Recycling of EV batteries:
Legal context and Umicore technology

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(H)EV Battery Recycling: legislative context

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Why Battery Recycling?

Part of the clean mobility global picture

clean mobility

Choice of transport mode	Clean vehicles	Clean energy

Exhaust control

Electrification

Vehicle and battery recycling

C

Why battery recycling?

- EHS concern: EV-Batteries = a complex mixture of chemical elements and compounds:
  - Li-ion: H, Li, C, O, F, Al, (Si), P, (Ti), Mn, Fe, Co, Ni, Cu, (Sn)
  - NiMH: H, C, O, K, Fe, Co, Ni, La, Ce, Pr, Nd
  - Electrolyte, solvent, plastics…
- Legislative context in EU
  - End of Life of Vehicles Directive (ELV): removal of batteries
  - Batteries Directive: ban on incineration and landfill of industrial batteries
    - To avoid dissemination of hazardous compounds
    - Resource efficiency
    - Quality target: recycling efficiency (RE) ≥ 50 %
      RE = (battery recycled materials)/(battery input materials on dry basis)

BD: Producers obligations regarding recycling

- Basic principle:
  - Extended Producer Responsibility
  - Producer = *any person in a Member State that… places batteries or accumulators, including those incorporated into appliances or vehicles, on the market for the first time within the territory of that Member State on a professional basis* ➔ for same type of EV, sold in different countries, ‘battery Producer’ can be different
- (H)EV batteries are ‘industrial’ batteries, not automotive batteries (= limited to SLI-batteries).
  - no collection target, but take-back obligation (➔ reuse, recycling)
- Recycling Efficiency target (RE)
  - 50% of battery weight has to be transformed into an *output fraction that has ceased to be waste or that will be used for their original purpose or for another purpose (without undergoing further treatment).*

Calculation of the Recycling Efficiency

- the Battery Directive's RE is a process efficiency indicator
  - Calculated per calendar year
  - On process/operator level:
    - 2 operators with 'same' process = different processes
    - 1 operator with 2 processes = different processes
    - 1 operator processing different battery chemistries together = same process
  - Refers to 'recycling' only, not including other recovery (energy).
  - Including all steps until the 'end of recycling' (output fractions with a 'purpose' without further treatment)

➔ <u>All batteries processed during the same year in the same process generate 1 RE!</u>

- the Battery Directive's RE is calculated on 'battery level'
  - Non-battery materials, e.g. casing of battery packs, are excluded
  - EV-battery assemblies are not considered as 'packs' but as 'batteries'
  - Battery cells are also considered as batteries
- Reporting: responsibility of first recycler (= operator that 'breaks' the battery)
  - ➔ consolidation of all subsequent recycling operations

Calculation of the Recycling Efficiency

Non-active battery parts recycled according to existing schemes: partial RE (calculated according to BD) to be reported to '1st recycler'

Considered as 'battery': breakdown of battery = 1st recycling step; agglomerated RE includes partial RE of all subsequent process steps

50 % target applicable, when offered as such to recycling company

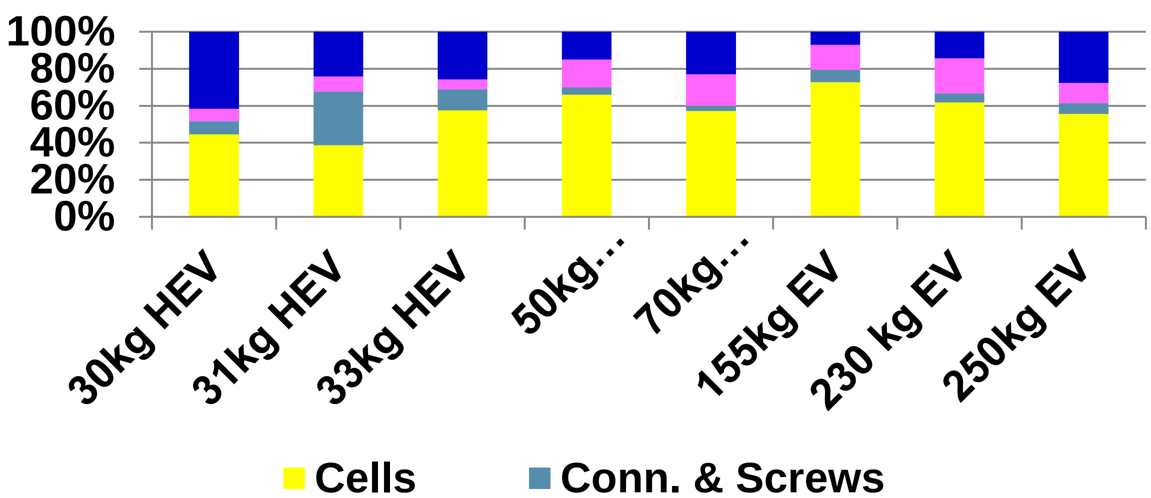
Active battery parts recycled according to dedicated battery recycling schemes: partial RE to be reported to '1st recycler'

50 % target applicable, when offered as such to recycling company

Calculation of the Recycling Efficiency

Impact of material choices of non-active parts

- Based on interviews, Recharge[1] concluded that relative % (w/w) of cells varies between 40-70% of (H)EV battery assembly weight; metals: 15-40%; plastics: 10-15%. Main difference is OEM's choice for protective casing material (metal or synthetic fibres)
- For same partial RE for each material flow, resulting agglomerated RE can vary significantly

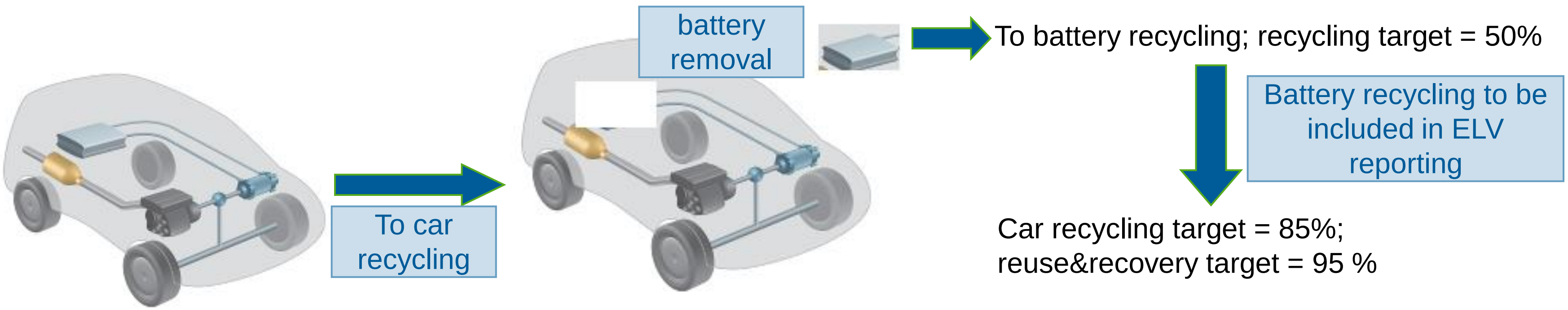


	Cells	Metals	Plastics	Agglomerated RE
Partial RE (%)	*50*	*95*	*10*	
Composition (%)	50	40	10	
Partial RE	25	35	1	**61**
Composition (%)	70	15	15	
Partial RE	35	14.25	0.15	**49.40**

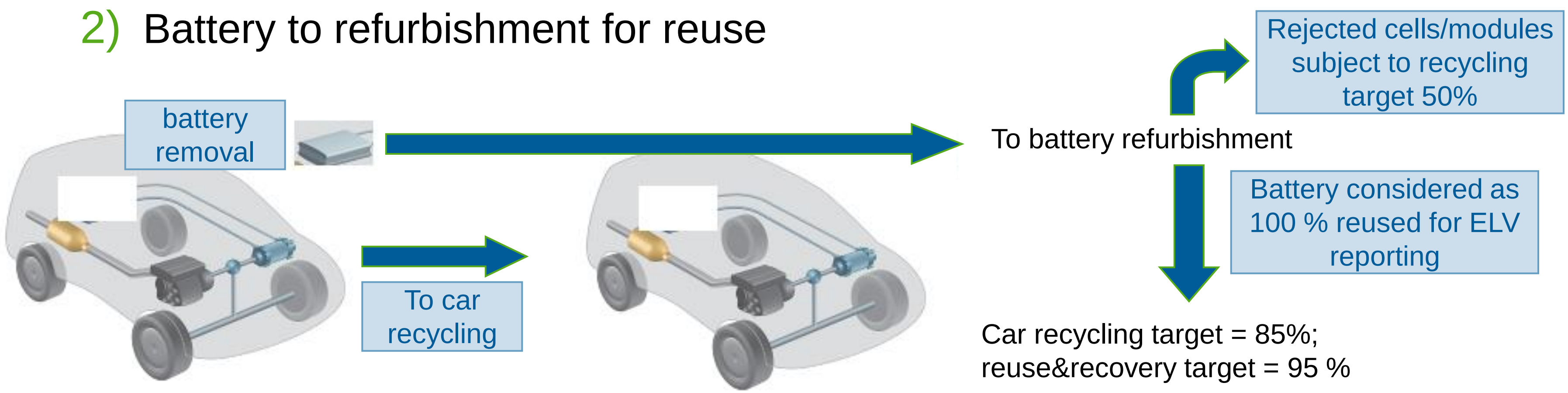
[1]Recharge is the European sector association for the advanced rechargeable batteries industry (http://www.rechargebatteries.org/)

Consolidation of batteries RE in ELV reporting

1) Battery to recycling



2) Battery to refurbishment for reuse



Consolidation of batteries RE in ELV reporting

- BD RE and ELV recycling rates are other concepts

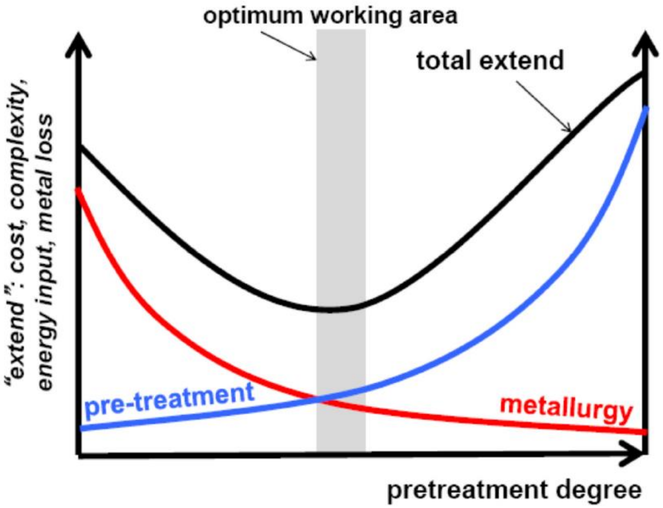
BD	ELV

• Process focus
  • Including process steps until end of recycling of all fractions
  • Possible to treat also non-vehicle batteries in same process
• Recycling only
	• Product focus
	  • Materials flow reporting (weight fractions to recycling or landfill)
	  • Does not include recycling steps until the ‘end of recycling’ as defined for batteries
	• Also reporting reuse and energy recovery

- Suggestion: to consider batteries as 100 % recycled if delivered to compliant battery recycler

Battery recycling technology

Battery recycling concepts



	Early process steps	Later process steps
Pre-treatment	Low investment cost; low environmental burden; high labour cost	High metal losses; high labour cost; moderate investment costs
Metallurgy	High investment; moderate environmental burden; low labour cost	Efficient metal recovery; low labour cost; moderate investment cost

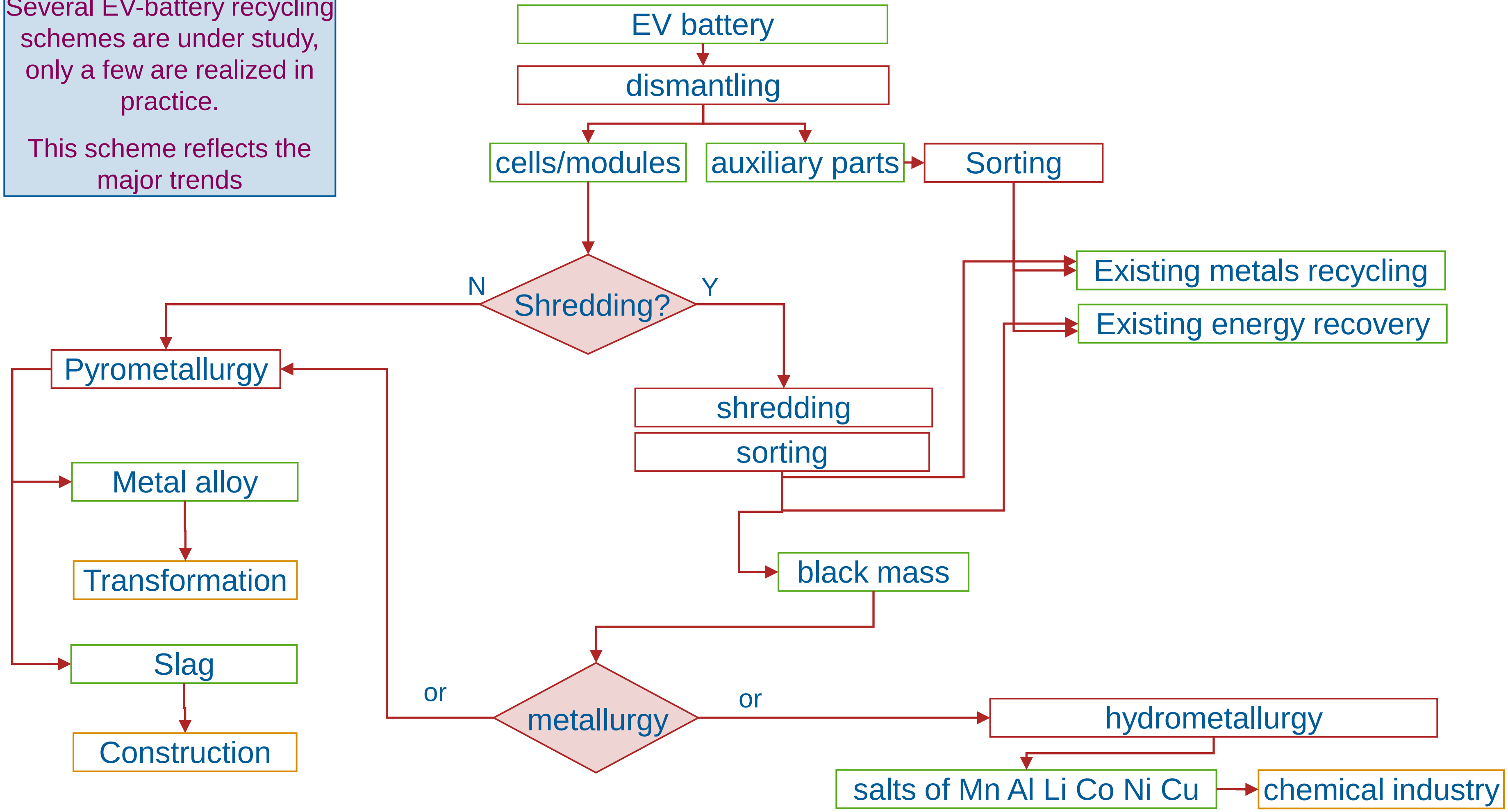
Source: prof. B. Friedrich, RWTH

- All recycling concepts are combinations of 'pre-treatment' (disassembling, shredding, pyrolysis) and metallurgical processes (pyro or hydro)
- Optimum combination depends on battery chemistry and design, scale leverage effects, processes, …

Battery recycling concepts: simplified flow sheet

Several EV-battery recycling schemes are under study, only a few are realized in practice.

This scheme reflects the major trends



Battery recycling concepts: challenges

- Dismantling
  - Labour intensive: Manual ➔ semi-automated ➔ mechanical breaking
  - Safety: State of Charge?
- Shredding
  - Charged batteries + inflammable solvents = fire risk; ➔ inert atmosphere or cryogenic shredding
  - Alternatively: pyrolysis before shredding
- Pyrometallurgy
  - Optimum conditions for maximum metal yields
- Hydrometallurgy:
  - Robustness of the process to cope with variety of input materials
- General
  - Quality of the recycled products: should meet industry standards
  - Cost: complex material flow and (still) small quantities

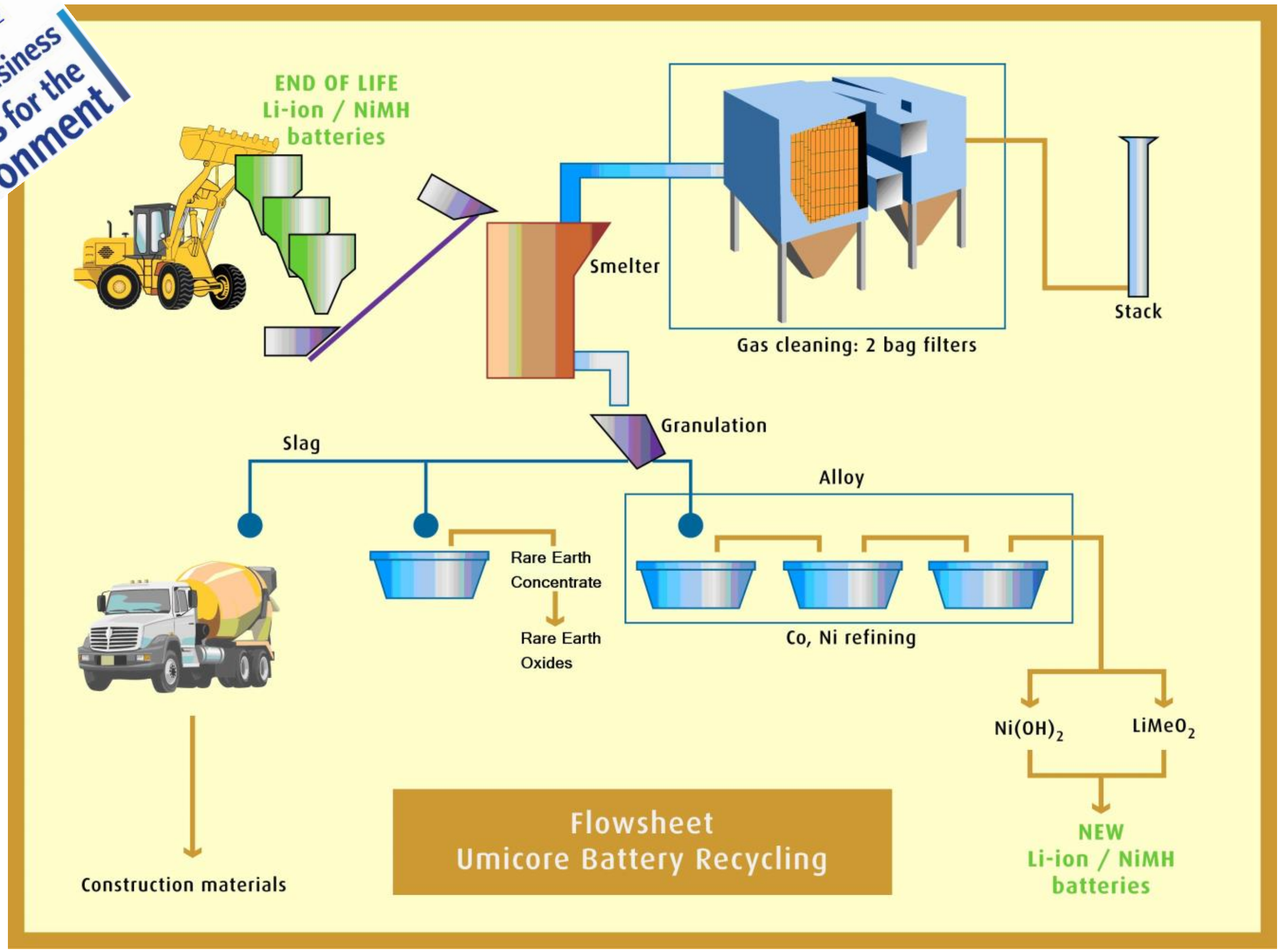
Battery recycling concepts: process choices

Shredding	
+	**-**
cost	
• smaller fraction to metallurgical process: lower investment cost	• several consecutive operations: more labour cost
Life Cycle Assessment (LCA)	
• more LCA credits for recovered Al (as metal)	• safety risk (fire) requires discharging or shredding under inert shield gas or cryogenic shredding ➔ more LCA burden

Pyro or hydro	
pyro	**hydro**
cost	
• low value metals are recycled at low cost • *higher investment cost*	• *need to refine also low value metals (mainly labour cost)*
Life Cycle Assessment (LCA)	
• slag forming additives are fully recycled • energy to heat furnace recovered from battery materials	• *need of chemicals* • *waste water treatment* • higher credits for recovered materials *(however, quality not yet proven)*

Pilot test needed to quantify the effects
Scale leverage effects can significantly influence the conclusion

Umicore Process description



RE calculation applied to the Umicore process

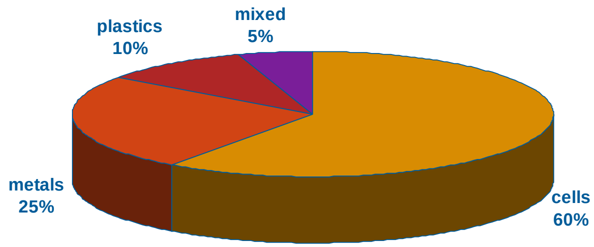
- Table 1:
  - Possible example of elemental composition of EV-battery modules *(not an industrial average, not representing a 'real' battery)*
  - Calculation of theoretical RE on module level:
    - Metals and P are supposed to end up in the right fraction
    - O is partially recovered in metal oxides (slag) and partially emitted as CO_2 and H_2O
    - C and H are emitted as CO_2 and H_2O
    - F is collected in a waste fraction

Table 1: calculation of RE on module level

modules	Al	Li	Ni	Mn	Co	O	Cu	C	F	P	H	
element composition input fraction (%)	12	3	5	12	5	17	10	30	3	1	2	100
recycling efficiency per element (%)	100	100	100	100	100	50	100	0	0	100	0	
recycled in output fraction (%)	12	3	5	12	5	8,5	10	0	0	1	0	RE (rounded) = 57%

RE calculation applied to the Umicore process

- Table 2:
  - Calculation of consolidated RE on battery assembly level for:
    - Typical battery assembly with steel casing
    - Typical battery assembly with synthetic fibre casing



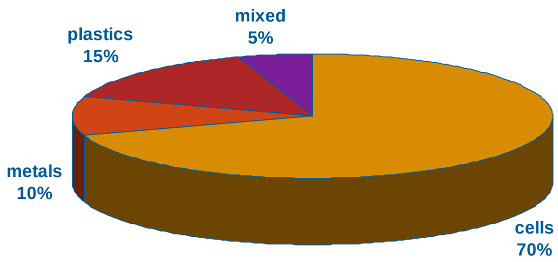


Table 2: calculation of a consolidated RE on battery level (calculated for a 100 kg battery)

RE estimation	steel casing			synthetic fibre casing		
	input fraction (kg)	partial RE	output fraction (kg)	input fraction (kg)	partial RE	output fraction (kg)
modules	60	**57%**	33,9	70	**57%**	39,6
metals	25	98%	24,5	10	98%	9,8
plastics	10	0%	0	15	0%	0
mixed	5	30%	1,5	5	30%	1,5
RE (rounded)			60 %			51 %

Conclusions

- EV recycling is subject to ELV and BD; BD recycling efficiency is distinguished from ELV recycling rate
- EV battery recycling is a combination of pre-treatment and metallurgical and chemical processes; the optimum combination depends on many variables (volume, battery chemistry and assembly design, investment and labour cost, …)
- Low volume of EV batteries today and the uncertainty of the ultimate cell chemistry, make it difficult to fully assess the cost / benefit ratio of EV battery recycling.
- There is a broad range of battery chemistries and the diversification is still going on. Therefore, an EV-battery recycling process has to be robust, in order to cope with this variety.
- The RE is highly influenced by the composition of non-active parts (mainly the protective casing)
- The Umicore process is compliant with the BD RE targets

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Thanks!

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