

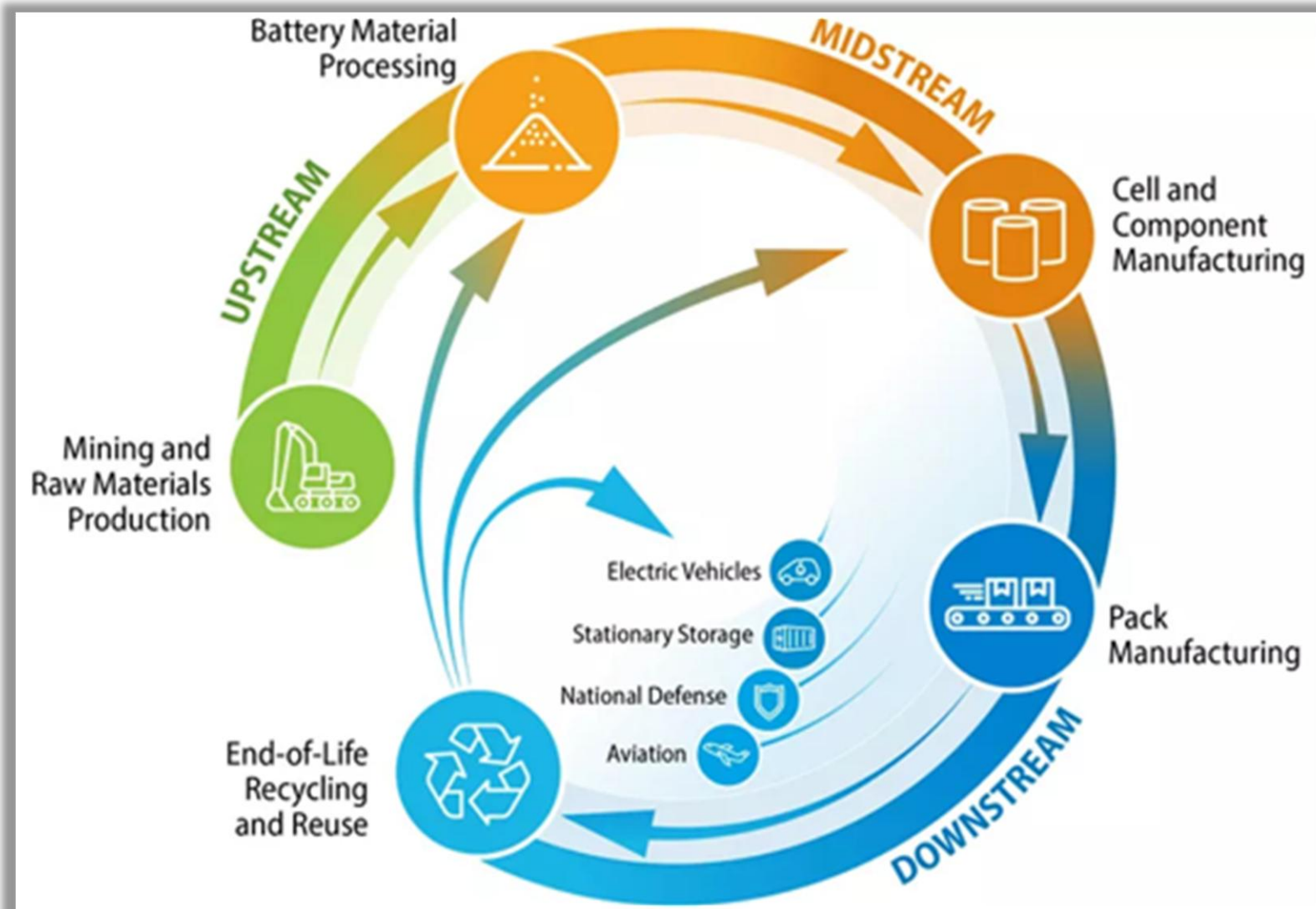


SSbD Implementation in Battery Recycling Innovative Developments: RESTORE Project

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Human & Environmental Health & Safety (HEHS) Group

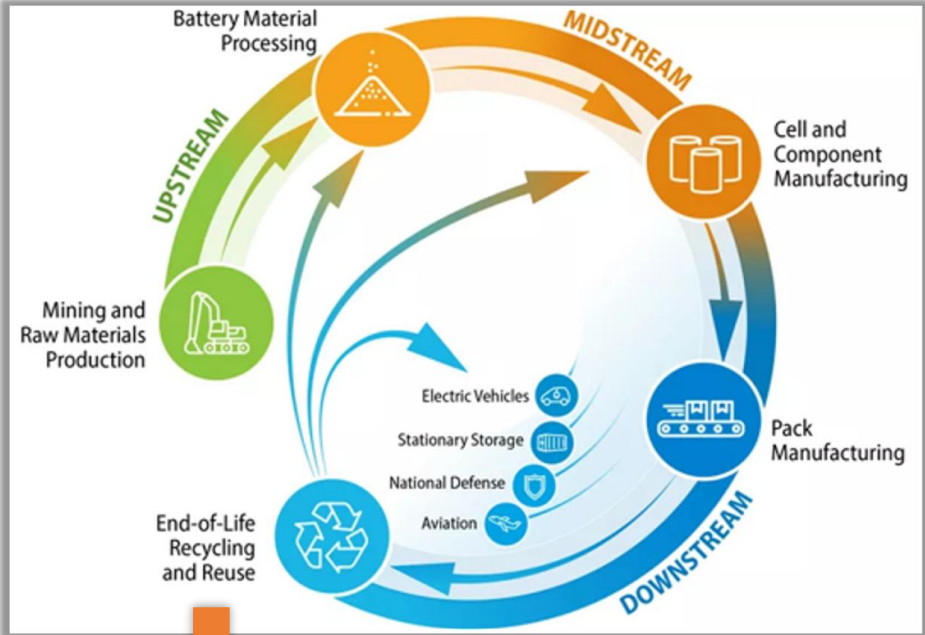
Circular Economy & Decarbonization (CED) Department



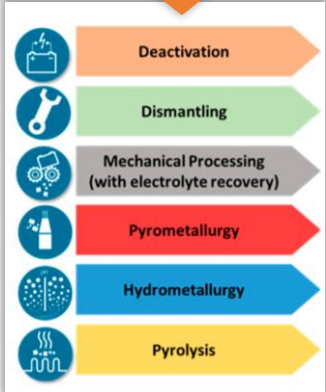
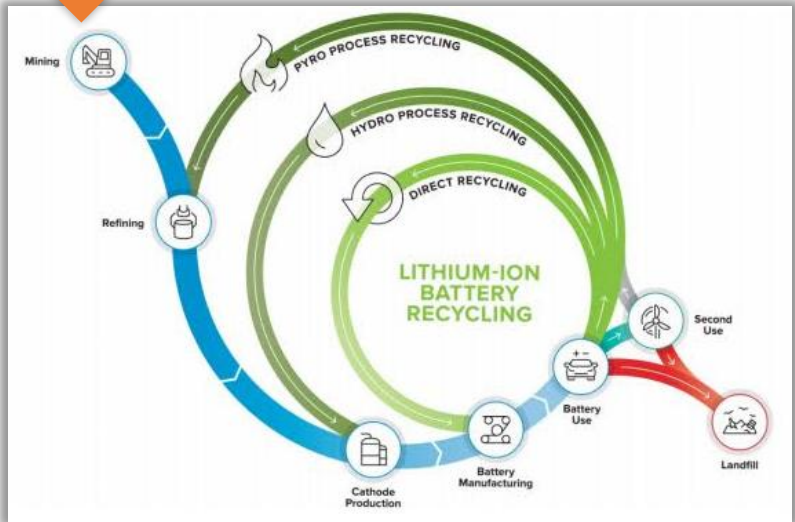
STEPS TOWARDS SAFETY ASSESSMENT

- Identifying hazardous substances
- Mapping activities & processes
- Identifying potential receptors
- Determining exposure pathways
- Quantifying releases & emissions
- Assessing exposure frequency & duration
- Characterizing exposure risks
- Prioritizing Hotspots & mitigation actions

Mapping Potential Hotspots (The Case of Batteries)

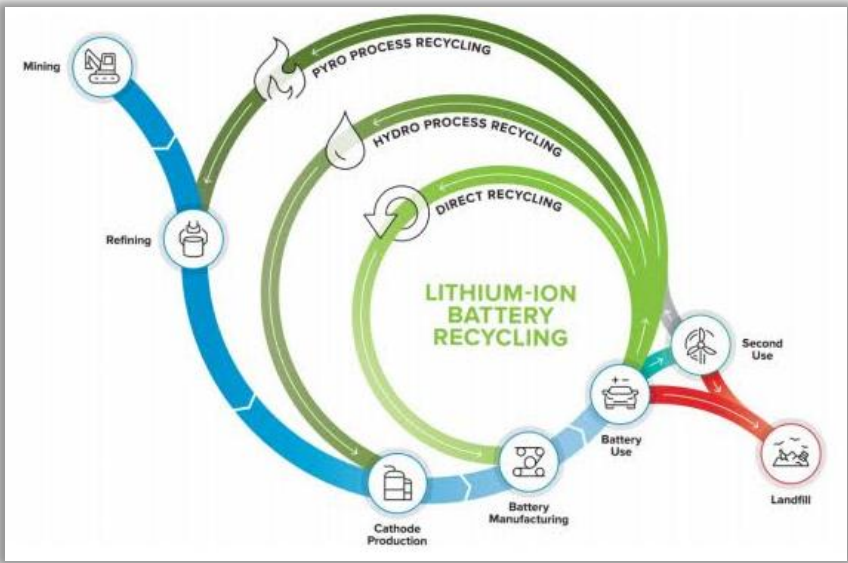


 Life Cycle Stage	 Main Releases / Emissions	 Hotspot Significance
 Raw Material Extraction	CO ₂ , SO _x , particulate matter, mine tailings, wastewater	 Very High
 Material Refining & Processing	CO ₂ , chemical emissions, wastewater	 Very High
 Cathode Material Production	CO ₂ , process emissions, fluorinated compounds	 Very High
 Battery Cell Manufacturing	Electricity-related CO ₂ emissions, solvent emissions	 High
 End-of-Life & Recycling	Residual chemicals, energy-related emissions, waste streams	 Medium-High



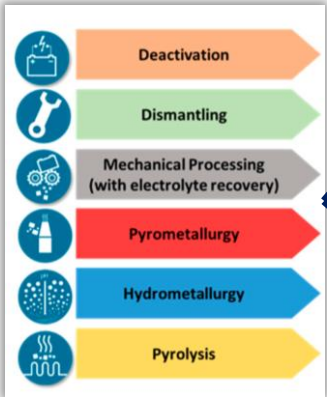
Process Stage	Worker Exposure	Environmental Release Potential	Overall Hotspot
Collection & Storage			
Discharge / Deactivation			
Manual Dismantling			
Mechanical Shredding			
Physical Separation			
Black Mass Handling			
Pyrometallurgy			
Hydrometallurgy			

Substances of Concern and Exposure Hotspots



SUBSTANCE PRIORITIES

- Metals and metal compounds
- Electrolyte related substances
- Organic Solvents
- PFAs and Fluorinated polymers
- Dust and Particulates
- Process chemicals used in hydrometallurgical recycling
- Combustion and thermal decomposition products



Recycling Stage	Key Substances of Concern
Collection & Storage	Electrolytes, VOCs, HF (damaged batteries)
Discharge & Dismantling	LiPF ₆ , solvents, metal dust
Shredding & Crushing	Black mass, Co, Ni, Mn, graphite
Mechanical Separation	Dusts, nano-particles
Pyrometallurgy	HF, metal fumes, PAHs
Hydrometallurgy	Acids, alkalis, dissolved metals
Metal Refining	Metal salts, metal fumes
Residue/Waste Handling	Mixed metals, process chemicals

Automated so**R**ting and saf**E** pre-proces**S**ing of EoL Ba**T**teries with n**O**vel smart and fast dismantling, and sepa**R**ation technologies for direct reuse of high purity materials in **E**nergy storage application

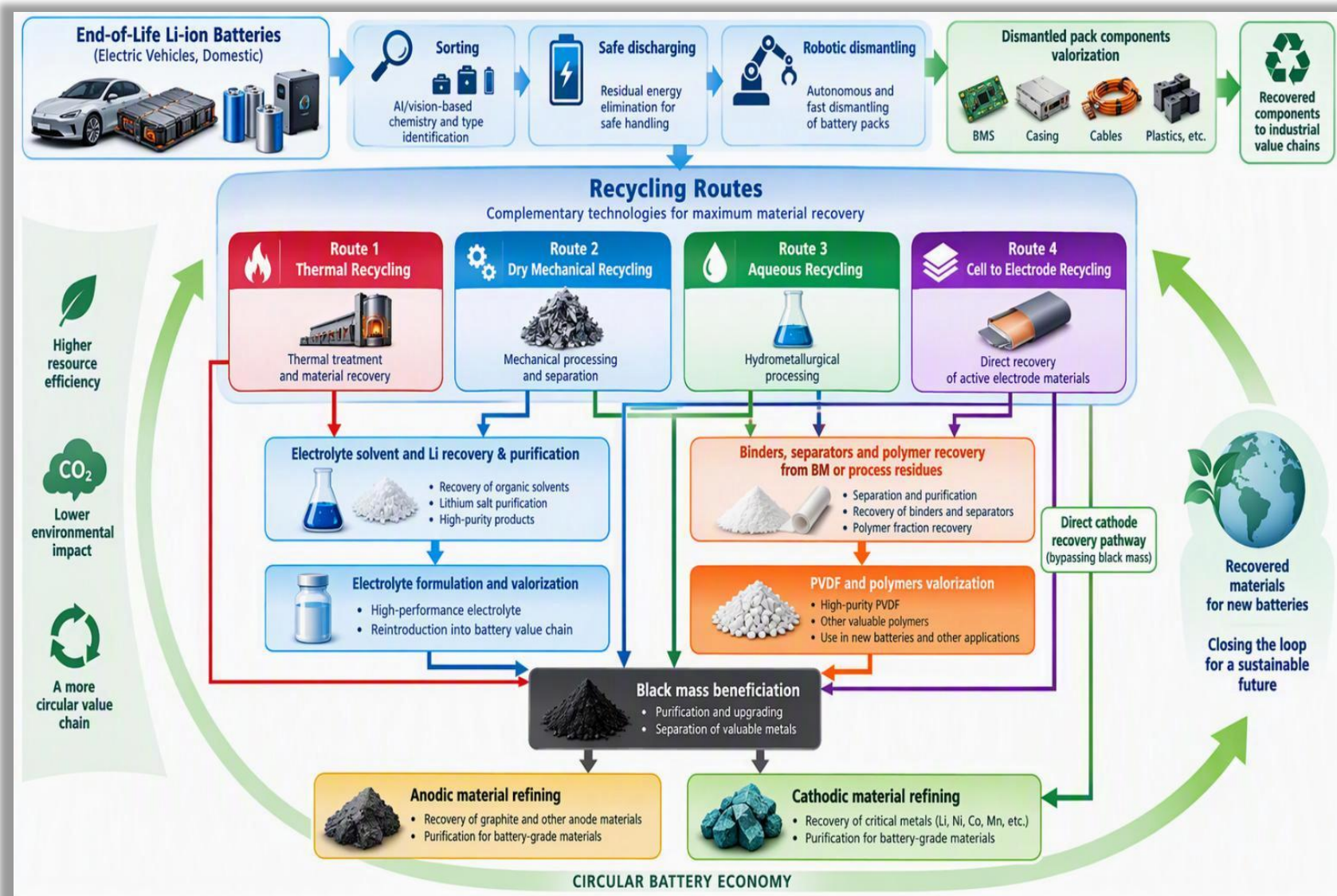
...**develop** and demonstrate **processing routes** (TRL 5) **for recycling** all end-of-life (EoL) **battery materials** from electric vehicles (**EVs**) and domestic lithium-ion batteries (**LIBs**).

...**refining** these **materials into battery-grade quality** for direct reintegration into the battery production value chain.

...**demonstrate** that the 2031 battery **regulation targets for recyclability** are achievable:

- > 95 % for Co, Ni, and Cu
- > 80 % for Li
- > 70 % by average weight of Li-based batteries

**Using flexible, cost-effective
& SSbD processes**



SSbD system: EoL of LIBs batteries from electric vehicles and domestic batteries.

Innovation

- **Goal:** Recycling processes for the recovery and refining of battery components/materials for direct reintegration into the battery production value chain.
- **(re)design action:** efficient, safe, economically and environmentally sustainable processes for **battery recycling (pre-processing)**

DESIGN PRINCIPLES

SSbD3 Design for energy efficiency
SSbD5 Prevent and avoid hazardous emissions
SSbD6 Reduce exposure to hazardous substances

- **Indicators and decision rules:** types, quantity and purity of materials recovered.
(e.g., anodic and cathodic components, solvents and Li-salts in electrolyte, other non-active materials (binder, separators, and other polymers))

Innovation

- **Maturity** of innovation at TRL5
- **Actors** in the life cycle: companies performing pre-processing (4 recycling routes), but also companies owning upstream and downstream processes

Intermediate SSbD Assessment. *Collaborative innovation. This innovation might affect near life cycle stages and trigger innovation considerations upstream and downstream*

SSbD SCENARIO

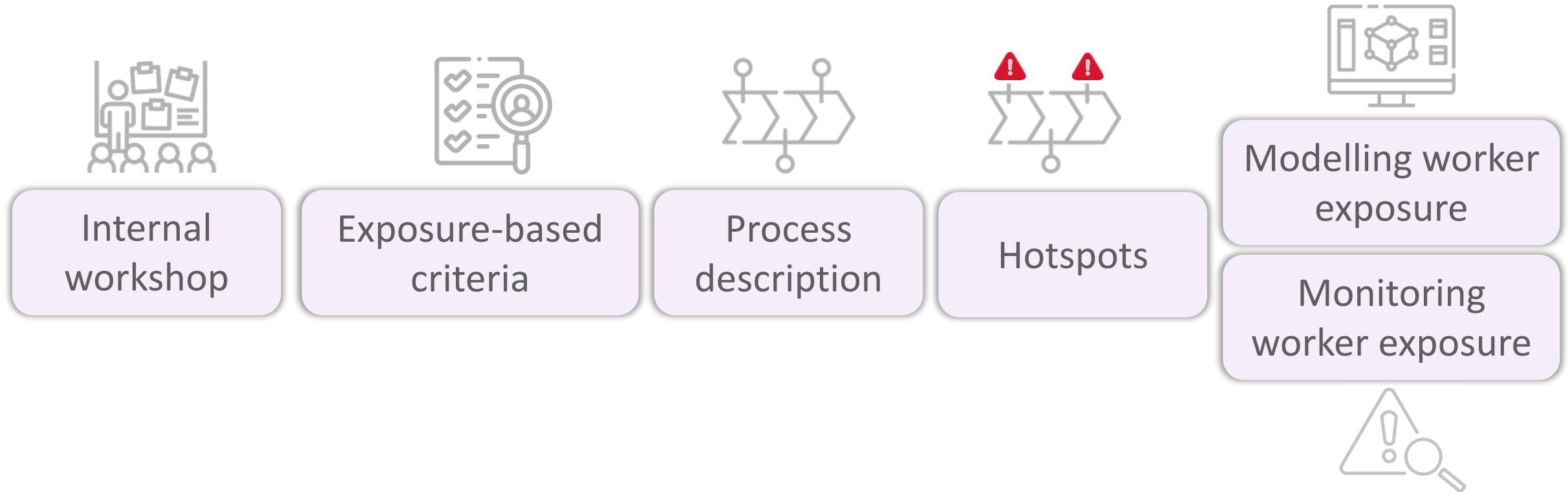
SSbD system	Process(es) for battery recycling
Type of innovation	Incremental breakthrough innovation
Objectives	Safety & Sustainability Technol. Efficient & cost-effective
(Re)design	Recycling process(es)
Maturity	TRL5 - technology validation in relevant environment

Initial Hazard Assessment



OUTPUT – each substance, material categorized as H1, H2, H3, what to do for each H class and when a H1 is “allowed”

Exposure Assessment



OUTPUT – processes ranked for their safety, mitigation measures and recommendations provided.

Human Exposure Assessment

Worker/ Consumer exposure is determined by many factors, including:

- **substance properties**
- type of **products/ articles**
- type of **process, containment** and **engineering control**
- type and condition of **use**
- **operational conditions** (T, conc., amount, duration & frequency)
- **risk mitigation measures** and their **effectiveness**

What is used?

- o pure substance
- o mixture
- o article/ product

Where is used?

- o enclosed
- o indoor controlled env.
- o indoor open sources
- o outdoor; etc.

How is used?

- o high/ low energy process
- o remote/ intimate contact

Human Exposure assessment can be performed by using:

1- Modelled estimates of exposure levels,

2- Measured representative exposure data for the assessed substance

Exposure assessment can be performed by using **modelled** estimates of exposure levels

Inhalation exposure models

- o ECETOC TRA
- o MEASE
- o EMKG-Expo-Tool
- o Stoffenmanager
- o ART

Dermal exposure models

- o ECETOC TRA
- o MEASE
- o RISKOFDERM
- o BEAT

LEGENDA: TIER 1 MODELS

HIGHER TIER MODELS

Consumer exposure models

- o ECETOC TRA
- o EGRET
- o REACT
- o ConsExpo
- o RIVM emission model

Integration of SSbD results

- Integration of safety, sustainability and techno-economic aspects to support decision for the most promising flowsheet(s).
- Calculate individual scores for:
 - **Safety:** hazard (materials used/ generated), exposure (workers/ environment)
 - **Sustainability:** selected indicators (e.g., climate change, pollution, etc.)
 - **Techno-economic** aspects
- **Combine** the scores, eventually **weighing** them according to priorities
- **Document** and **communicate** results for decision-making





RESTORE PARTNERS

LEITAT
managing technologies

SKtes

ACCUREC

Vianode

ABB

 **SYENSQO**

 **sense2sort**
TORATECNICA

 **INDUMETAL**
RECYCLING

 **ELYTE**

 **ECO Recycling**

 **Fraunhofer**

HZDR
 **HELMHOLTZ**
ZENTRUM DRESDEN
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 **PNO INNOVATION**

 **CHALMERS**
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 **UiA** University of Agder

DLyte

Bat^tronics

 **KYBURZ**

 **REELEMENTS**

Thank you for your attention!

JOIN OUR COMMUNITY!



restorebatteryrecycling.eu



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