

CONTENT

Ø Umicore Battery Recycling & Process

Ø Life Cycle Assessment studies

- Li-ion battery (from cell production to end-of-life)
- NiMH battery (from battery production to end-of-life)
- Li-ion battery cathode production (natural resource saving)

Ø Conclusions



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

Umicore's Closed Loop Solution



Small
Applications

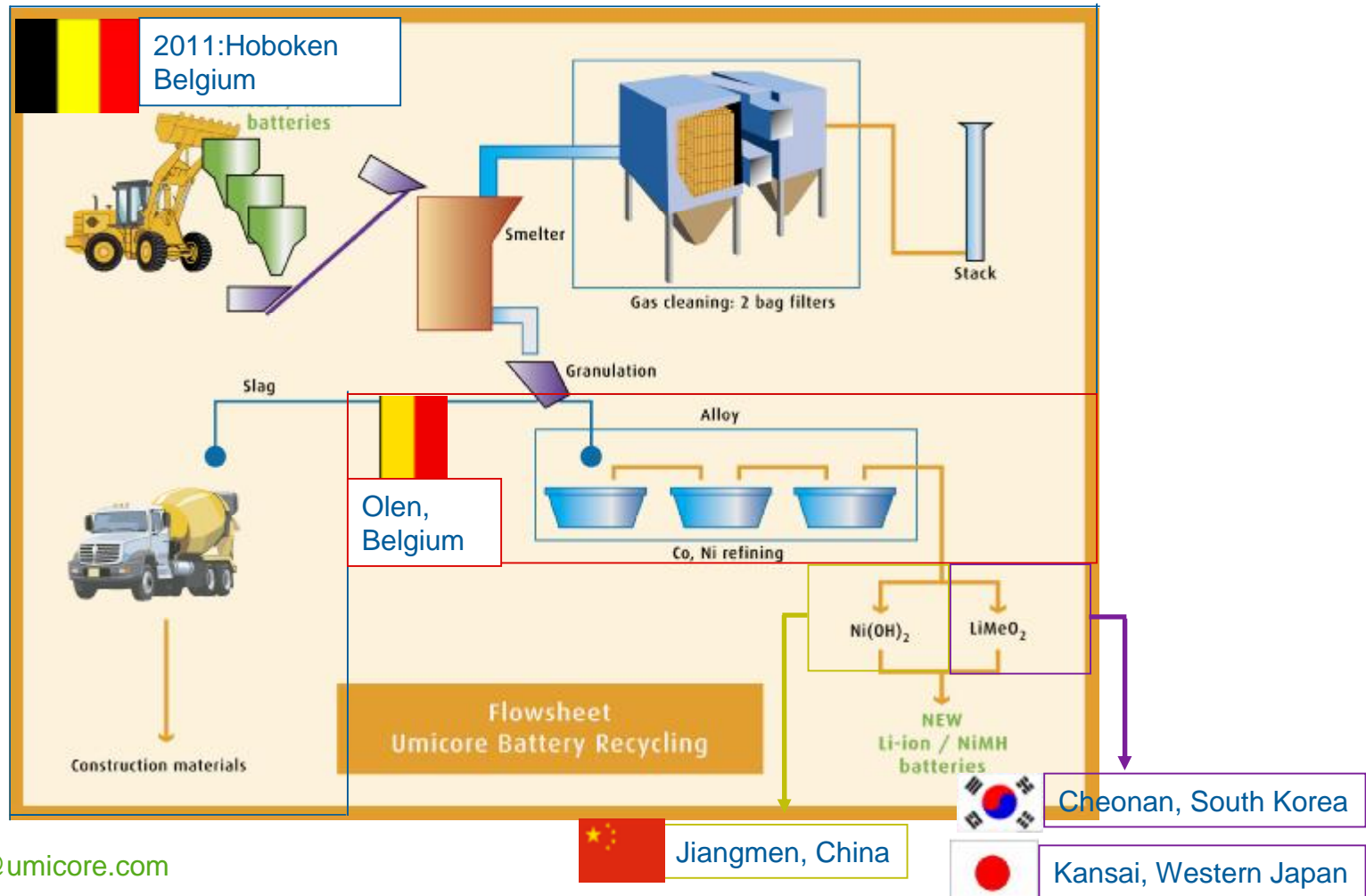
Industrial
Applications

(H)EV

Umicore Battery Recycling Process

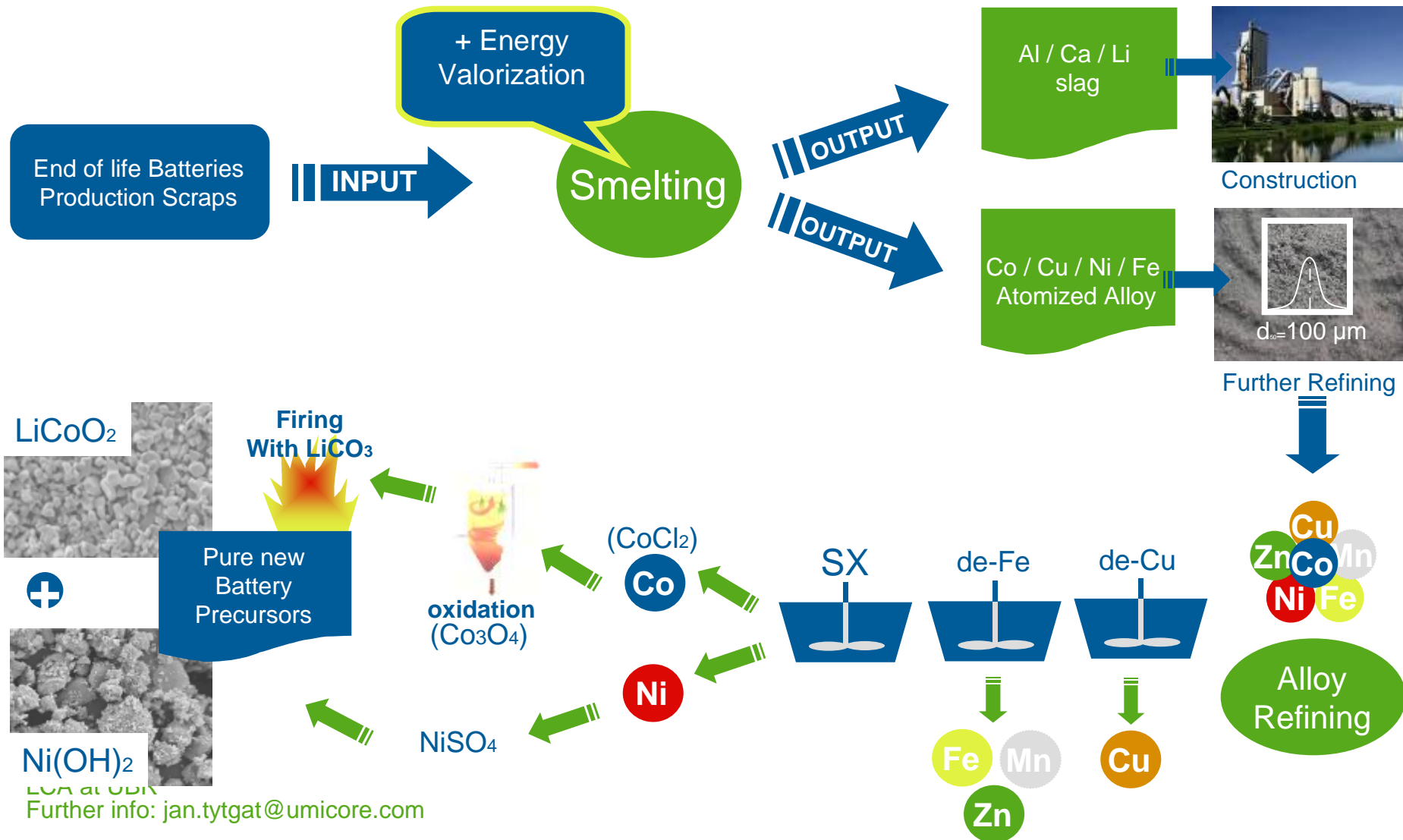
Li-ion
NiMH

The Unique Closed Loop Solution for batteries



LCA at UBR
Further info: jan.tytgat@umicore.com

Overview of the Umicore battery recycling process



LCA studies Umicore involved

Ø SAFT LCA : Li-ion battery (LiCoO₂ chemistry)

Ø Prius LCA: NiMH battery

- Recharge (40%)
- Nickel Institute (40%)
- Toyota (10%)
- Umicore (10%)

Ø Ghent University: Li-ion battery (LiMeO₂ chemistry)

LCA studies Umicore involved

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Ø Ghent University: Li-ion battery (LiMnO₂ chemistry)

Simplified LCA by SAFT

Ø Goal & scope:

- To compare impact of recycling on **impact categories** (CO₂ production & energy consumption) for the production of a Saft MP 176065 Integration® cell
- Production of LiCoO₂ material :
 - **Option 1** : from Ni, Co ores extracted from mines
 - **Option 2** : from Ni, Co recycled from Li-ion batteries

Ø Functional unit:

- Production of 1 Saft MP 176065 Integration® cell

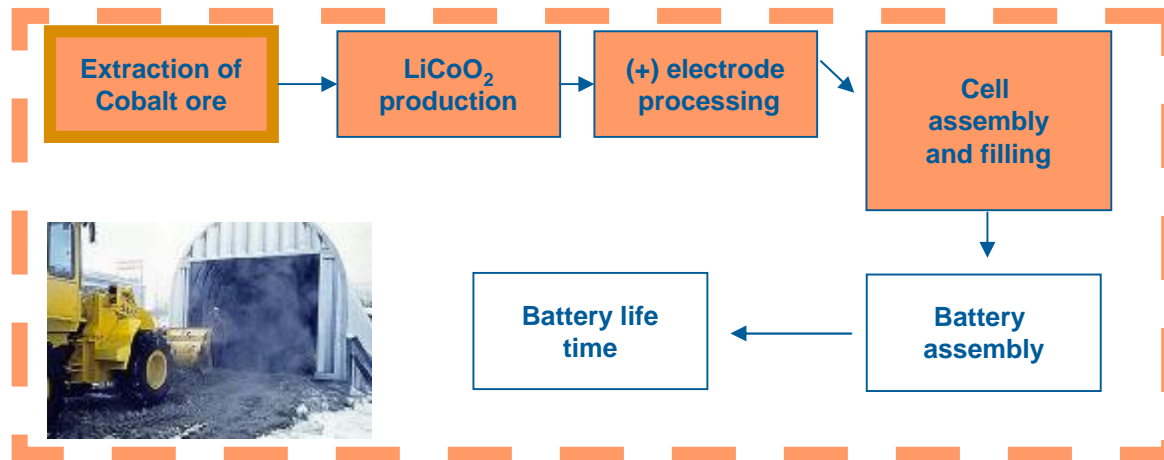
Ø Data collection:

- Based on published data:
 - www.informine.com
 - www.oee.nrcan.gc.ca & www.nickelinstitute.org
- Based on Umicore Battery Recycling process

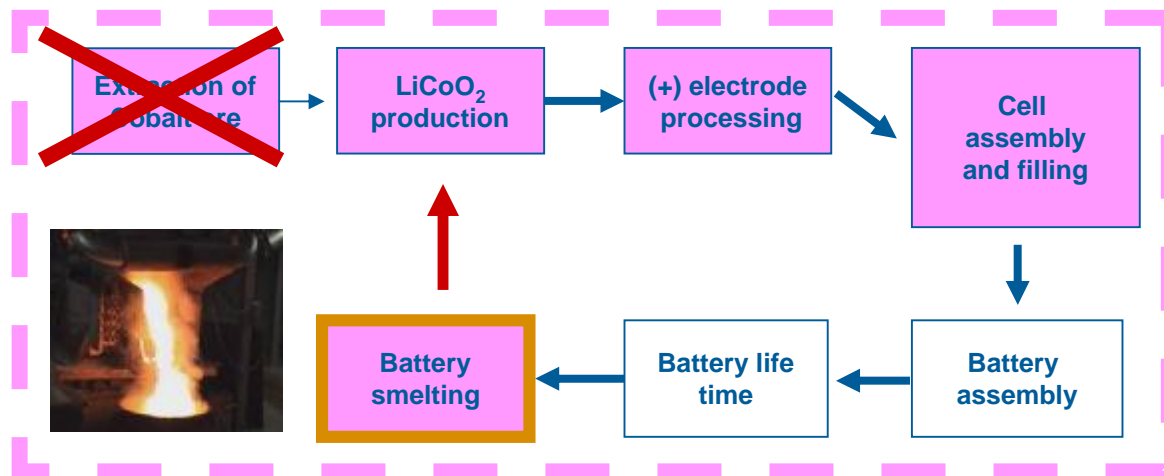


Functional unit:
production of 1
SAFT MP cell

System boundaries



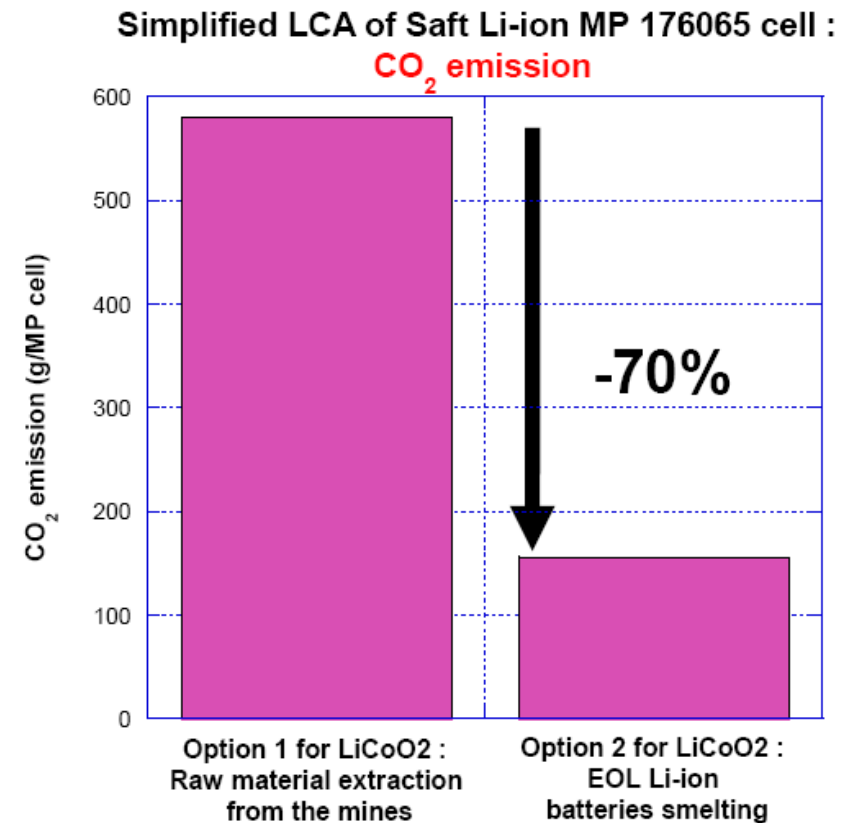
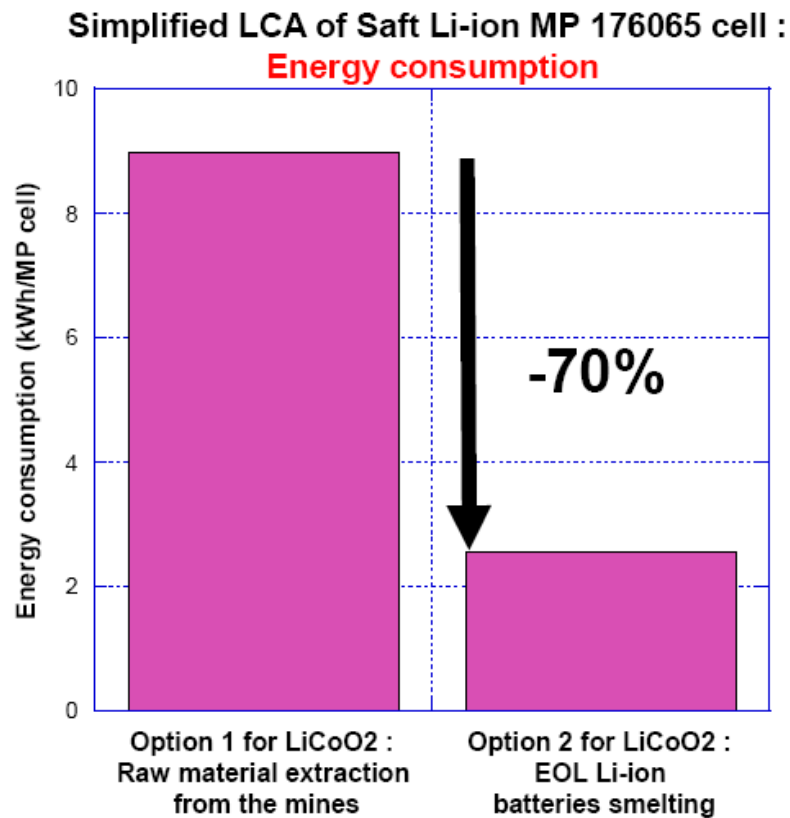
1st option : Extraction of Co ore from Ni/Cu mines



2nd option : Battery closed loop recycling

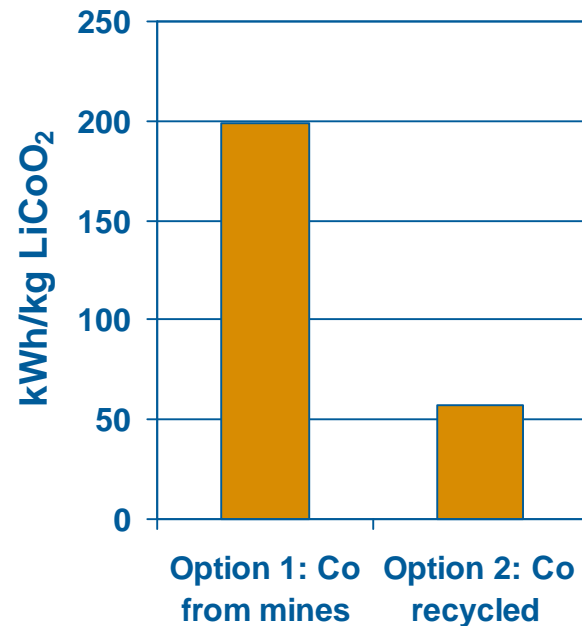
Conclusions SAFT

- Less environmental impacts when LiCoO_2 is produced from recycled Li-ion batteries

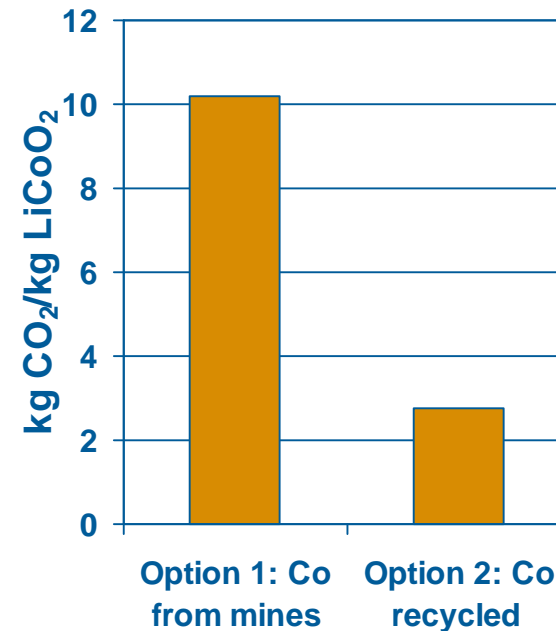


Conclusions SAFT recalculated per kg LiCoO_2

energy consumption for production of 1 kg of LiCoO_2



CO_2 emission for production of 1 kg of LiCoO_2



Ø Comments:

- Co extraction from ores is very energy intensive and produces more CO_2
- battery recycling doesn't consume energy but produces excess of energy (recoverable) and produces much less CO_2 than ore smelting.

Conclusions SAFT LCA study

- ∅ This LCA study shows that recycling of the batteries
 - is anyway better for the preservation of the natural resources and
 - and keeping the metals into the loop allowing lower environmental impacts (-70% of energy consumption and of CO₂ emissions)

LCA studies Umicore involved

Ø SAFT LCA : Li-Ion battery (LiCoO₂ chemistry)

Ø Prius LCA: NiMH battery

- Recharge (40%)
- Nickel Institute (40%)
- Toyota (10%)
- Umicore (10%)

Ø Ghent University: Li-Ion battery (LiMnO₂ chemistry)

LCA on Prius NiMH battery by Öko Institute

Ø Goal & scope:

- To investigate the impact of nickel in rechargeable batteries,
- To identify the key environmental parameters influenced by the production, the use and the end of life;
- To identify areas for possible improvements
- To compare the net impact of driving a Prius vs. a conventional car.

Ø Functional unit:

- Production of 1 Toyota Prius HEV NiMH battery + use phase (150.000 km) + End-of-life



LCA on Prius NiMH battery by Öko Institute

Ø Data collection:

- The LCA is performed by Öko Institute on behalf of RECHARGE (40%), Nickel Institute (40%), Umicore (10%), Toyota Europe (10%).
- According to the ISO criteria: Critical review is done by EMPA, Switzerland

Ø Impact categories

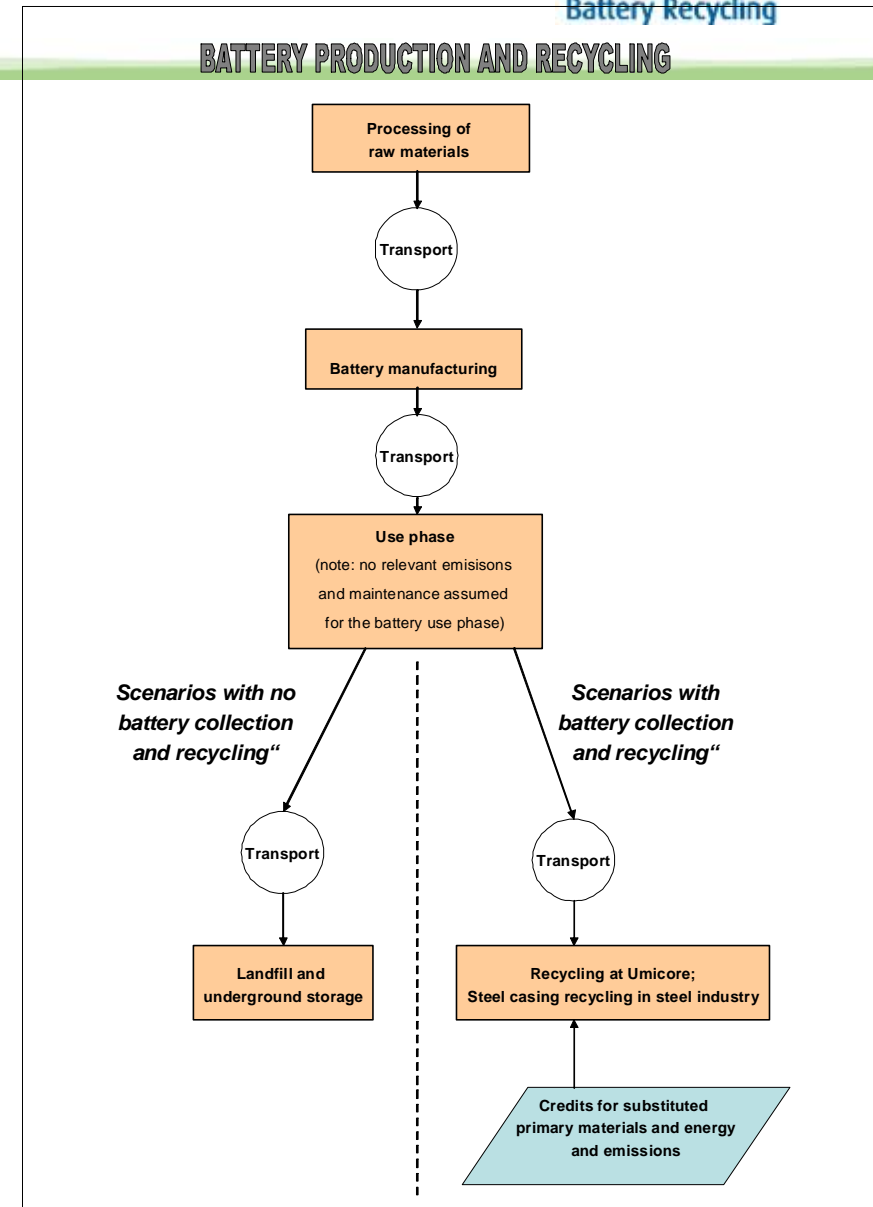
- Global Warming Potential
- Acidification Potential (air, water, soil)
- Eutrophication Potential
- Photochemical Ozone Creation Potential
- Use of non-renewable energy carriers
- Ozone depletion potential
- Depletion of mineral resources

System boundaries

∅ For the battery production = the whole process chain of the production

∅ For the battery recycling in Umicore plants = the whole recycling process. Credits are given for the primary production of an equivalent amount of nickel sulphate and cobalt sulphate

∅ For the scenario without collection system the disposal in landfills and underground storage is taken into account.



LCA on Prius NiMH battery: impact of recycling

Ø In order to assess the impact of recycling (Umicore process) on the production & use phase, three scenarios are compared:

- **Scenario 1: maximum battery collection and recycling:** This scenario is designed to show the maximum effect of recycling. It implies a collection rate of 99 % and a transfer of all collected batteries to Umicore.
- **Scenario 2: 50 % battery collection and recycling:** This scenario implies a collection rate of 50 % and a transfer of all collected batteries to Umicore.
- **Scenario 3: no battery collection and recycling**

*Following slides: only effect of recycling (0%, 50% or 100 %) is illustrated!
Effects of use phase (hybrid driving versus conventional driving): available on request.*

LCA on Prius NiMH battery: conclusions for recycling

Ø Global Warming Potential (GWP) and non-renewable energy carriers: limited impact because:

- Main GWP saving is realized during use phase, not during production phase
- Öko didn't valorize energy recovery during recycling process, because the recovered energy only substitutes biomass for district heating near Umicore's recycling plant. → situation is improved with new Hoboken plant

Ø Ozone depletion:

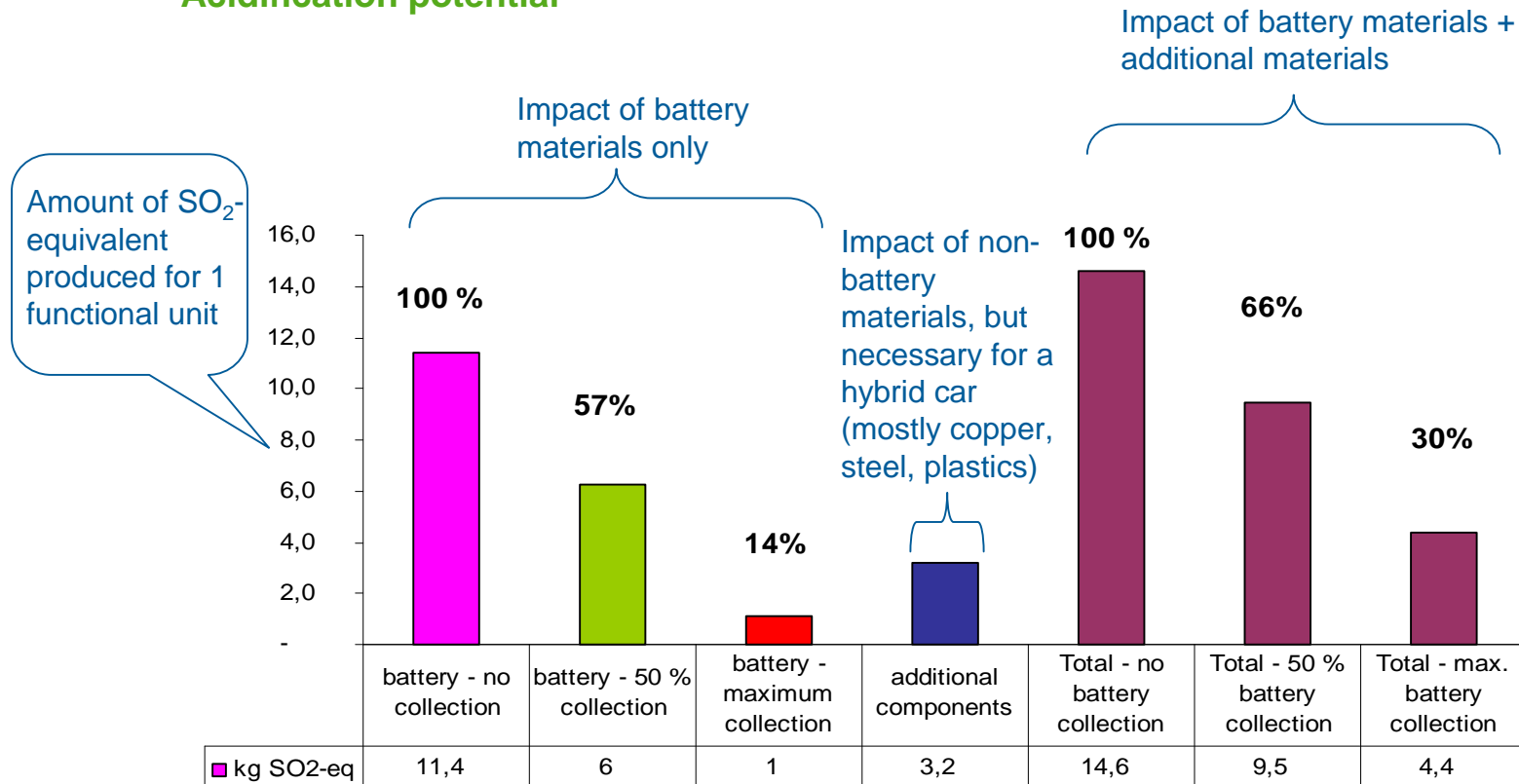
- main source of ozone depletion is production of PTFE (tetrafluoroethylene [battery compound]). As this is not recycled in Umicore's process, no positive impact.

Ø For all other selected impact parameters: excellent results

- Without recycling, Acidification and Eutrophication would be 'negative' for NiMH driving (= worse compared to conventional car): primary Ni production releases SO_2 and NO_x in nature; fully neutral if recycled Ni is used

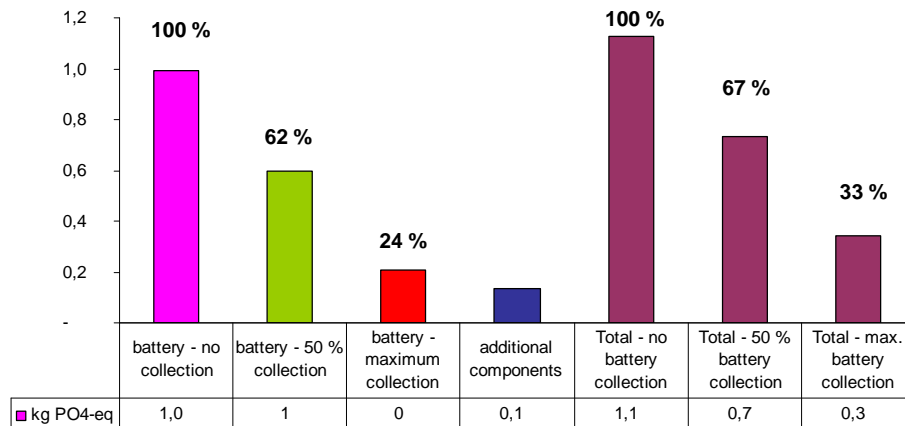
LCA on Prius NiMH battery: detailed results

Acidification potential

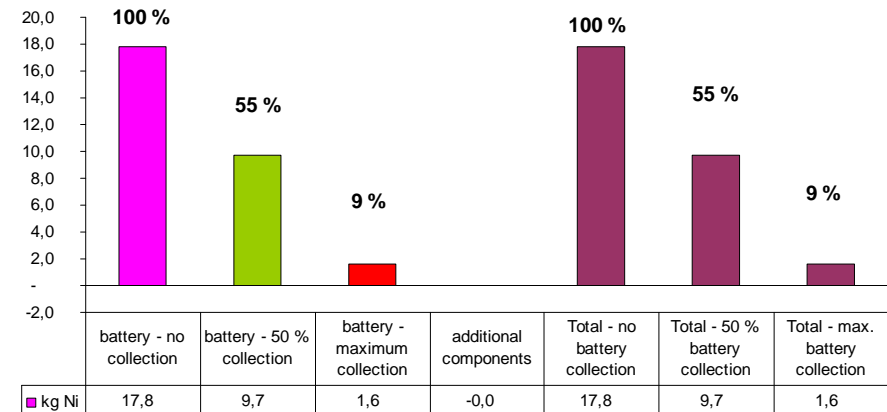


LCA on Prius NiMH battery: detailed results

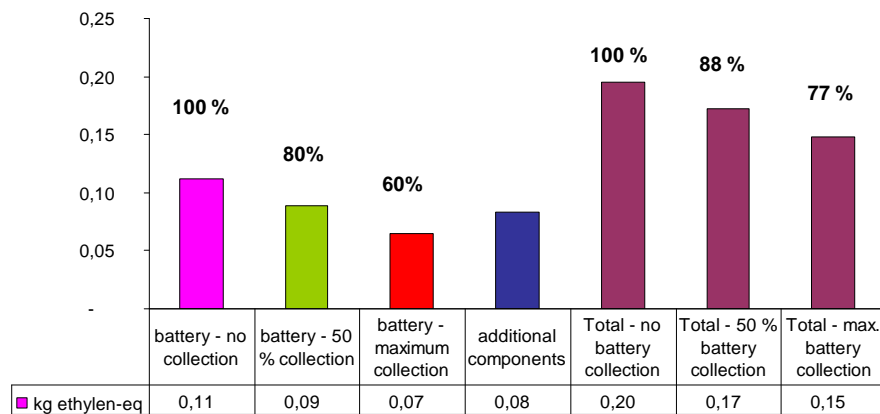
Eutrophication Potential



Depletion of mineral resources



Photochemical Ozone Creation Potential



For 'additional components', market average recycling schemes are assumed (100 % recycling is supposed as it fits within existing car recycling)

Conclusions Toyota Prius study

∅ This LCA study shows that;

- Nickel supply chain is responsible for 90% of the acidification and eutrophication potential respectively within the battery supply chain (without battery recycling)
- The battery recycling is an essential factor for a better overall balance for the environmental performance (particularly for the acidification and eutrophication).
- Further advantages of battery recycling: protection of natural resources etc...

LCA studies Umicore involved

Ø SAFT LCA : Li-ion battery (LiCoO₂ chemistry)

Ø Prius LCA (Recharge + Nickel Institute + Toyota): NiMH battery

Ø Ghent University: Li-ion battery (LiMeO₂ chemistry)

LCA on mixed oxide Li-ion battery (Ghent University)

Ø Goal & scope:

- What resources can be saved through recycling Li-ion batteries?
 - Scenario A: cathode production from primary (ores) Co, Ni
 - Scenario B: cathode production from recycled Co, Ni (Mn into slag)

Ø Functional unit:

- Production of 1 kg of cathode material LiMeO_2 (Me= Ni, Mn, Co)

Ø Data collection:

- Umicore for cathode production and recycling
- Eramet, Xstrata
- Eco-invent

- The LCA is performed by Ghent University
- Critical review is done by EMPA, Switzerland



Functional unit:
production of 1 kg of
active cathode
material (NMC-type)

LCA on mixed oxide Li-ion battery (Ghent University)

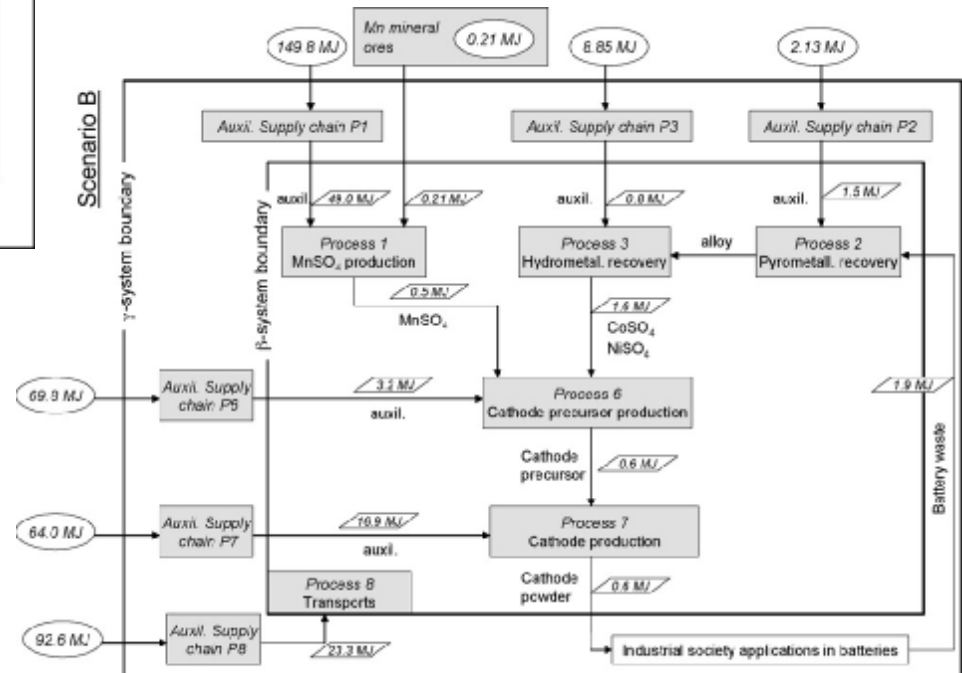
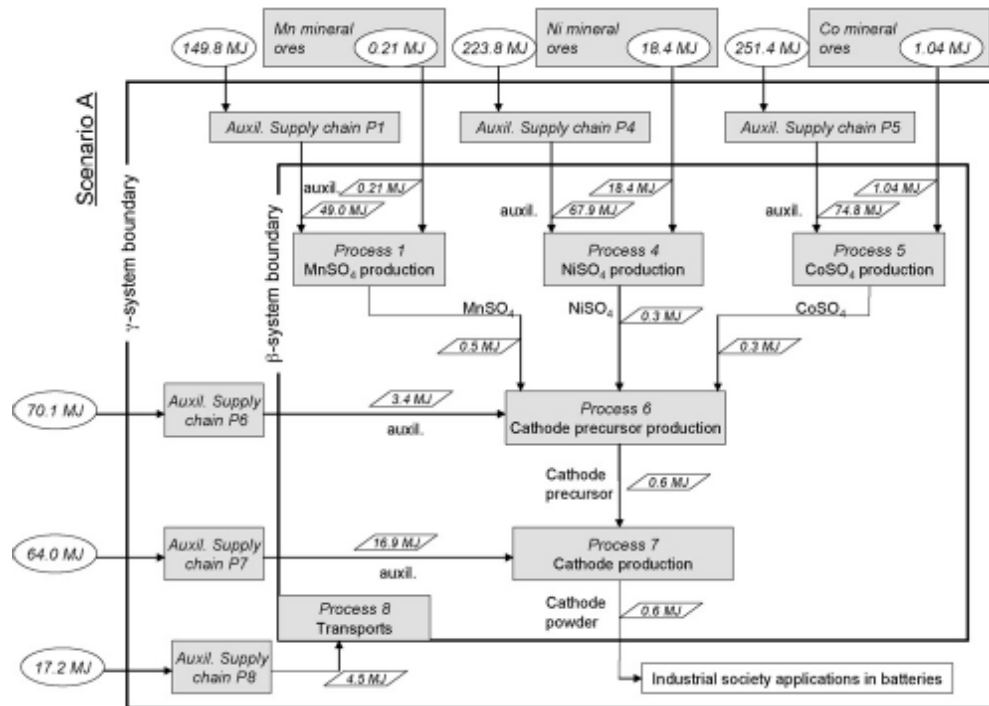
Ø Calculation method

- In order to aggregate use of energy and materials in one figure, a unique quantifier is used: Exergy; it is expressed in Joule
- Exergy represents the upper limit of the potential of a mass or energy flow to do work given the environmental conditions.
- All the LCI data is quantified in exergy.
- For more details please check: "*Exergy: Its potential and limitations in environmental science & technology*", Prof. Jo Dewulf, Ghent University

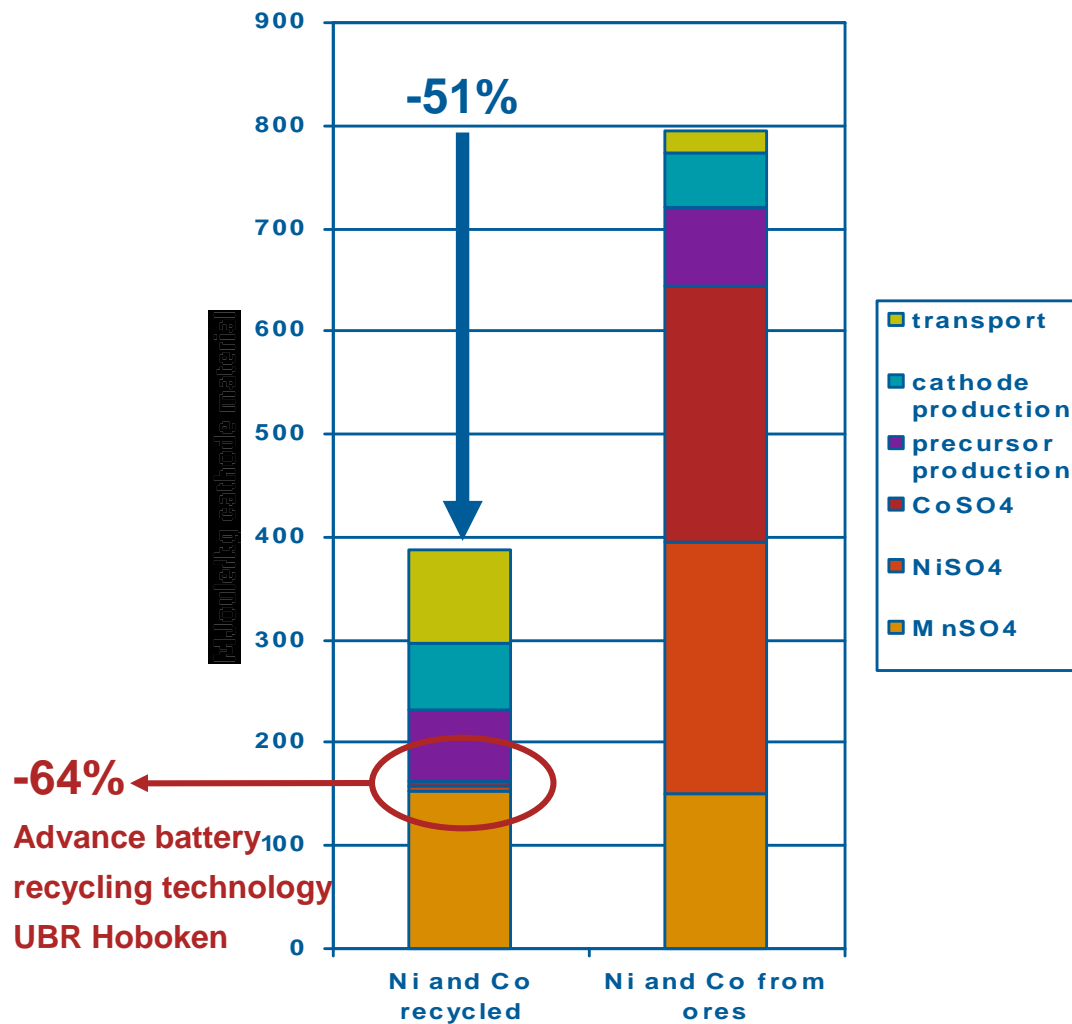
Ø Impact categories

- Natural resource consumption

System boundaries



Conclusions



-64% →
Advance battery recycling technology
UBR Hoboken

Saving of 51 % natural resources mainly due to:

- eliminating high demanding Ni/CoSO₄ from primary resources
- moderate demand of recycling in comparison with high demand of cathode production stages
- Mn is not considered as recycled (in slag, used as concrete additive)

Conclusions

- Ø Recycling is the most environmental friendly way of production of new battery materials and batteries.
- Ø To preserve using the natural resources and extraction of ores the best solution is recycling
- Ø To avoid landfill and reduce the impact of waste batteries, collection rates and recycling activities should be increased.

THANK YOU!

www.batteryrecycling.Umicore.com

Enclosures

- Additional reading
- Partners
- Glossary

To learn more...

Ø SAFT study on Li-ion battery

- award winning poster:
<http://www.batteryrecycling.umicore.com/download/PosterUmicoreandSaftclosingtheloop.pdf>
- detailed presentation available on request

Ø Öko Institute study on NiMH battery (Prius)

- report executive summary available on request

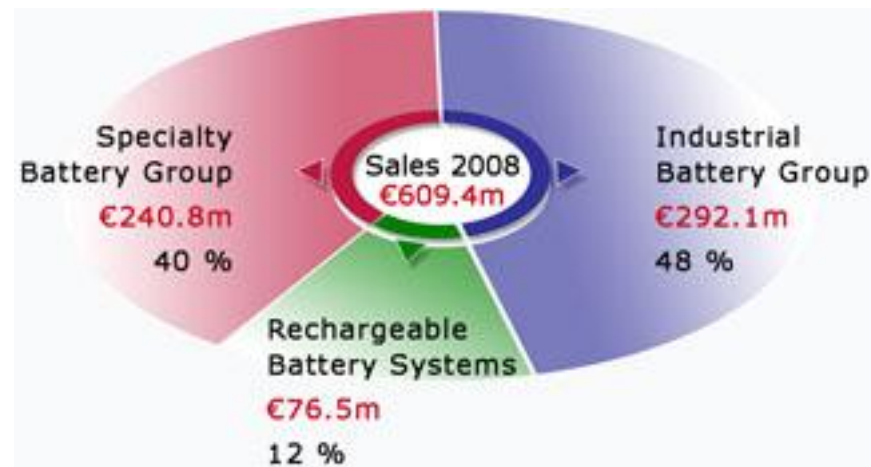
Ø Ghent University study on mixed oxide cathode material

- presentation Prof. Dewulf is available on <http://www.lcm2009.org/>
- detailed publication: Dewulf J, et al. "Recycling rechargeable lithium ion batteries: Critical analysis of natural resource savings"
- Resour Conserv Recy (2009), doi:10.1016/j.resconrec.2009.08.004
- Exergy concept: <http://www.aseanenvironment.info/Abstract/41017033.pdf>

LCA partners: SAFT

Ø SAFT (<http://www.saftbatteries.com>)

- Saft is the world's leading designer, developer and manufacturer of advanced technology batteries for industrial and defense applications.



Prius NiMH battery LCA partners:

Ø Öko institute (<http://www.oeko.de>)

- The Öko-Institut is a leading European research and consultancy institution working for a sustainable future. It employs more than 120 staff, including 80 researchers, at three locations: Freiburg, Darmstadt and Berlin.

Ø Toyota Motor Europe (<http://www.toyota.eu>)

- Toyota Motor Europe NV/SA (TME) oversees the wholesale sales and marketing of Toyota and Lexus vehicles, parts and accessories, and Toyota's European manufacturing and engineering operations. The TME Head Office is located in Brussels

Ø The Nickel Institute (<http://www.nickelinstitute.org>)

- The Nickel Institute is a nonprofit organization that represents the interests of 24 companies which together produce more than 90% of the world's annual nickel output. The Institute was established on January 1, 2004, through the merger of the Nickel Development Institute (NiDI) and the Nickel Producers Environmental Research Association (NiPERA).
- We promote on behalf of our members the production, use and re-use (through recycling) of nickel in a socially and environmental responsible manner.

LCA partners: Gent University

Ø Research Group ENVOC, Ghent University (<http://www.envoc.ugent.be/>)

- Exergy as a tool in the sustainability assessment of technology - Prof. dr. ir. Jo Dewulf
- Technology assessment in terms of sustainability is not an easy subject. If one looks for the environmental sustainability assessment, it is obvious that one should not limit the assessment to emissions abatement, but resource intake (renewables, non-renewables, ...) and the processes themselves (efficiency) should be taken into account. Assessing how clean technology is, benefits from a generic approach. Our assessment tools start from thermodynamics: exergy analysis. This scientifically sound and generic approach offers unique potential in environmental sustainability assessment of technology.

Critical reviewer: EMPA, Switzerland

- EMPA (<http://www.empa.ch>) is an interdisciplinary research and services institution for material sciences and technology development within the domain of the Swiss Federal Engineering Universities.
- EMPA's research and development activities are oriented to meeting the requirements of industry and the needs of our society, and link together applications-oriented research and the practical implementation of new ideas, science and industry, and science and society.

Glossary

- Acidification: examples are: Sulphur dioxide (SO₂), Nitrogen oxides (NO_x), Ammonia (NH₃). Acid depositions have negative impacts on natural ecosystems and the man-made environment incl. buildings. The main sources for emissions of acidifying substances are agriculture and fossil fuel combustion used for electricity production, heating and transport.
- Depletion of abiotic resources: Consumption of non-renewable resources, such as zinc ore and crude oil, thereby lowering their availability for future generations.
- Eutrophication: is the enrichment of nutrients in a certain place. Eutrophication can be aquatic or terrestrial. Air pollutants, waste water and fertilization in agriculture all contribute to eutrophication. The eutrophication potential is calculated in phosphate equivalents (PO₄ -eq).
- Exergy: represents the upper limit of the potential of a mass or energy flow to do work given the environmental conditions.
- Non-renewable resource: Minerals, ores and fossil fuels. Their use as material and energy sources leads to depletion of the Earth's reserves as they do not be renewed in human relevant periods of time.

Glossary

- Ozone depletion potential: The integrated change in total stratospheric ozone per unit mass emission of a specific compound, relative to the integrated change in the total ozone per unit mass of a reference emission (e.g. CFC-11).
- Photochemical ozone creation potential: Chemical reactions brought about by the light energy of the sun. The reaction of nitrogen oxides with hydrocarbons in the presence of sunlight to form ozone is an example of a photochemical reaction.
- In Life Cycle assessments, photochemical ozone creation potential (POCP) is referred to in ethylene-equivalents (C₂H₄-eg.)