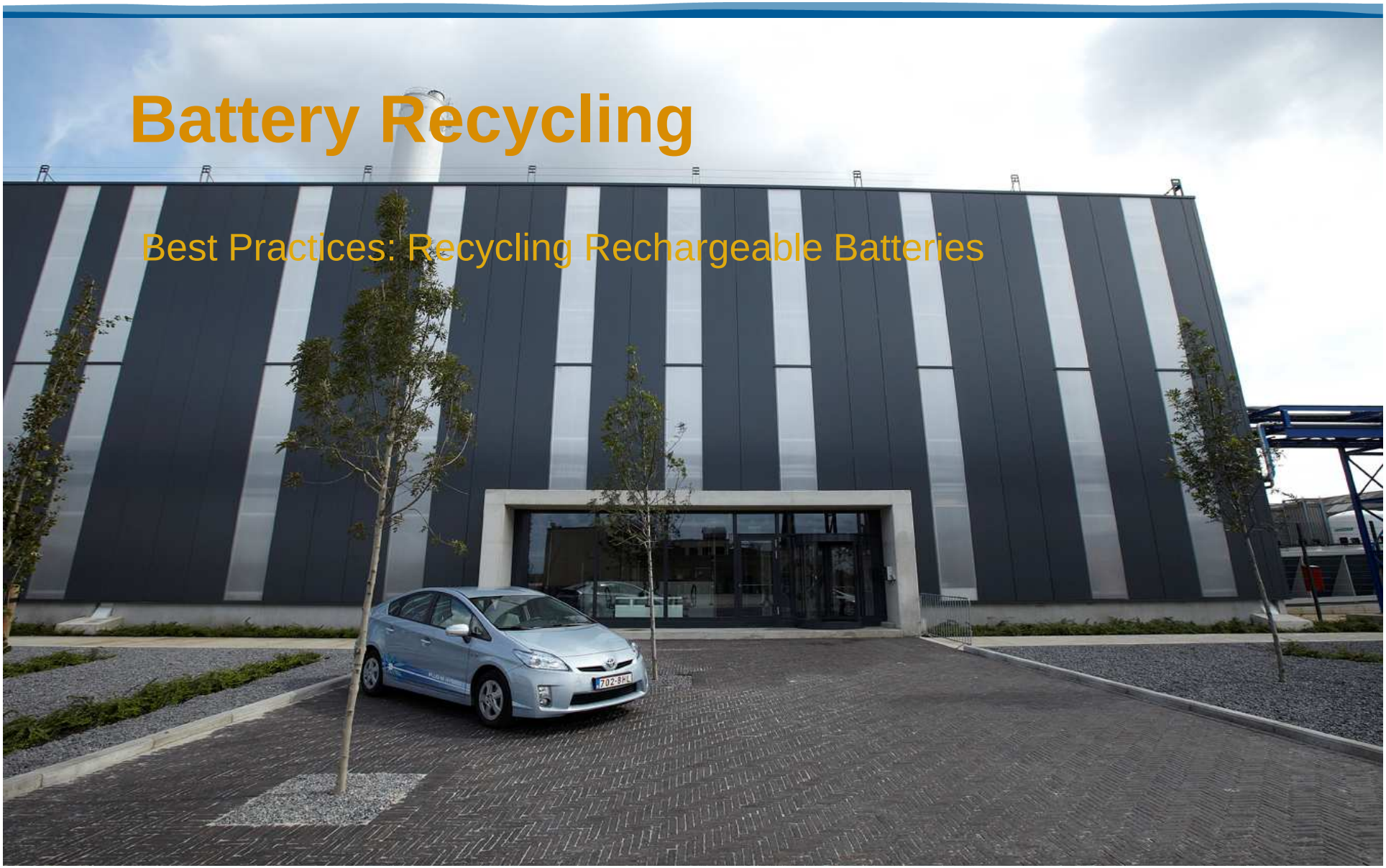
Battery Recycling

Best Practices: Recycling Rechargeable Batteries



Agenda

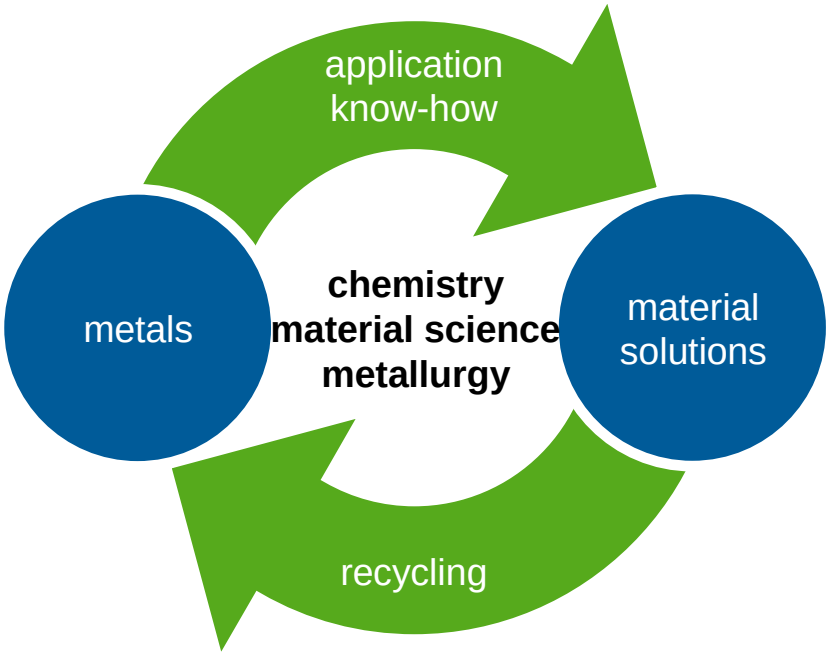
- Umicore in 2 slides
- Umicore Battery Recycling
  - History and investment
  - Process capabilities/benefits
  - Process description
  - Pilot plant
  - Safety issues
  - Scale up
  - Life cycle analysis
  - Conclusions

Umicore in 2 slides

Umicore today- a materials technology group

“Less is more”

Metal related materials can be efficiently and infinitely recycled, which makes them the basis for sustainable products and services



Umicore's businesses today

Energy Materials

- We develop materials which enable the clean production and storage of energy
- The business is driven by the demand for clean, low-carbon energy solutions

Catalysis

- We develop technologies to treat automotive emissions
- The business is driven by increasingly stringent emission norms to promote clean air

Recycling

- We operate a unique recycling process to deal with complex industrial residues and end-of-life materials
- The business is driven by materials scarcity and recycling legislation

Performance Materials

- We produce a range of essential materials and chemicals based on precious metals and zinc
- Diverse applications:
  e.g. high-purity glass, construction, pharma, electrics/electronics

Umicore Battery Recycling

History and investment

Umicore competencies to develop a recycling process for rechargeable batteries

Based on Umicore's long technological history (1880's), unique competencies have been developed in following areas:

- Metal recycling
  - -pyro-metallurgy
  - -hydro-metallurgy
- Cobalt and Nickel compounds refining and production
  - -9,000 metric tons of Cobalt per year = Market Leader
- Battery compounds developer and manufacturer
  - -$LiCoO_2$, $LiMeO_2$ [LCO, LCA, CMA, NCA,…)
  - -Nickel hydroxide, other Cobalt and Nickel compounds

Recycling of NiMH and Li-ion batteries

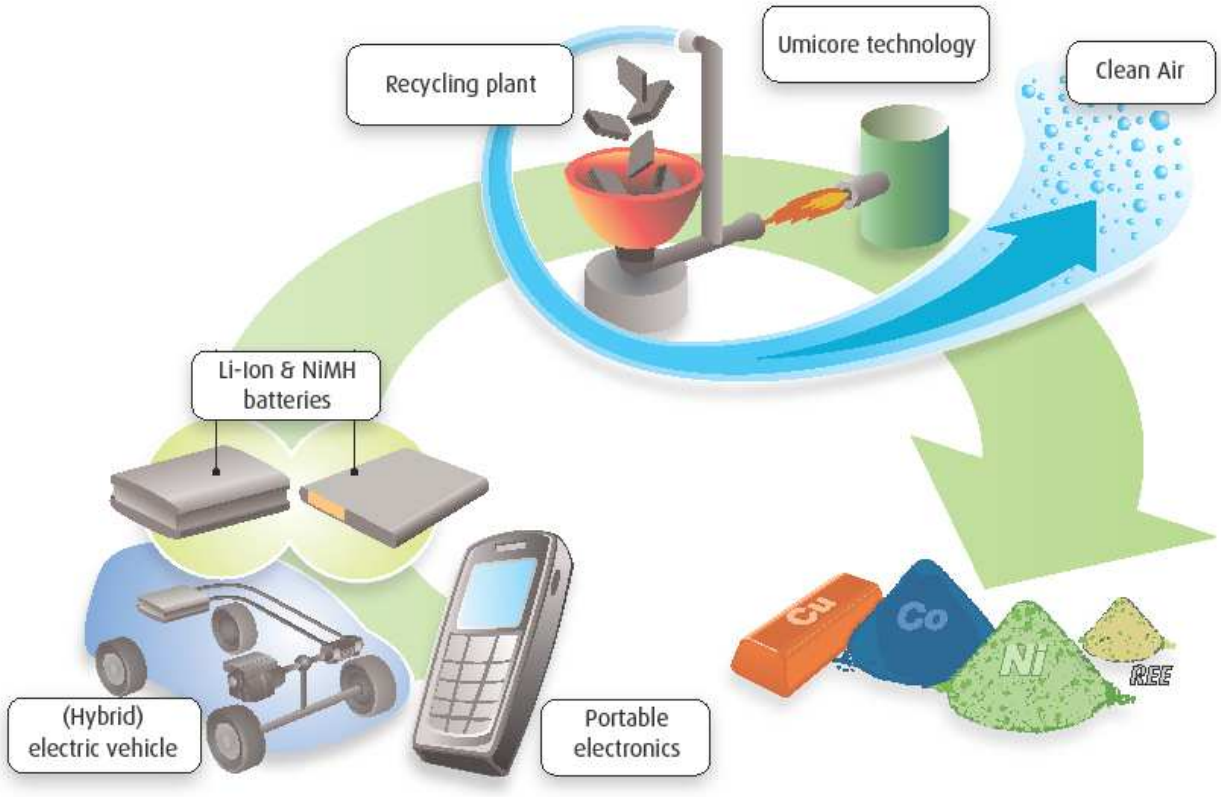
Umicore's Closed Loop Solution

Small Applications

Industrial Applications

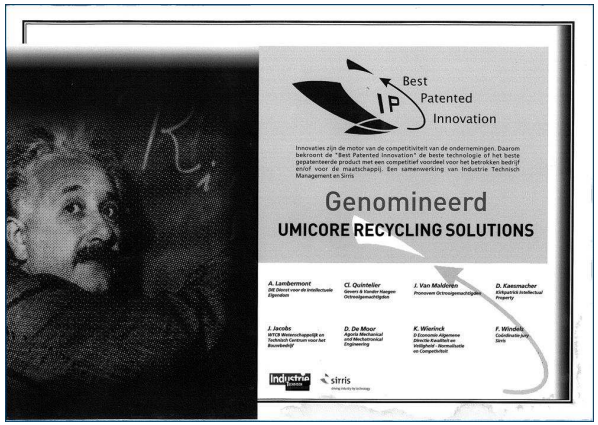
(H)EV

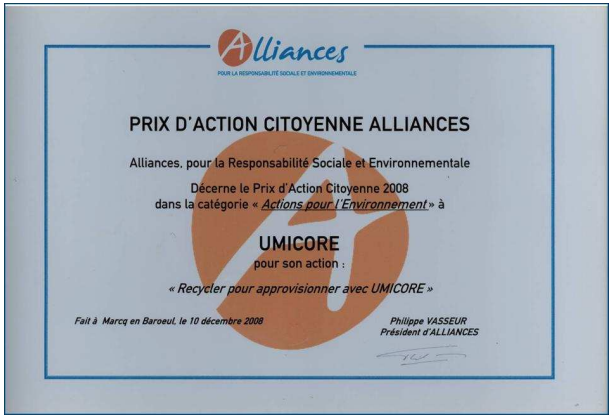
Closing the loop for rechargeable batteries



Umicore's recycling process gathers rewards

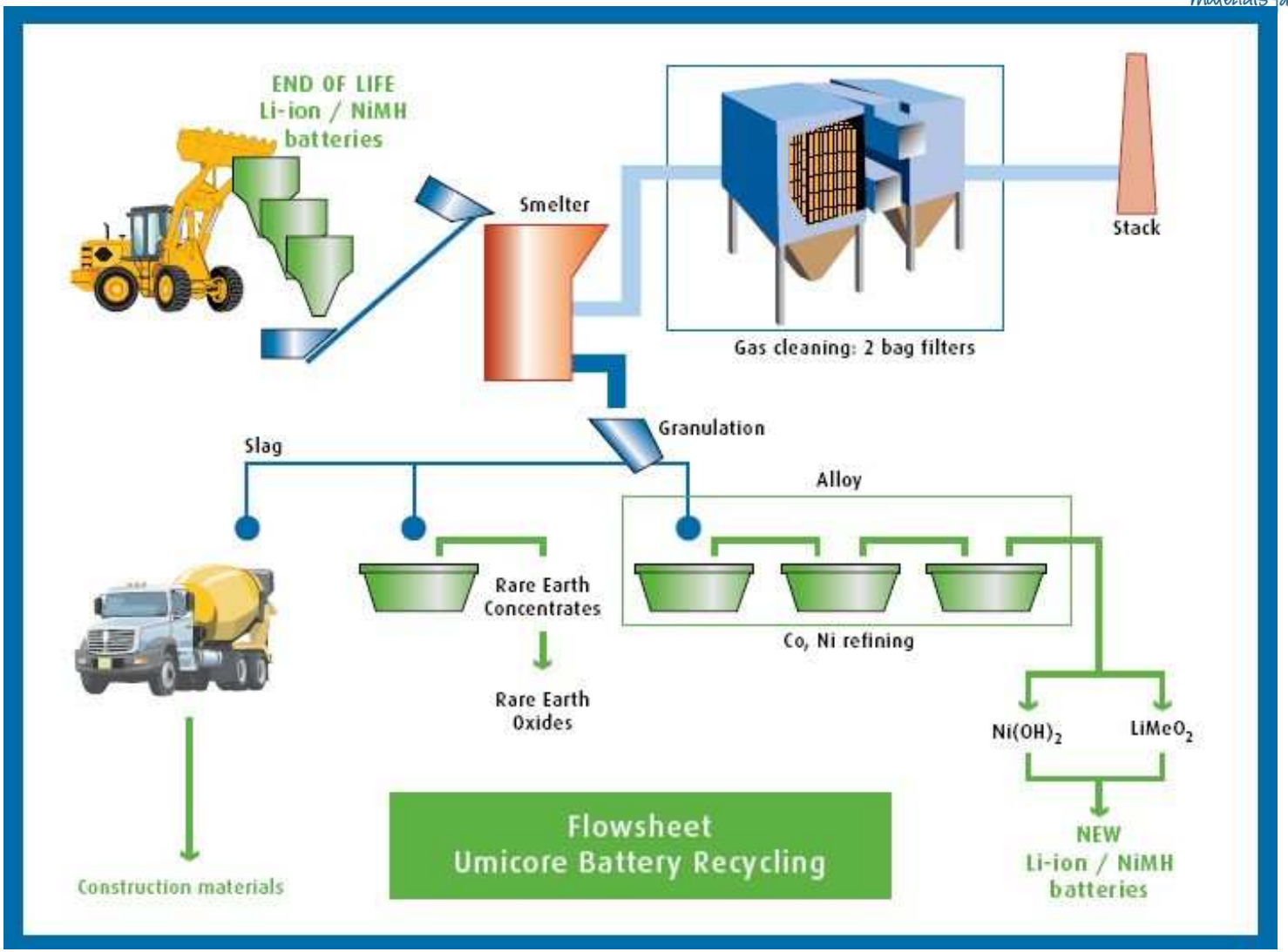
Umicore nominated as one of Europe's most innovative clean tech companies



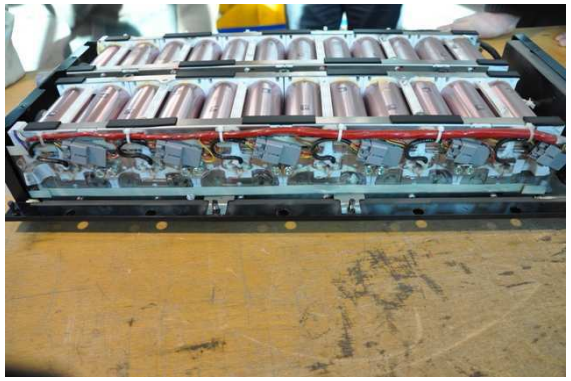


Umicore Battery Recycling

Process capabilities and benefits


END OF LIFE
Li-ion / NiMH
batteries
Smelter
Stack
Gas cleaning: 2 bag filters
Granulation
Slag
Alloy
Rare Earth
Concentrates
Rare Earth
Oxides
Co, Ni refining
$Ni(OH)_2$
$LiMeO_2$
NEW
Li-ion / NiMH
batteries
Construction materials
Flowsheet
Umicore Battery Recycling

Pack dismantling line – U.S. + Germany


- Maxton, North Carolina, USA – semi-automated line
- Hanau, Germany – manual line
- Dismantling avoids transport of parts which are ‘easy’ to recycle locally
- Creates valuable, more basic, jobs

Specific economic benefits

❶ Move away from dependence on mining
❷ No subcontractors
❸ Complete destruction of used batteries.
❹ Availability of electronics recycling making one-stop shop
❺ Possibility to return recycled battery materials

Specific environmental benefits

❶ High Recycling Efficiency (RE): > 50% per EU Battery Directive

❷ No hazardous pretreatment

❸ Gas cleaning process

❹ The whole process is energy efficient.

Umicore Battery Recycling

Process description

Recycling process

+ Energy Valorization

INPUT

Smelting
Al Li Co Ni Mn Cu REE's Fe

OUTPUT

Slag
Al Mn Li REE's

Recovery REE's REE's

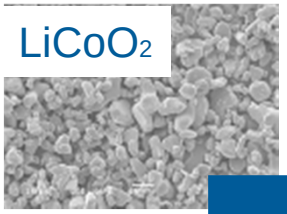
Construction

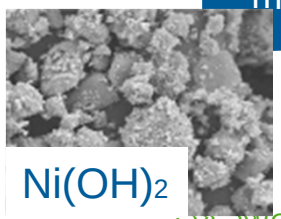
Potential Li-extraction Li

OUTPUT

Alloy
Co Ni Cu Fe

Further Refining





New battery materials

Firing With Li_2CO_3

oxidation (Co_3O_4)

$(CoCl_2)$

Co

Ni

$NiSO_4$

SX

de-Fe

de-Cu

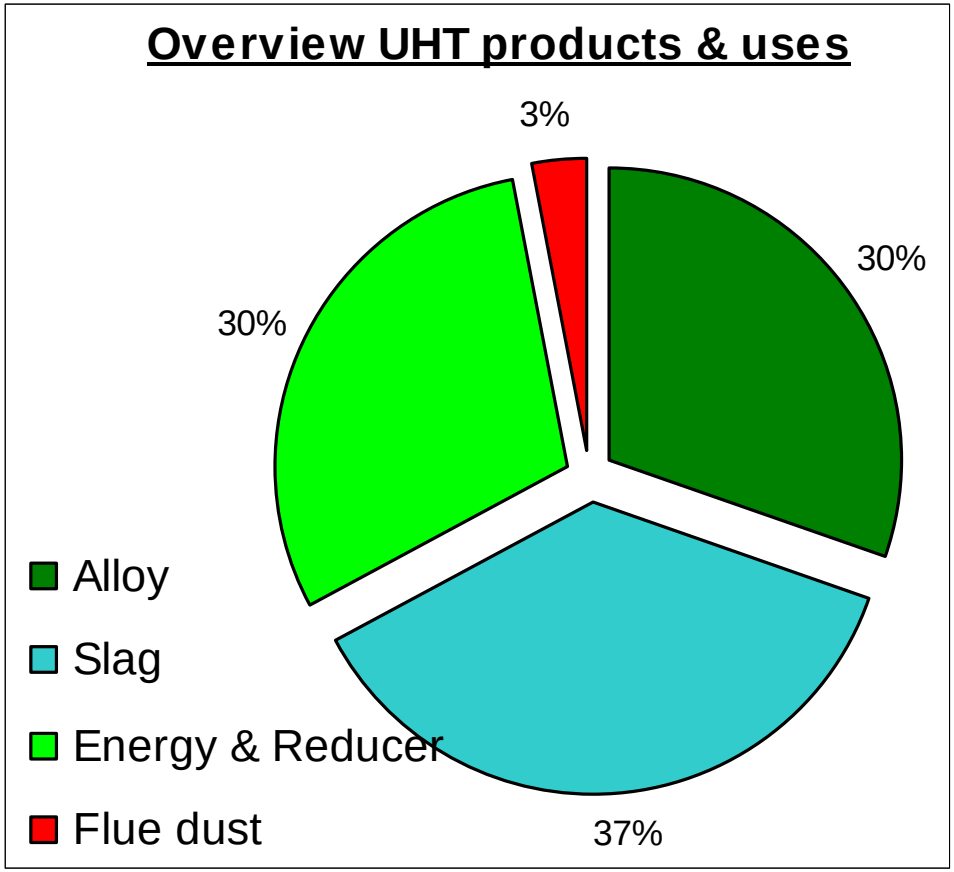
Fe

Cu

Co Cu Ni Fe

Alloy Refining

Products from UHT battery process less than 3% land filled today



Umicore Battery Recycling

Pilot plant

Feed structure

Small applications

Industrial applications

xEV (ind. applications)

Recycling process

Feeding equipment / batteries handling

- No dismantling, crushing…
  - Safe for workers
  - Safe for Environment
  - Cost Effective
- For any size of batteries
  - Small electronic appliances
  - Industrial batteries
  - HEV/ EV batteries

Recycling process
Smelting batteries

- Specially designed furnace
  - Intellectual property of Umicore
  - No explosion of batteries (safety)
  - No cell dismantling/No cell shredding

- Products
  - Alloy
  - Slags

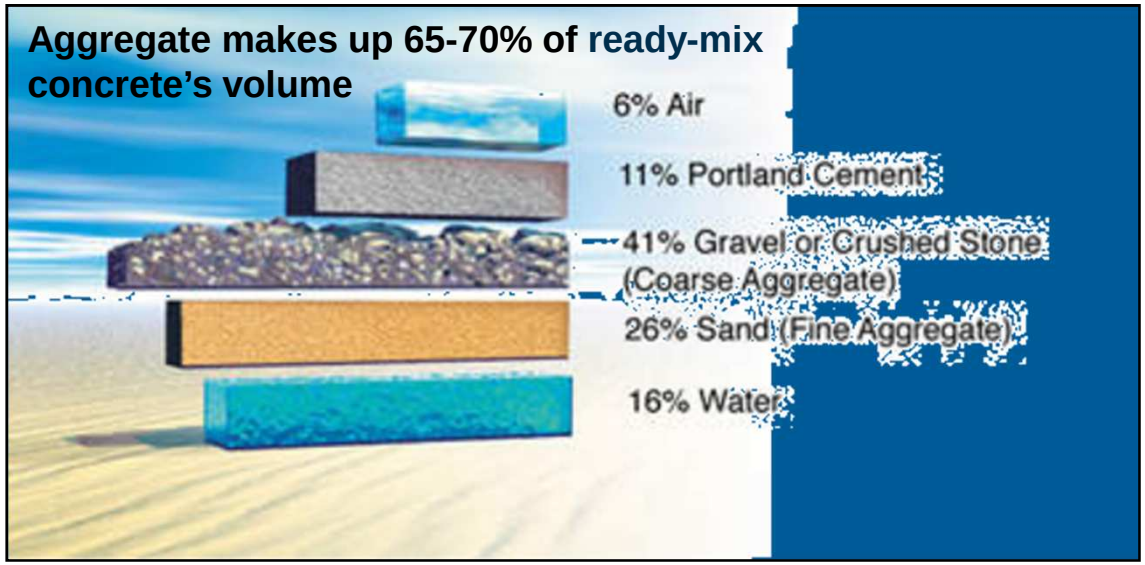
Recycling process
Smelting batteries

- Specially designed gas treatment
  - A unique Umicore design
  - No VOC formation
  - All dust removed
- Gas cleaning technology
  - Low volume gas
  - Low CO_2 footprint

Li-ion battery slag

- Slag composition
  - main components: $CaO – Al_2O_3 – SiO_2$
  - minor components: $FeO_x – Li_2O – MnO$

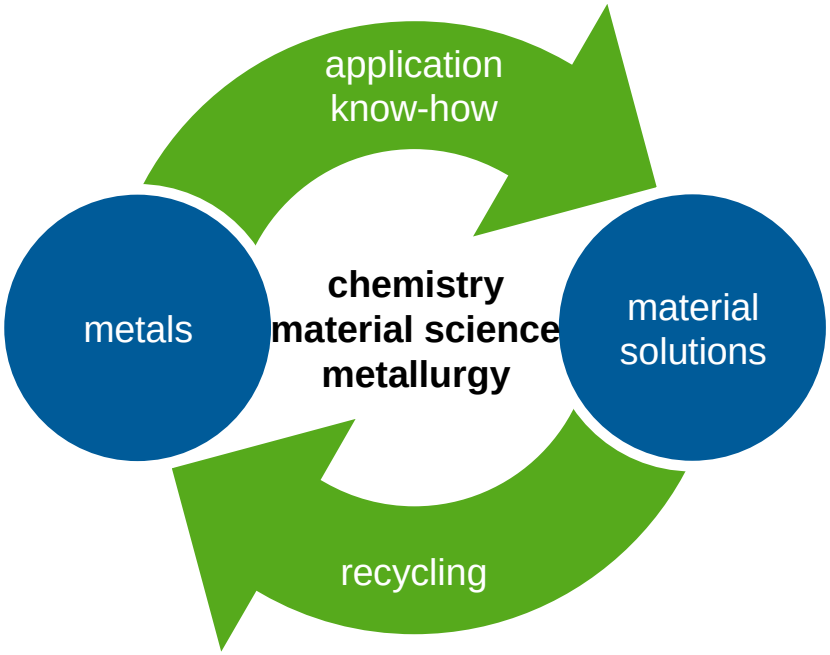
- Application as an aggregate in concrete



Umicore committed to closing the loop

Umicore is also focusing on the other elements in the batteries:

- Recovery on R&D Level
  - -Lithium: extraction of Li from slag
  - -Fluor: fluorspar
- Operational
  - -Rare Earths: NiMH battery slag



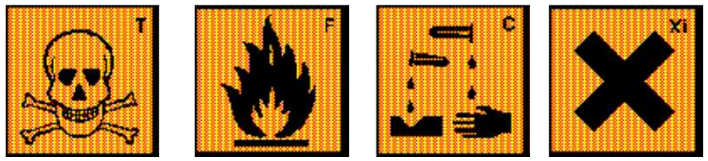
Umicore Battery Recycling

Safety issues

Safety – Environment – Health first!

Energy content

Chemicals inside



❑Transport

- Supplier: knowledge of battery composition, safety precautions
- Umicore: knowledge transport rules (land, sea, air, national & international)

➔Safe procedure to be developed for larger quantities

❑Dismantling

- Supplier: to supply relevant information (BOM, MSDS, safety instructions)
- Umicore: to design safe process with zero risk

Umicore Battery Recycling

Robust and easily scaled up

Umicore's recycling process is robust (1/2)

Early stage standardization and **volume driven** unit process: recovery of metals

- Minimum sorting and mechanical preconditioning
- Pyrometallurgical separation of metals; use of organics as fuel or reducing agent
- Resulting metal alloy can be used as such or is further refined

Ideally, metals are further refined to the level that they can be transformed into new battery materials

Umicore's recycling process is robust (2/2)

- ➔ Allows any metal composition input to deliver a standard metal alloy
- ➔ Output allows straightforward manufacturing of battery materials regardless of the input battery grade
- ➔ Typically large scale, volume driven installation

Umicore's recycling process can be easily scaled up:

	Small Recycling Plant	Large Recycling Plant	Comments
Process Cost	High	Low	Some element recycling needs scale effects to become profitable
Transport • Batteries • Recycled Products	 Less More	 More Less	 • Distance travelled • Several recycled products are special products with no local market
Energy Efficiency	Worse	Better	Generally speaking: energy efficiency measures pay off better in large installations
Investments	Incremental	Capital	To cope with growing business, small plants can follow market needs more precisely

- Appropriate capacity for recycling plant depends on:

  -process

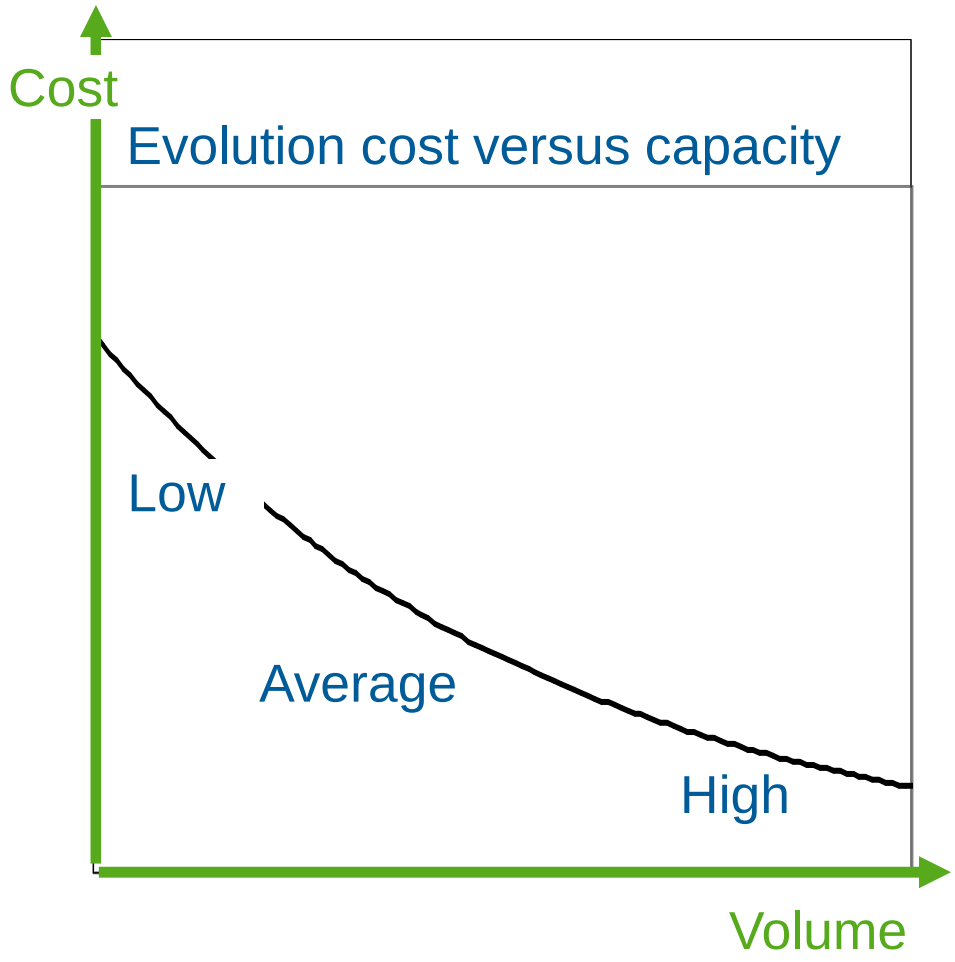
  -markets for recycled products

➔ LCA can help to assess the environmental aspects of the above.

Scale up issues and cost benefits

- Umicore's battery recycling experience:
  - Lab scale
  - 1,500 ton per year
  - 7,000 ton per year

- Umicore also recycles over 350,000 tons of materials per year containing platinum group metals (PGM's)



Umicore Battery Recycling

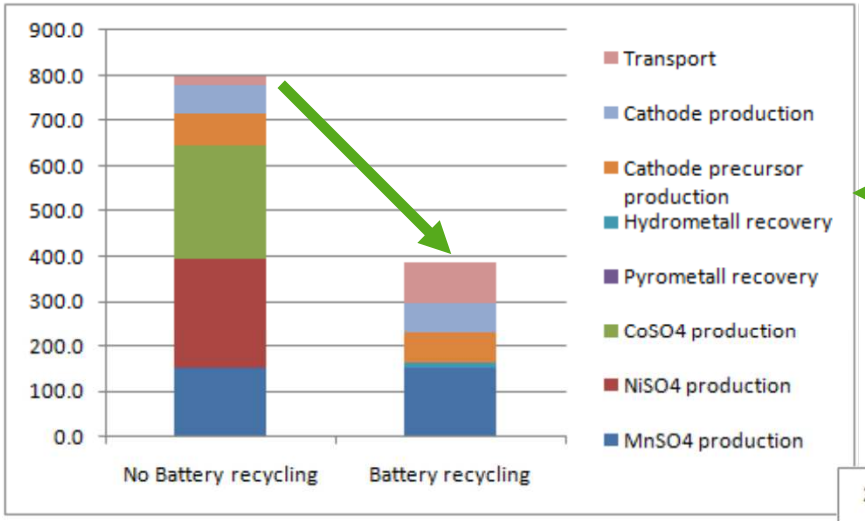
Life cycle analysis

Life cycle analysis published

- Several LCA's, together with customers:
  - Recycling reduces
    - global warming
    - acidification potential
    - ozone depletion potential of EV's

    (impact reductions from 20 to > 90 %)
  - Very low CO_2-footprint and nearly no added external energy - even if transport of batteries is included in the LCA scope
  - Resource efficiency: Metals are infinitely recyclable
  - Study by University of Ghent shows more than 50 % resource efficiency credits
  - Chemicals used in the process are recycled for construction

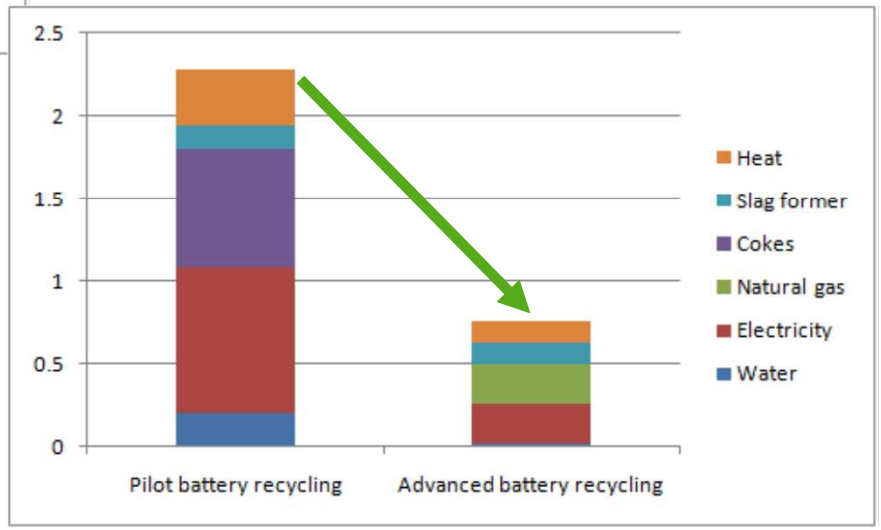
Resource savings by battery recycling



LCA study to determine gains (51%) between mining and our initial battery recycling process

"Resource savings by "Advanced Battery Recycling"
Geert Van der Vorst1, Begum Yazicioglu2,Jan Tytgat2, Benedicte Robertz2, Jo Dewulf1
1Ghent University
2Umicore Battery Recycling"

Additional LCA study to determine further gains (66%) between our initial battery recycling process and the new 7,000 metric ton pilot



Conclusions

Umicore’s 7,000 metric tons battery recycling facility

Summary

Umicore is closing the materials loop

Umicore is recycling in an environmentally sound way.

Above all, the process developed by Umicore combines many advantages:

- No hazardous pre-processing of batteries; i.e., no shredding
- No hazardous gas produced: gas treatment installation avoids any formation of dioxins or VOC's
- The materials loop is closed: main metals are re-used in new battery technologies or other high end applications
- All plastics are fully utilized as energy source
- Plant design will enable significant cost decrease with growing market availability of feed
- Process can handle large variability of Li-ion battery chemistries and returns stable quality alloy for easy processing into high quality battery materials

Thank you

www.batteryrecycling.umicore.com

www.umicore.com

Battery cell materials are well characterized (ANL 2010) and each has its use and destination within the UHT process

Materials	Weight (kg)	Percent	UHT Destination
LiO2	0.91	5.3%	Slag
Nickel	0.46	2.7%	Alloy
Cobalt	0.46	2.7%	Alloy
Manganese	0.43	2.5%	Slag
Graphite and carbon	1.82	10.6%	Energy & Reducer
Binder	0.35	2.0%	Energy & [F] Flue Dust
Copper parts	4.21	24.5%	Alloy
Aluminum parts	3.2	18.6%	Reducer & Slag
Aluminum Casing	1.82	10.6%	Reducer & Slag
Electrolyte	1.5	8.7%	Energy & [F] Flue dust
Polypropylene	1.39	8.1%	Energy & Reducer
Polyethylene	0.492	2.9%	Energy & Reducer
Steel	0.029	0.2%	Alloy
Thermal insulation	0.089	0.5%	Energy
Electronic parts	0.056	0.3%	Alloy
Total Battery Mass	17.216	100.0%	

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