries
- Ever-evolving cell design and using new chemical materials in batteries
- Different physical/chemical (or combination of them) reactions could be used: They have their own specific requirements
- Closed loop or open loop
- N*n*n situations


Inputs
Battery pack
by-products/
emissions
Process flows
Energy
Auxiliary Materials
Discharging
Dismantling (Pack)
Modules
Performance Test
Secondary Applications
Performance Test
Cells
Dismantling
Plastics
Crushing
Sieving
Separation
Ferrous Metals
Emissions
Crushing
Sieving
Separation
Al/Cu Foils
Flotation
Dissolution
Anode
Cathode materials
Active Materials
Further Treatments


Inputs
by-products/
emissions
Process flows
Thermal Treatments
Pre-heating
Smelting/
Calcination
Gas cooling/
treatment
Metal salts
Slag
Energy
Mechano-chemical
Milling
Water
leaching
Emissions
Leaching
Alkali leaching
Leaching
Al/Cu
Foils
Inorganic acid
Leaching
Organic acid
Leaching
Bioleaching
Bioleaching
Solutions from
Leaching
Different
Metals in
separate
forms
Auxiliary
Materials
Electrodeposition
Solvent extraction
Chemical Precipitation
Emissions
Cathode
materials for
closed-loop
Applications
Re-synthesis of cathode materials
Sol-gel
Co-precipitation
Thermal treatment




scCO₂
Acetonitrile
Shredding
Electrolyte extraction
Magnetic separation
Plastics
Binder
Air jet sieving
Zig-zag classifier
Thermal treatment
Organic carbonates
LiPF₆
Iron
Leaching
H₂SO₄
H₂O₂
Copper
Precipitation
pH
Aluminum
Graphite
Cathode material
Sintering
Ratio adjustment
1/3 Mn(OH)₂
1/3 Ni(OH)₂
1/3 Co(OH)₂
1 LiOH

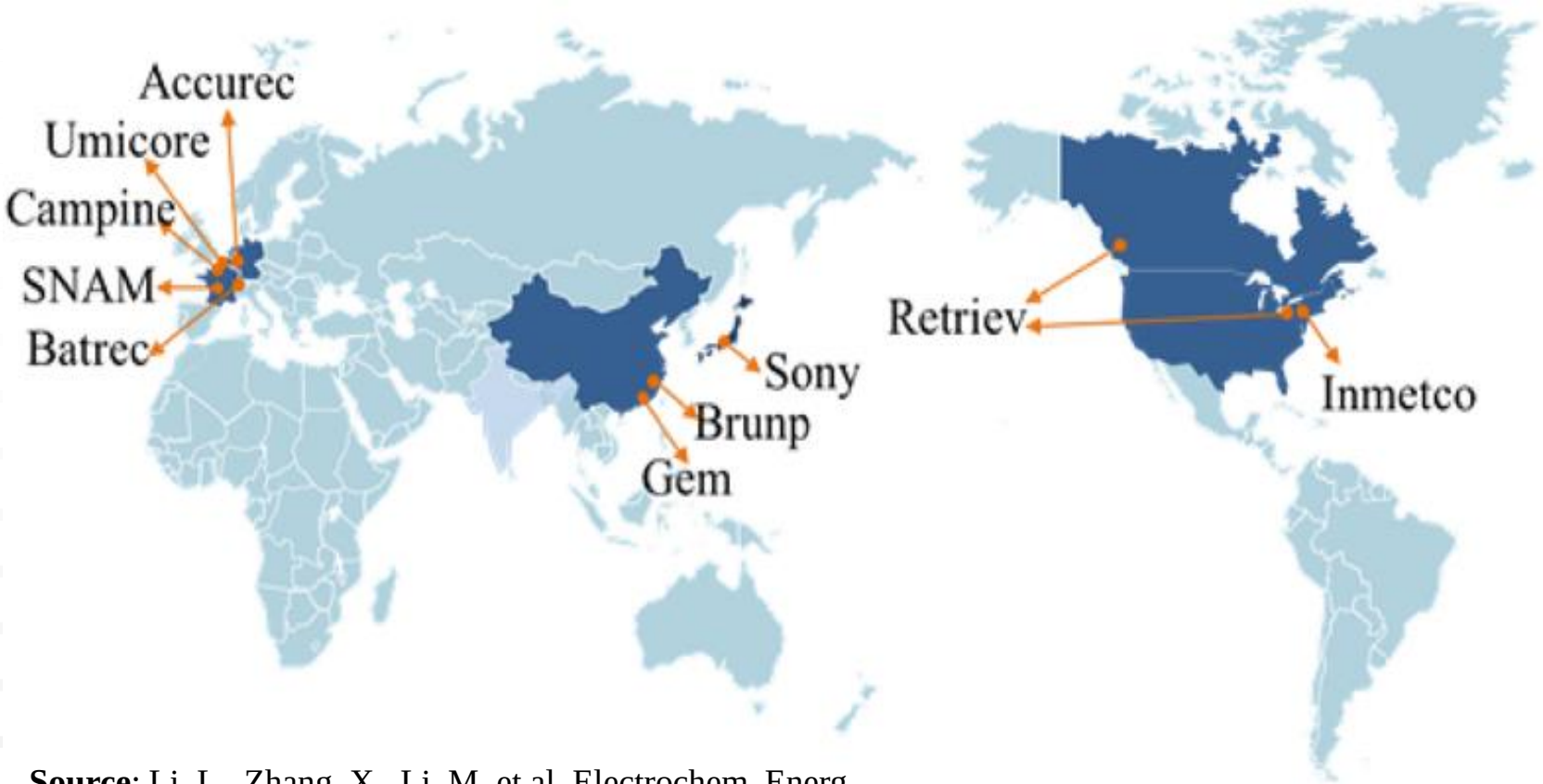

Spent Batteries
Discharging and Disassembly
Spent Cells
Supercritical CO_2
Electrolyte Organics
Flash
Extraction
Size Reduction
Li-ion Battery Manufacturing
Anode Carbon
Recycling
Al, Cu, Fe
Physical Separation
Surfactants and Water
Cathode Materials
$LiMn_2O_4$
Relithiation
Li_2CO_3


Environmental
A viable natural environment
Sustainable natural and built environment
Sustainable economic development
Sustainable development
Social
Nurturing community
Equitable social environment
Economic
Sufficient economy

-Inputs, outputs and environmental impacts of a product system throughout its life cycle

-Address the environmental aspects and potential environmental impacts throughout a product life cycle:

- from raw material acquisition, through production, distribution, use, end of life treatment, recycling, and final disposal.
- a cradle to grave
- well to wheel



Source: Li, L., Zhang, X., Li, M. et al. Electrochem. Energ. Rev. (2018) 1: 461. https://doi.org/10.1007/s41918-018-0012-1

Literature

-There are 10 papers that considered recycling of LIBs in their LCA study.

-The LCI data used mainly referred to GREET and Ecoinvent

-The impact category covered are diverse.

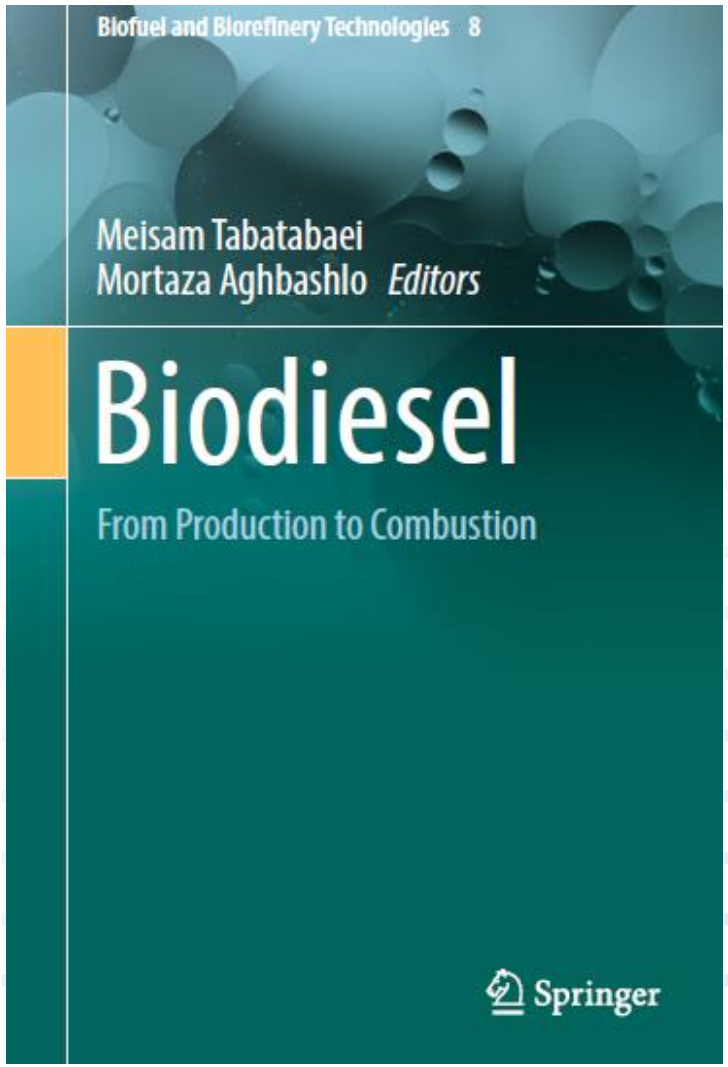
-Diverse goal and scope

-Diverse battery material.

-Diverse LCIA.

Challenges

- *The laboratory scale treatment methods needs to be scaled up to pilot and industrial (commercial) scales*
- *Consistent data base are needed for recycling of LiBs, based on real-data (average) rather than a mix of industrial processes from different activities or theoretical assumptions*
- *Complete impact category coverage*
- *Consequential impacts of Recycling of LIBs need to be considered (CLCA)-What are the impacts on circular economy!*
- *Consistent data base for the production of battery packs are needed based on real-data (average) rather than a mix of literature studies on the production of LIBs*
- *Material flows from raw material extraction points to battery production needs to be determined!*



Chapter 8
Biodiesel Production and Consumption: Life Cycle Assessment (LCA) Approach

Mohammad Ali Rajaeifar, Meisam Tabatabaei, Mortaza Aghbashlo, Saeed Sadeghzadeh Hemayati and Reinout Heijungs

Abstract Like all energy carriers including renewable energies, the production to combustion cycle of biodiesel should also be assessed from the sustainability point of view. Life cycle assessment (LCA) is a promising approach capable of assisting decision makers to find the environmental consequences of the existing or future biodiesel production plans. For instance, for different feedstocks, production technologies, downstream processes implemented, etc., an LCA of biodiesel production cycles could result in different recommendations ranging from agricultural practices to production and combustion stages. Despite the fact that an ISO standard is available for conducting LCA studies, there are still many challenging issues faced when performing LCA studies concerning biodiesel production and consumption. These challenges include the functional unit, the choice of system boundaries, the impact categories to be assessed, the treatment of land use change,

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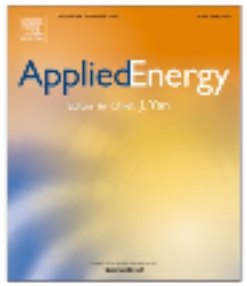

The role of electric vehicles in near-term mitigation pathways and achieving the UK's carbon budget

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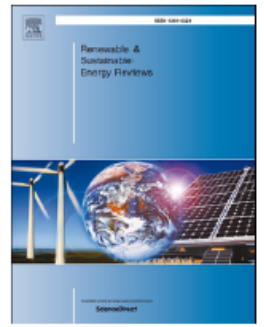

Emissions from urban bus fleets running on biodiesel blends under real-world operating conditions: Implications for designing future case studies

Mohammad Ali Rajaeifar[a,**], Meisam Tabatabaei[b,c,d,*], Mortaza Aghbashlo[e], Abdul-Sattar Nizami[f], Oliver Heidrich[g]

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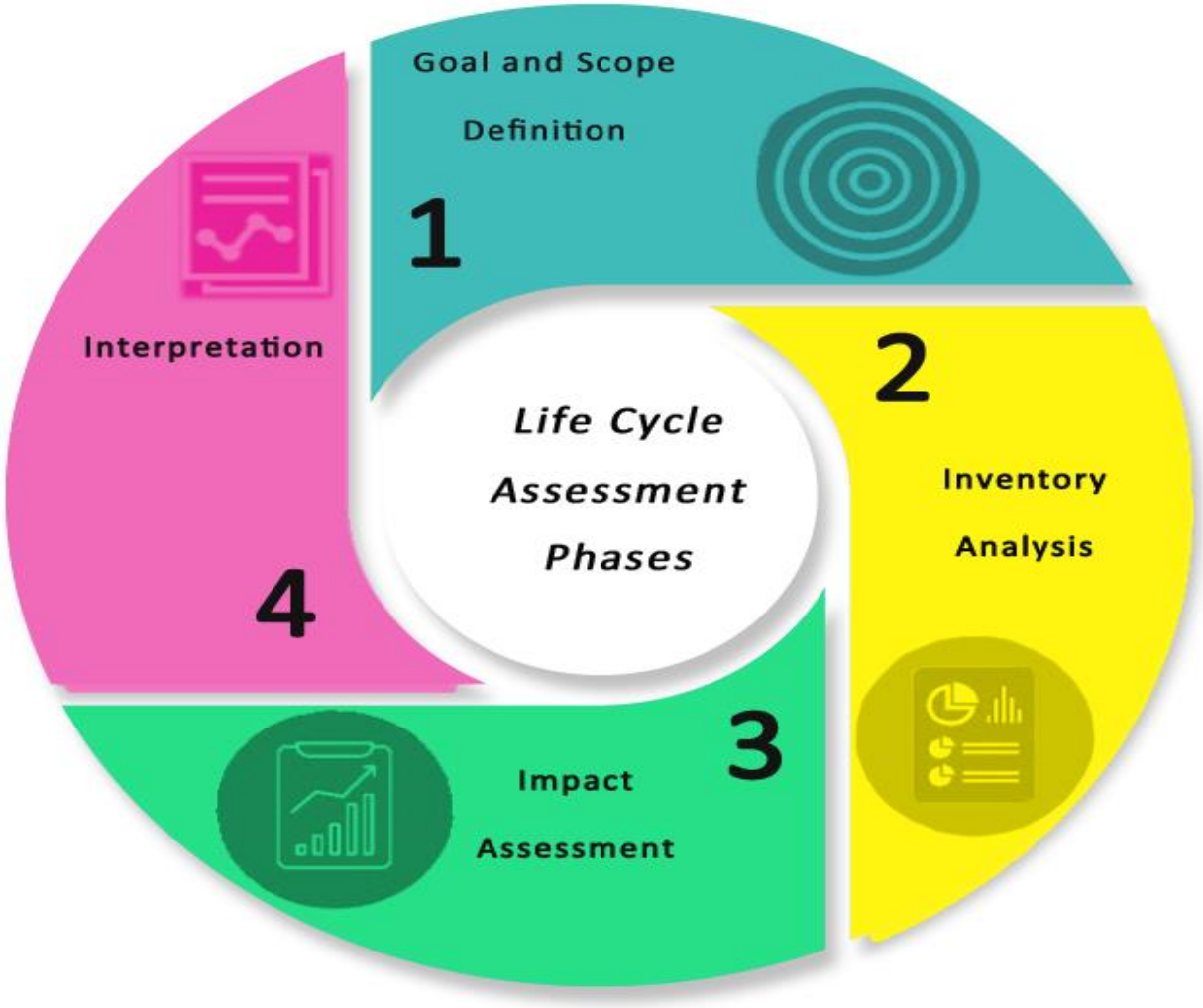
Thank you for your attention

Contact: Mohammad.Rajaeifar@ncl.ac.uk

-Different databases available:

- Ecoinvent
- Open LCA
- Greet
- JRC
- USDA
- GaBi
- Agri-footprint
- UVEK LCI Data

WS3;WP5-LCA


Goal and Scope Definition
1
2
Inventory Analysis
3
Impact Assessment
4
Interpretation
Life Cycle Assessment Phases

ReLiB

-Design environmentally friendly, economically and industrially feasible process to treat Spent LIBs

-Provide a benchmark for recycling of LIBs and perform LCA of LIBs using practical data

-Model the avoided upstream flows of battery materials (from raw material acquisition) in a closed-loop concept

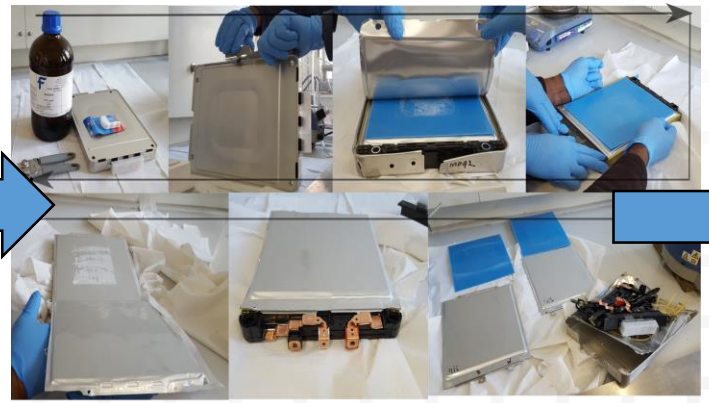
-Provide a model for assessing different impacts of recycling of spent LIBs considering different chemistries, using a consistent goal and scope as well as LCIA

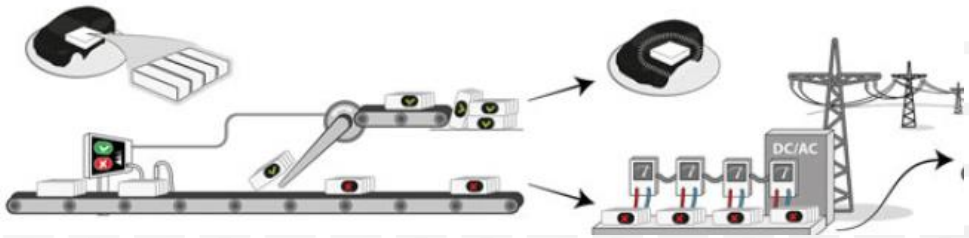
-Considering consequential impacts of recycling of spent LIBs in other supply chains, e.g. raw battery material market

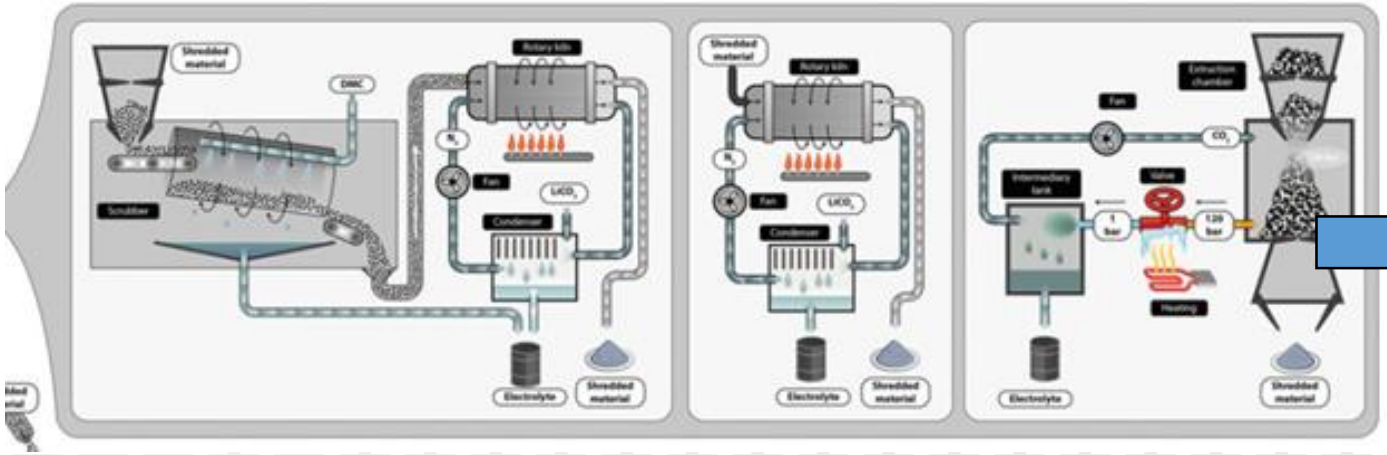
-Different LCA models available:

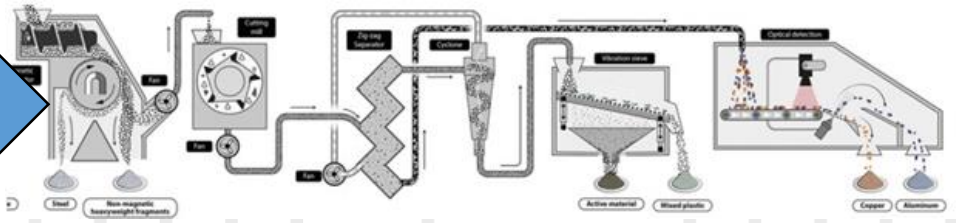
- *Simapro*
- *Open LCA*
- *Greet*
- *Gemiss*
- *Umberto*
- *GaBi*
- *Athena*


48
battery modules




DC/AC





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UNIVERSITY OF LEICESTER
diamond