European Commission (DG ENV)

# COMPARATIVE LIFE-CYCLE ASSESSMENT OF NICKEL-CADMIUM (NiCd) BATTERIES USED IN CORDLESS POWER TOOLS (CPTs) VS. THEIR ALTERNATIVES NICKEL-METAL HYDRIDE (NiMH) AND LITHIUM-ION (Li-Ion) BATTERIES

## PRELIMINARY FINDINGS

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# Content

# Objectives

- Objectives
  - To conduct a comparative Life Cycle Assessment (LCA) of portable NiCd, NiMH and Li-ion batteries used in CPTs
  - To identify the life cycles steps that generate the most environmental impacts for each battery individually
  - To compare the environmental impacts of the three battery technologies

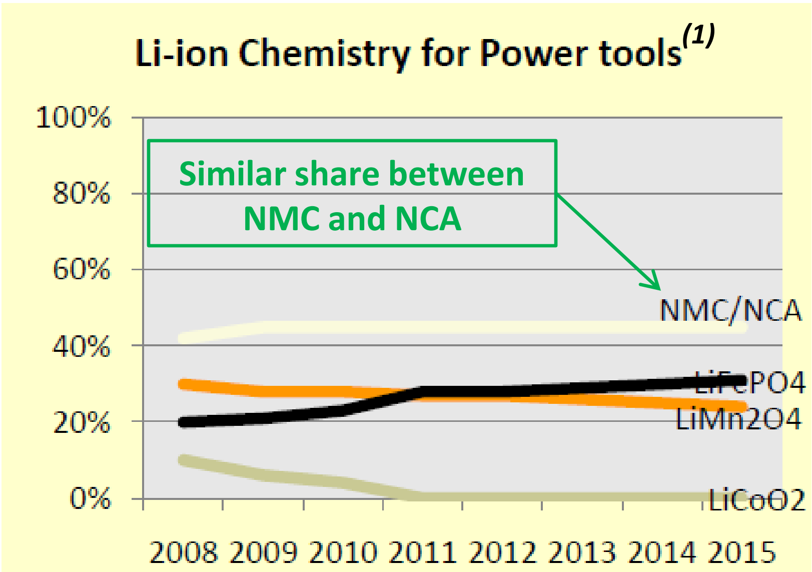
# Content

# Methodology

## Products selection

- Batteries used in CPTs
  - Focus on one particular application: Power Drill
    - can use the three battery types
  - Focus on the professional market segment
    - Use-phase well defined
    - Significant market share for the drill application

  - Regarding Li-Ion battery, focus on one particular technology: Lithium Iron Phosphate (LiFePO4)
    - main Li-ion technology in terms of current market shares




*(1) Source: Portable Rechargeable Battery Market in Europe 2008-2015 – Avicenne for Recharge, 2010*

# Methodology

## Environmental impact indicators

- Methodology: **Life Cycle Assessment**

- Selected environmental impact indicators: correspond to the major environmental stakes related to the life-cycle of batteries

| LCIA method | Potential environmental impact indicator | Unit |
|---|---|---|
| **ReCiPe** | **Global Warming Potential (GWP)** | kg $CO_2$ eq |
| | **Photochemical oxidant formation Potential (POFP)** | kg NMVOC eq |
| | **Terrestrial Acidification Potential (TAP)** | kg $SO_2$ eq |
| **CML** | **Abiotic resource depletion potential (ADP)** | kg Sb eq (1) |
| **USEtox** | **Human Toxicity Potential (HTP)(2)** | CTU (4) |
| | **Freshwater Aquatic Ecotoxicity Potential (FAEP)(3)** | CTU (4) |

- In addition, one flow indicator:

| Source | Flow indicator | Unit |
|---|---|---|
| **Ecoinvent data** | **Cumulative Energy Demand (CED)** | MJ |

[1] Sb is the chemical symbol of Antimony.
[2] Estimated increase in morbidity in the total human population (cases), taking into account cancer and non-cancer cases.
[3] Estimate of the potentially affected fraction of species (PAF) integrated over time and volume (PAF $m^3$ day).
[4] CTU: Comparative Toxic Unit

# Content

# Data and assumptions

## Functional Unit

- The Functional Unit (FU) of the environmental assessment is the reference unit that allows **quantifying the service given by the system under study**. Then, the environmental impacts quantified over the product life cycle of the system are scaled to the Functional Unit: each flow involved during the life cycle (e.g. material and energy flows) is transposed to this reference.

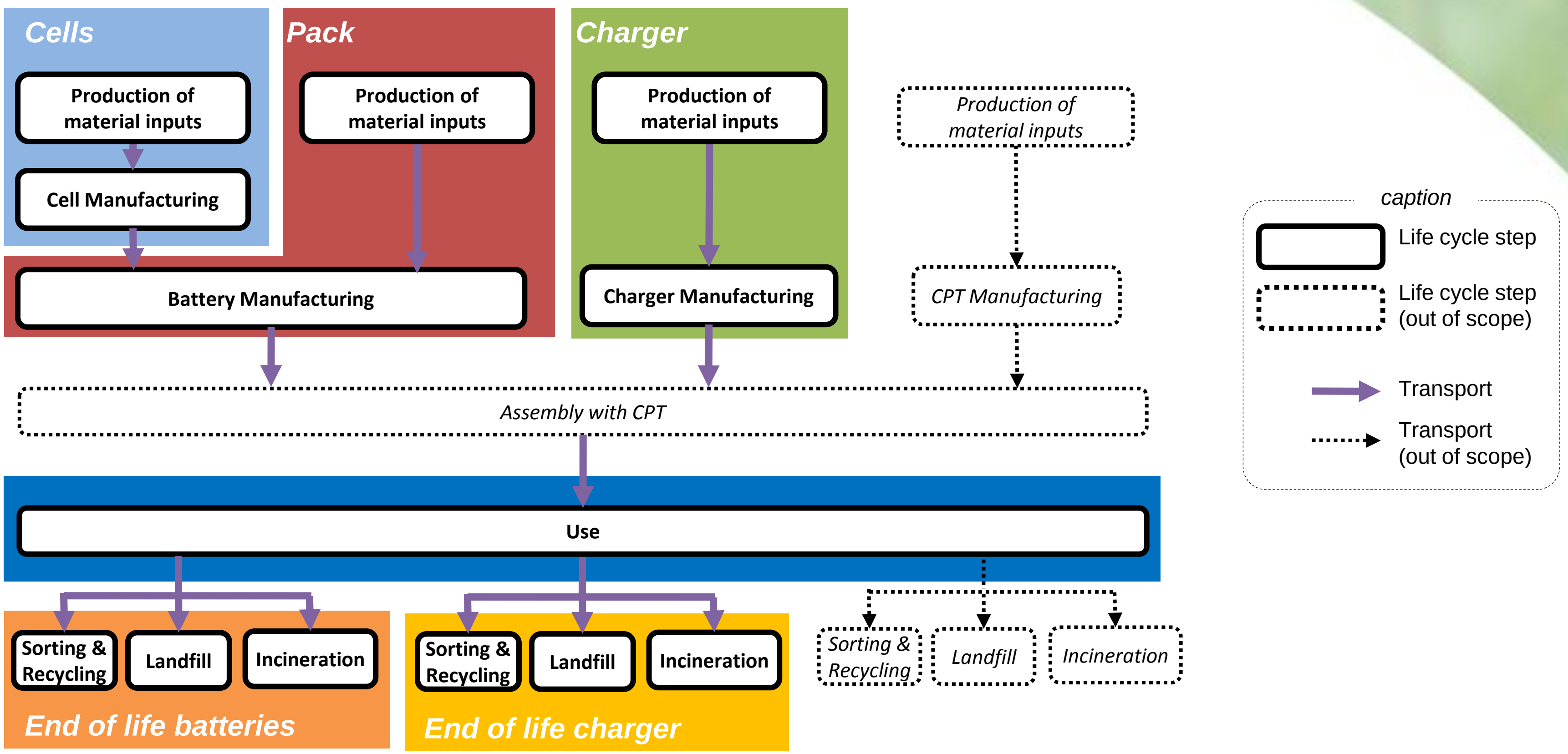
- For this LCA, the following Functional Unit was used:

**“1 kWh of energy delivered by the battery to the CPT”**

# Data and assumptions

## System Boundaries

- Similar characteristics of the CPT for the three battery technologies → **out of scope**



# Data and assumptions

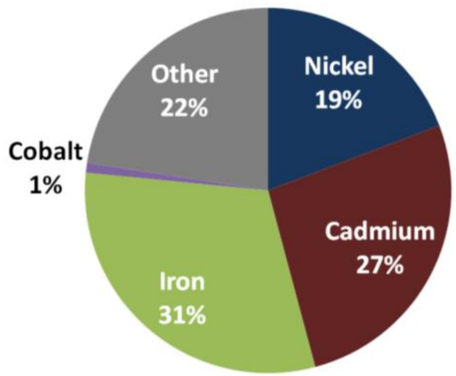
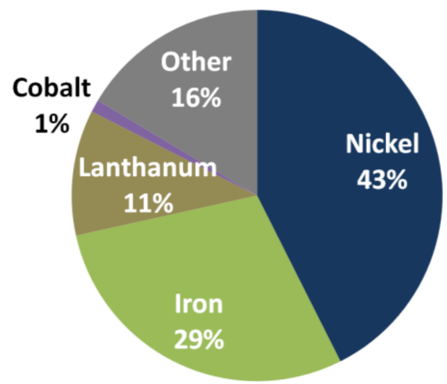
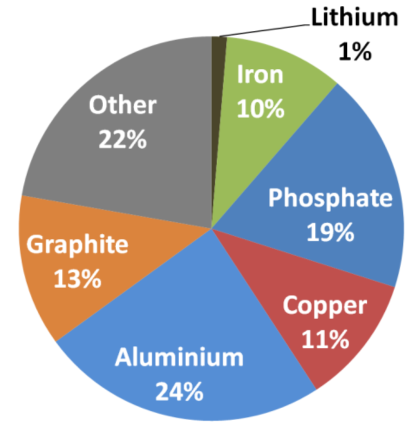
## Data collection

- Primary data from:
  - manufacturers of CPTs and batteries;
  - industry associations.
- Secondary data ("generic data") from Ecoinvent v2.2 database
  - Except for the production of $LaNi_5$ (68% Ni / 32% La): taken from GaBi database.
- Some Inventories recalculated based on literature:
  - Production of the $LiFePO_4$ compound: based on data from Majeau-Bettez et al.[1]
  - Inventories for recycling processes: based on data from ERM[2].
  - Production of nickel hydroxide – $Ni(OH)_2$
  - Production of cobalt hydroxide – $Co(OH)_2$
  - Production of cadmium hydroxide – $Cd(OH)_2$

*(1) Majeau-Bettez et al. (2011) Life Cycle Environmental Assessment of Lithium-Ion and Nickel Metal Hydride Batteries for Plug-In Hybrid and Battery Electric Vehicles, Environmental Science & Technology*
*(2) Fisher et al. (2006) Battery Waste Management Life Cycle Assessment, ERM – Study for DEFRA*

# Data and assumptions

## Characteristics of the cells

| | | NiCd | NiMH | $LiFePO_4$ |
|---|---|---|---|---|
| CELL | **Capacity (mAh)** | 2400 mAh | 3200 mAh | 2000 mAh |
| | **Voltage (V)** | 1.2 V | 1.2 V | 3.3 V |
| | **Depth of discharge** | 100% | 100% | 100% |
| | **Mass (g/cell)** | 51.6 g | 58 g | 38.3 g |
| | **Mass composition** |  |  |  |

PRELIMINARY FINDINGS

# Data and assumptions

## Characteristics of the battery packs

| | | NiCd | NiMH | $LiFePO_4$ |
|---|---|---|---|---|
| PACK | Capacity of the battery pack | 2400 mAh | 3200 mAh | 4000 mAh |
| | Voltage of the battery pack | 18 V | 18 V | 19.8 V |
| | Type (Parallel packs) | 1P | 1P | 2P |
| | Cells per battery pack | 15 in series | 15 in series | 12 (2 x 6 cells in parallel) |
| | Mass (excl. cells) | 194 g | 194 g | 210 g |
| | Total mass of pack (g) | 965 g | 1064 g | 670 g |
| | Number of packs sold with CPT | 2 | 2 | 2 |
| CHARGER | Type | NiCd/NiMH charger considered | | Specific $LiFePO_4$ charger considered |

PRELIMINARY FINDINGS

# Data and assumptions

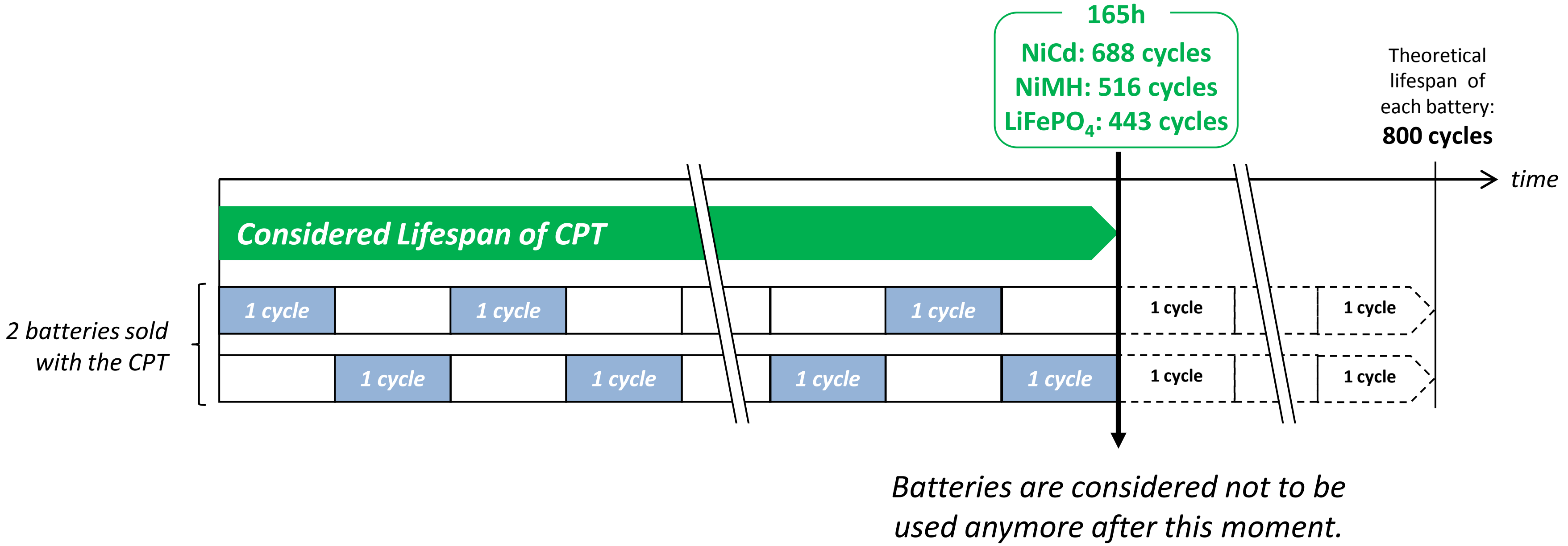
## Manufacturing

- Only energy consumption is taken into account for the modelling of the manufacturing of the cells, pack and charger.
- No production waste or direct emissions to air/water/soil →limitation of the study

# Data and assumptions

## Use phase – Lifespan considered

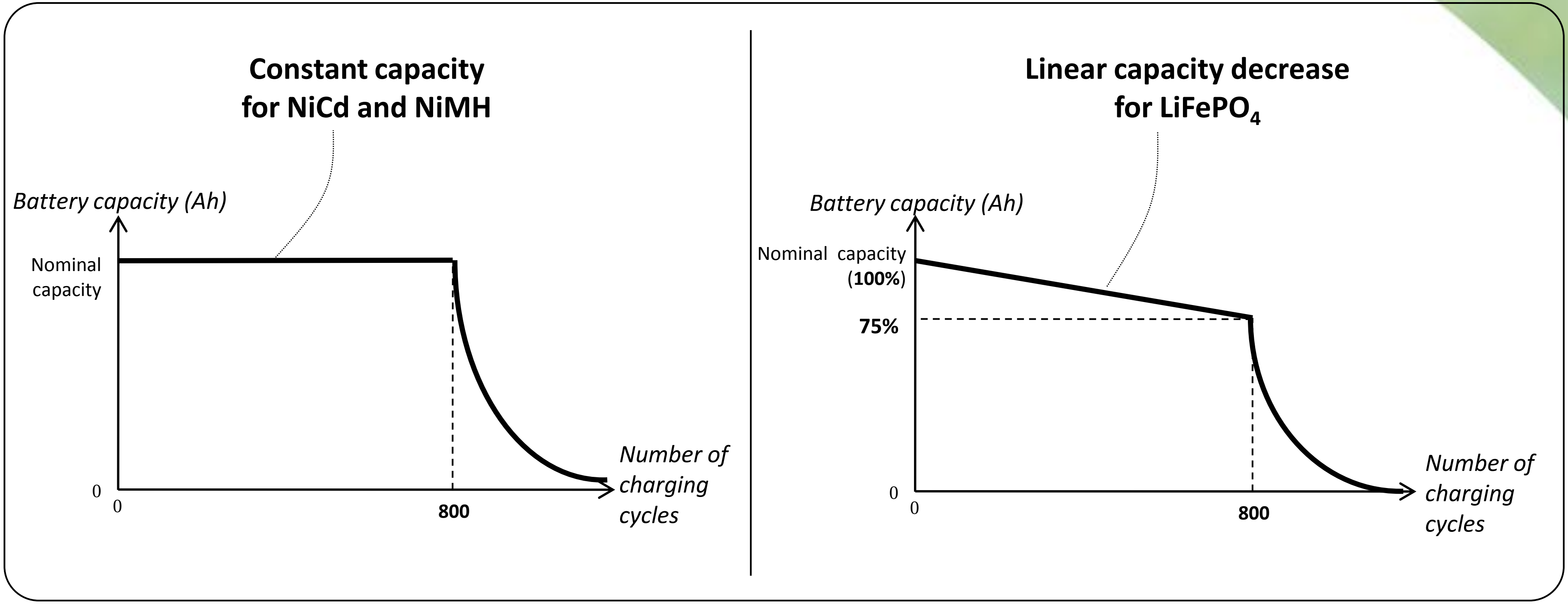
- Theoretical batteries lifespan: 800 cycles
  - (After 800 cycles: rapid decrease of their capacity)
- CPT: used during 165 hours
- Average intensity considered: 20 A
- CPT and the 2 batteries cease to be used at the same time, i.e. after 165 h.



# Data and assumptions

## Use Phase – Capacity decrease

- Batteries capacity can evolve through time.
  - Considered model for this study:



PRELIMINARY FINDINGS

# Data and assumptions

## Use phase – Charging parameters

- Average charging parameters for the three technologies (simplified model based on measurements):

| Phase | Current drawn (A) | Duration of phase (h) | Voltage (V) | Charging efficiency |
|---|---|---|---|---|
| **NiCd** | | | | |
| **Active charging phase 1** | 2.6 | 0.917 | 21.2 | 0.68 |
| **Active charging phase 2** | 1.3 | 0.33 | 21.6 | |
| **Maintenance charging** | 0.25 | 0.753 | 21.5 | |
| **NiMH** | | | | |
| **Active charging phase 1** | 3.47 | 0.917 | 21.2 | 0.68 |
| **Active charging phase 2** | 1.73 | 0.33 | 21.6 | |
| **Maintenance charging** | 0.33 | 0.753 | 21.5 | |
| **$LiFePO_4$** | | | | |
| **Active charging phase 1** | 6 | 0.666 | 21.6 | 0.83 |
| **Active charging phase 2** | 3 | 0.166 | 21.6 | |
| **Maintenance charging** | 0 | 1.166 | 0 | |

NiCd → *1.48 kWh/FU*

NiMH → *1.48 kWh/FU*

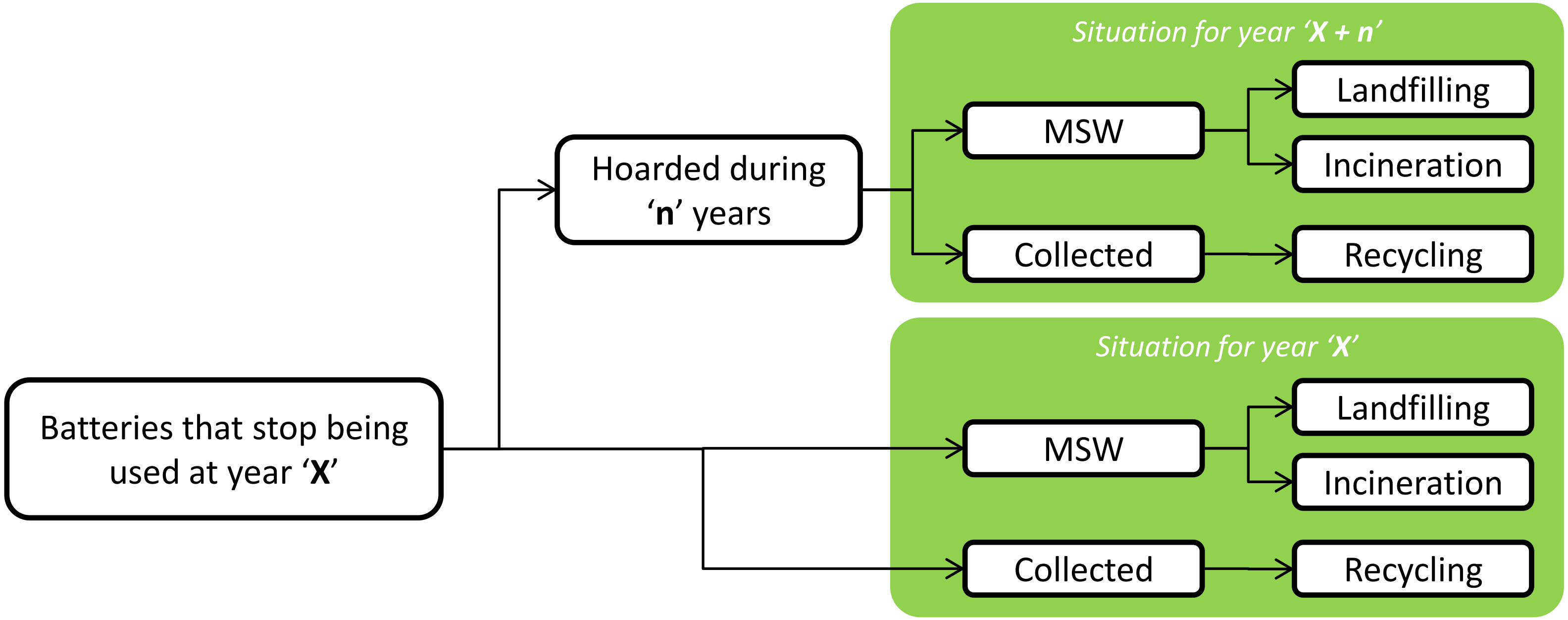
$LiFePO_4$ → *1.21 kWh/FU*

*Note: no maintenance charging for $LiFePO_4$*

# Data and assumptions

## End-of-life – hoarding effect

- Hoarding effect + evolving market → **no correlation between the collection waste stream and sales at a given year**.
- For a given product: the hoarding effect postpones the moment at which the product will be **collected for recycling** or **disposed as MSW**:



PRELIMINARY FINDINGS



- Collection rate should be based on the quantity of spent batteries that are ”available for collection”.
- *But*: lack of representative data at EU level in order to estimate the current collection rate.
- Thus, working assumption→ **25% collection rate** (target of the Battery directive for 2012)

- For the batteries treated as municipal solid waste (MSW):
  - Incineration: 24.5%
  - Landfilling: 75.5%

  } *Data for EU-27 for the 2001-2003 period*[(1)]

*(1) Arche (2010) Update risk assessment - Targeted Report Cadmium (oxide) as used in batteries– Study for Recharge*

# Data and assumptions

## Modeling of the recycling

- Inventory data for recycling: taken from the ERM study[1]
- Adaptation of the quantity of recovered metals in order to reflect the composition of the 3 packs.

*Efficiencies considered for the recovery of materials during recycling for each technology of battery*

| Efficiency of the recovery | NiCd | NiMH | $LiFePO_4$ | |
|---|---|---|---|---|
| Recovered metals | Pyrometallurgical process | Pyrometallurgical process | Pyrometallurgical process | Hydrometallurgical process |
| Cadmium | 90% of the cadmium content of the pack | | | |
| Nickel-iron | 95% of the nickel-iron content of the pack | | | |
| Nickel-cobalt-iron | | 100% of the Nickel-cobalt-iron content of the pack | | |
| Aluminium | | | 100% of the aluminium content of the pack | 100% of the aluminium content of the pack |
| Copper | | | 100% of the copper content of the pack | 100% of the copper content of the pack |
| Source | ERM study (1) | ERM study (1) | Recharge | Recharge |
| Percentage of recovered materials | 57% of the pack = 77% of the cells | 59% of the pack = 73% of the cells | 24% of the pack = 35% of the cells | |

*(1) Fisher et al. (2006) Battery Waste Management Life Cycle Assessment, ERM – Study for DEFRA*

# Data and assumptions

## Incineration and Landfilling

- Inventories for incineration and landfilling: calculated with dedicated EcoInvent tool.

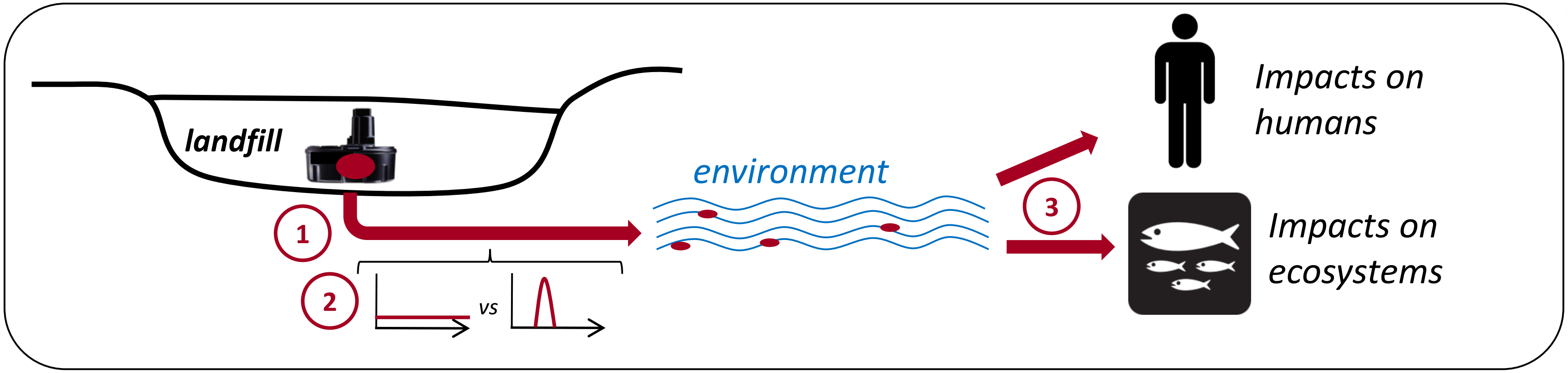
- **Incineration:**
  - Main sources of impacts: emissions of substances to air and emissions to water (landfilling of incineration residues)
  - Energy recovery taken into account

- **Landfilling:**
  - Main source of impacts: emissions of substances to water through leachage.
  - From a **short-term (ST) perspective**, e.g. less than 100 years for a landfill →battery mostly behaves like inert waste.
  - From **a long-term (LT) perspective** → a fraction of metals contained in the battery will eventually end-up in the environment.

# Data and assumptions

## Limits to the landfilling modelisation

- The environmental impact assessment of long-term emissions of metals from landfills carries several limits:
  - **For a given battery: ratio of metals that will eventually be released in the environment.** (1)
  - **LCA poorly equipped to handle the dilution in time of emissions (peak vs. diffuse emissions)** (2)
  - **Effect of heavy metals on toxicity and ecotoxicity not well known** (3)




- 3 situations considered for Human toxicity and Freshwater ecotoxicity:
  - **a short-term perspective** (only short-term emissions);
  - **a long-term perspective** (both short-term and long-term emissions) ;
  - **an intermediate situation** (short-term emissions + 5% of the long-term emissions)

# Data and assumptions

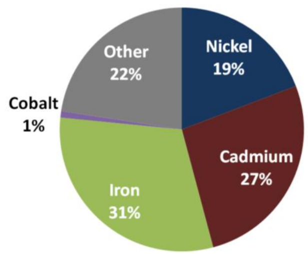
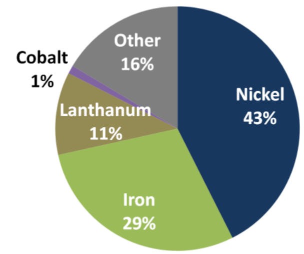
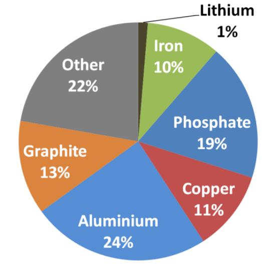
## Representativeness of the study

- ***Temporal representativeness***
  - Primary data collected directly from selected stakeholders **between February and June 2011.**
  - Secondary data taken from the Ecoinvent v2.2 database, published in **2010**.
- ***Geographical representativeness***
  - Production reflects the supply chain of CPTs manufactured for the **European market.**
  - Use phase: **European context** (European electricity mix is considered).
- ***Technological representativeness***
  - Composition of the cells: representative of the ones used in **CPTs**.
  - Secondary data: mainly representative of **European technologies**.

PRELIMINARY FINDINGS

# Data and assumptions

## Summary of the main data and assumptions

| | NiCd | NiMH | $LiFePO_4$ |
|---|---|---|---|
| Cells |  15 x 51.6 g |  15 x 58 g |  12 x 38.3 g |
| | 1.2 V - 2400 mAh | 1.2 V - 3200 mAh | 3.3 V - 2000 mAh |
| Pack | Same pack for NiCd and NiMH | | Contains electronic components |
| | 18 V - 2400 mAh | 18 V - 2400 mAh | 19.8 V - 4000 mAh |
| Charger | Same charger for NiCd and NiMH | | More electronic components than in the NiCd/NiMH charger |
| Use phase | 1.48 kWh/FU | | 1.21 kWh/FU<br>No maintenance charging |
| | Batteries stop being used after 165 h | | |
| | Theroretical lifespan: 800 cycles | | |
| | No capacity decrease considered | | Capacity decrease from 100% to 75% of the nominal capacity throughout the 800 cycles |
| Collection rate | 25% | | |
| Recycling | Recovery of cadmium, nickel and iron (57% of the pack = 77% of the cells) | Recovery of nickel, cobalt and iron (59% of the pack = 73% of the cells) | Recovery of copper and aluminium (24% of the pack = 35% of the cells) |
| Landfilling | Potential emissions of cadmium and nickel to water | Potential emissions of nickel to water | Potential emissions of copper to water |

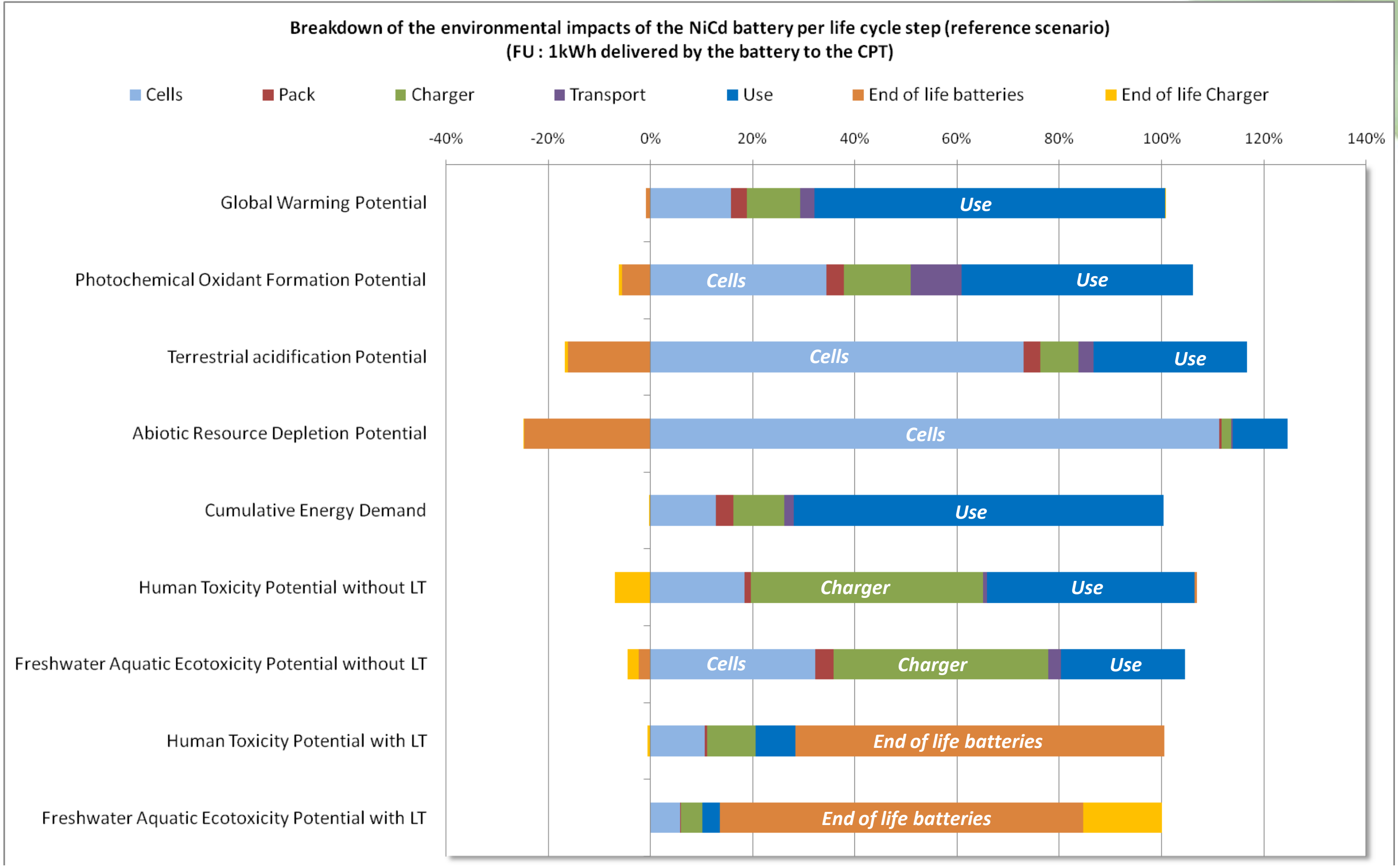
# Content

PRELIMINARY FINDINGS

# Preliminary results for NiCd technology

## Breakdown per life-cycle step

**The breakdown per life-cycle step varies highly from one indicator to another.**
**High contribution of the cells for abiotic resource depletion potential.**

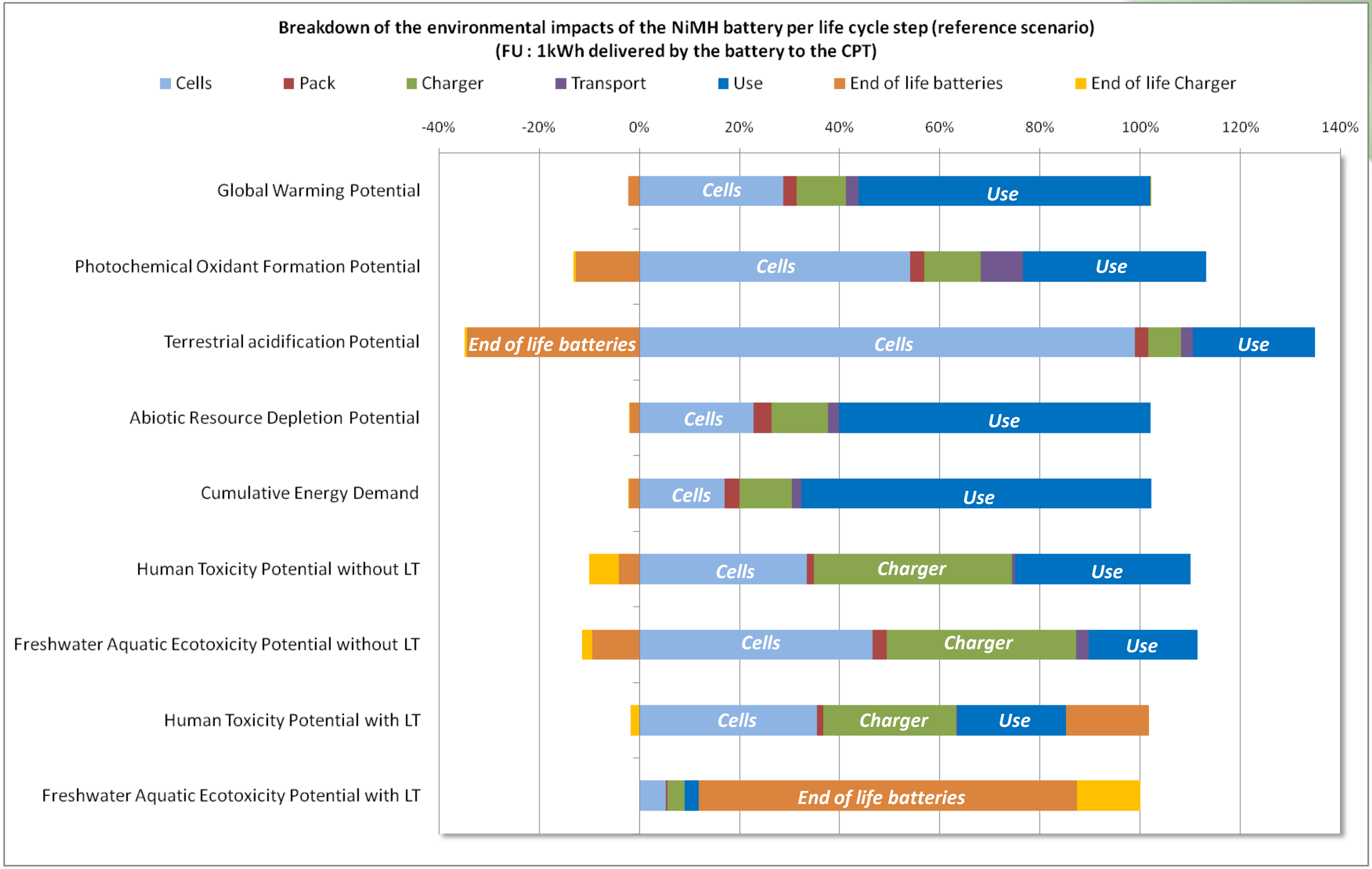


PRELIMINARY FINDINGS

# Preliminary results for NiMH technology

## Breakdown per life-cycle step

**The breakdown per life-cycle step varies highly from one indicator to another.**

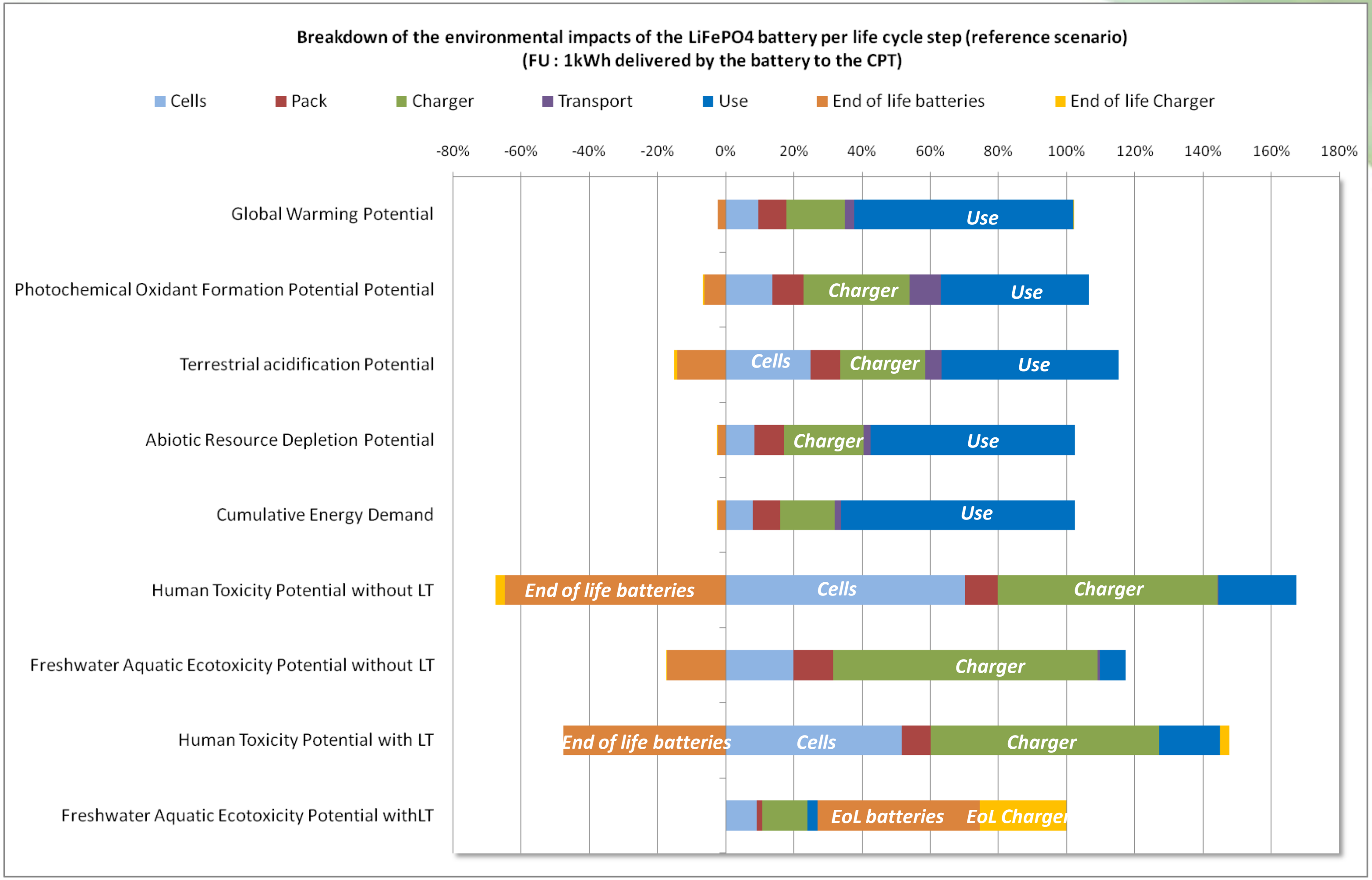


PRELIMINARY FINDINGS

# Preliminary results for $LiFePO_4$ technology

## Breakdown per life-cycle step

**For indicators other than human toxicity and ecotoxicity, the use phase is the main contributor**



# Content

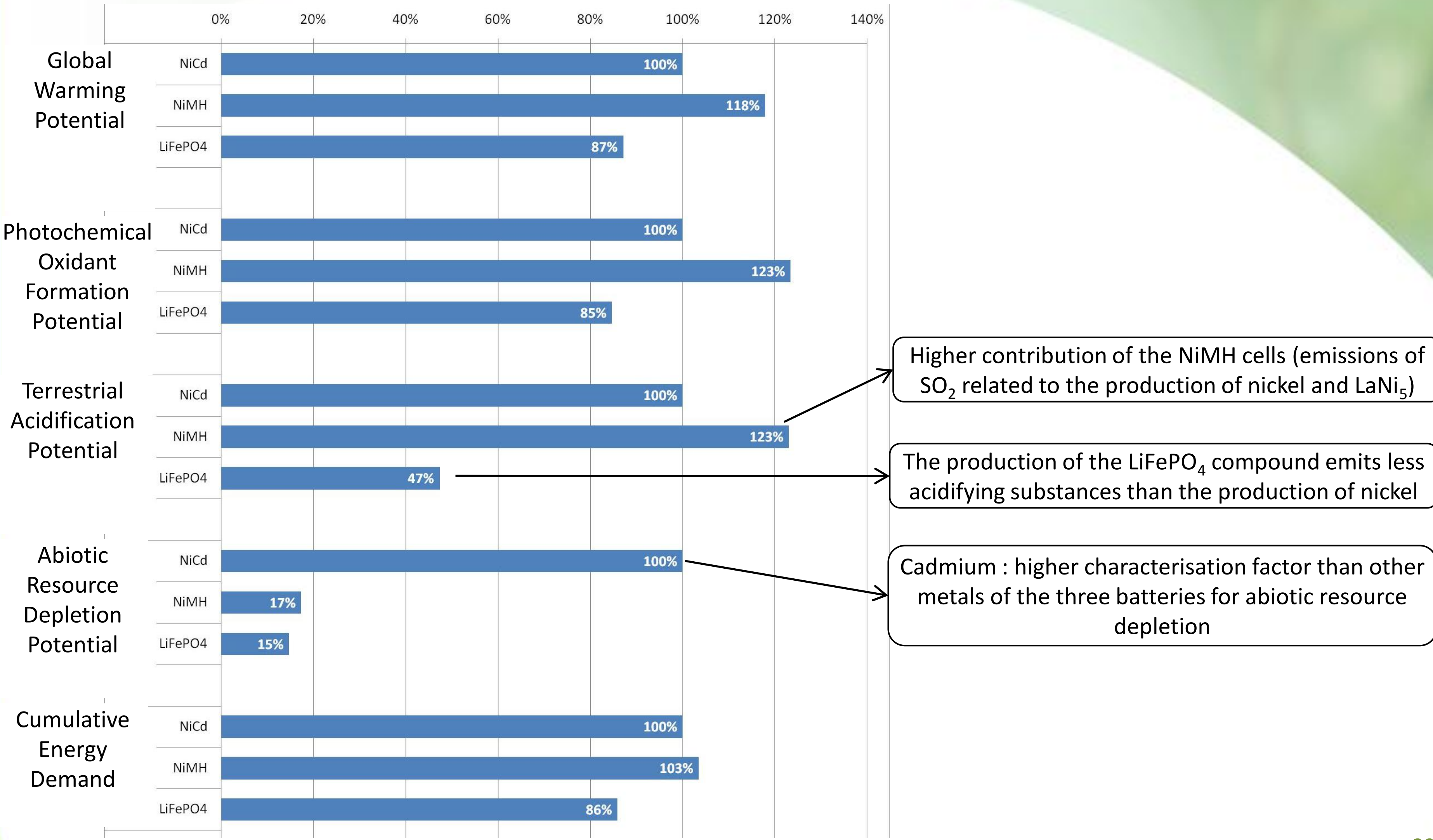
PRELIMINARY FINDINGS

# Comparative analysis of the LCA results

## Results (without toxicity indicators)

**No significant difference between batteries except for:**
**Abiotic resource depletion potential, for which NiCd shows higher impacts;**
**Terrestrial Acidification potential, for which LiFePO4 shows lower impacts.**

**reference (100%) : NiCd**
**FU: 1kWh delivered by the battery to the CPT**



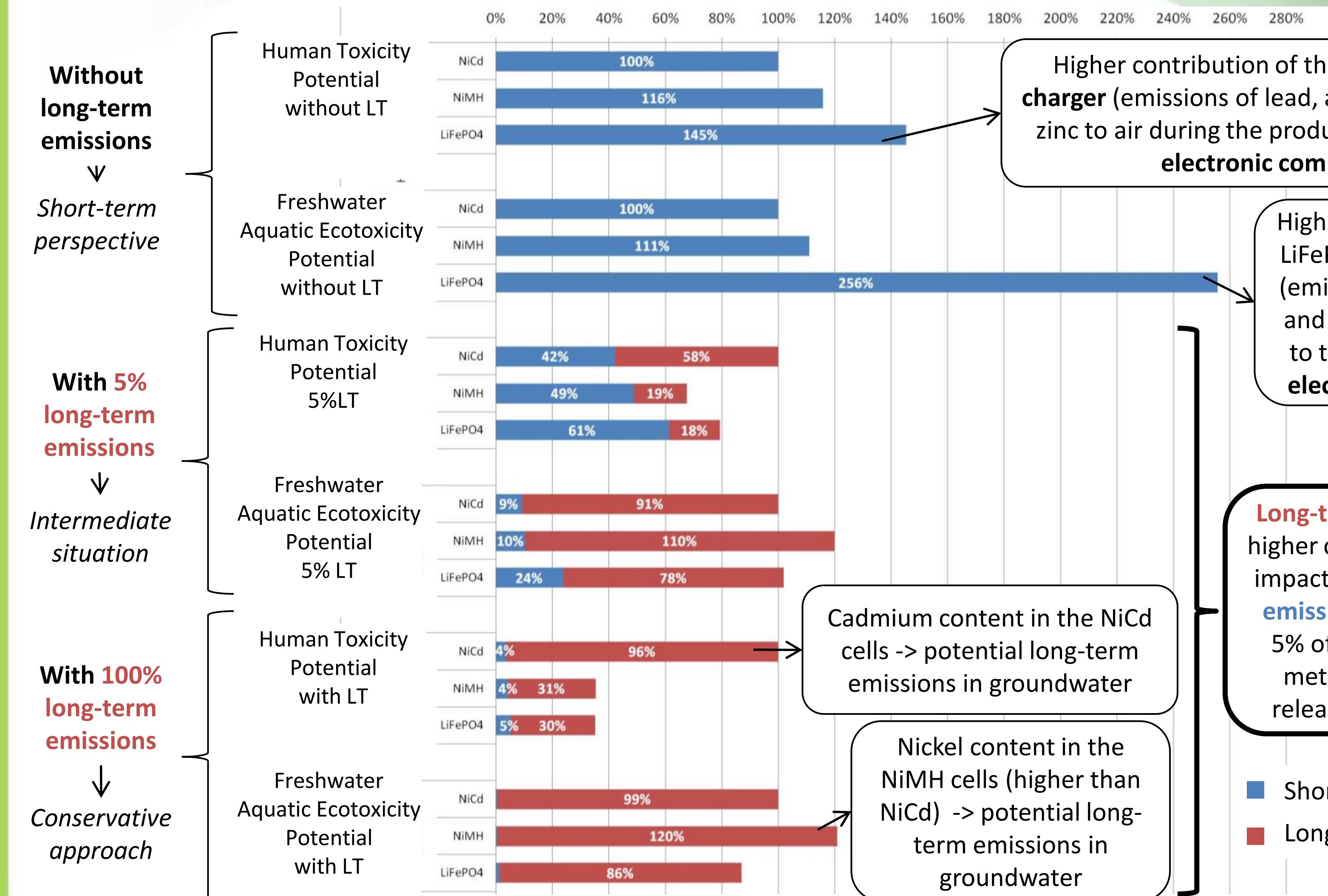
PRELIMINARY FINDINGS

# Comparative analysis of the LCA results

## Results (toxicity indicators)

**For toxicity indicators, the inclusion or exclusion of long-term emissions changes the ranking between batteries.**

**reference (100%): NiCd**
**FU: 1kWh delivered by the battery to the CPT**




Higher contribution of the $LiFePO_4$ **cells** and **charger** (emissions of lead, arsenic, cadmium and zinc to air during the production of **copper** and **electronic components**)

Higher contribution of the $LiFePO_4$ **pack** and **charger** (emission of zinc to water and copper to air related to the manufacturing of **electronic components)**

**Long-term emissions** have a higher contribution to toxicity impacts than the **short-term emissions**, even when only 5% of the total content in metallic substances are released in the long-term

Cadmium content in the NiCd cells -> potential long-term emissions in groundwater

Nickel content in the NiMH cells (higher than NiCd) -> potential long-term emissions in groundwater

PRELIMINARY FINDINGS

# Comparative analysis of the LCA results

## Sensitivity analysis on collection rate

- Sensitivity analysis on collection rate of batteries (prone to high uncertainty)
  - The alternative scenario is defined as follows:

| | Reference scenario | Scenario A |
|---|---|---|
| **Collection rate** | 25% | 45% |

PRELIMINARY FINDINGS

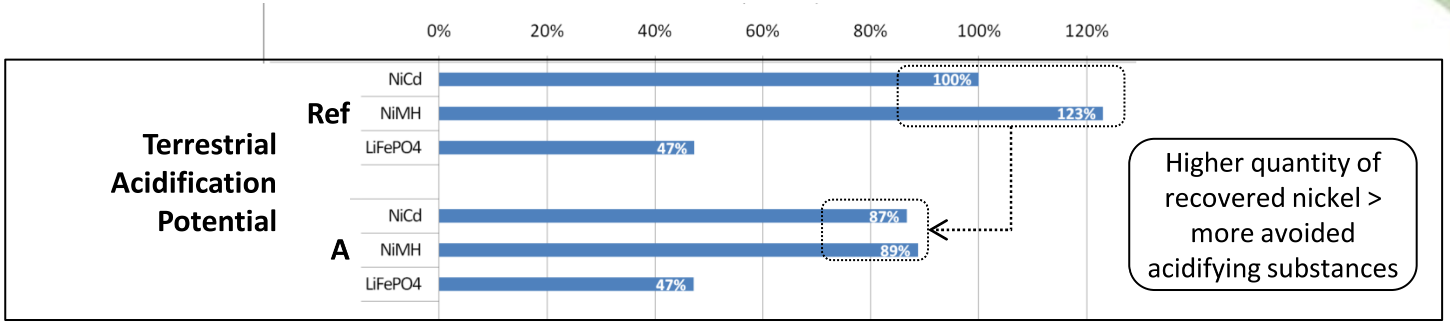
# Comparative analysis of the LCA results

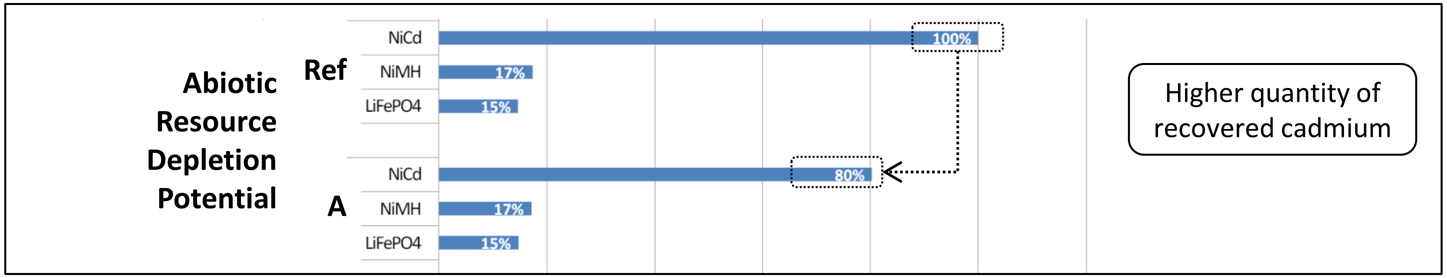
## Sensitivity analysis on collection rate (without toxicity indicators)

**A higher collection rate (45% compared to 25%) reduces terrestrial acidification for NiMH and NiCd and abiotic depletion for NiCd**

**reference (100%): NiCd (reference scenario)**
**FU: 1kWh delivered by the battery to the CPT**

*Low sensitivity on Global Warming Potential, Photochemical Oxidant Formation Potential and Cumulative Energy Demand*



PRELIMINARY FINDINGS

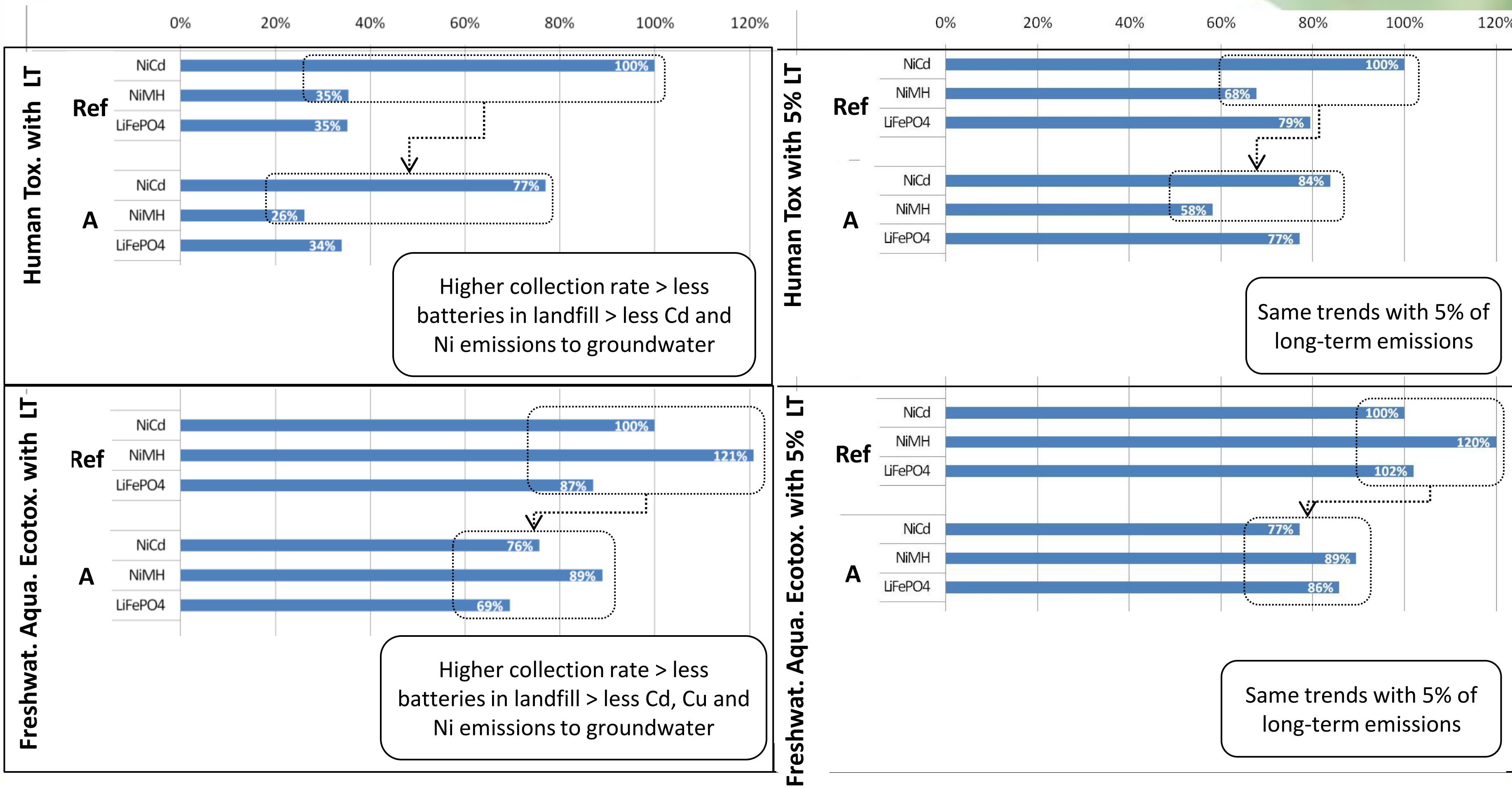
# Comparative analysis of the LCA results

## Sensitivity analysis on collection rate (toxicity indicators)

**A higher collection rate (45% compared to 25%) reduces Human Tox. long-term for NiMH and NiCd and Ecotox. long-term for all batteries**

**reference (100%): NiCd (reference scenario)**
**FU: 1kWh delivered by the battery to the CPT**

*Low sensitivity on Human Toxicity and Freshwater Aquatic Ecotoxicity Potentials without LT emissions*



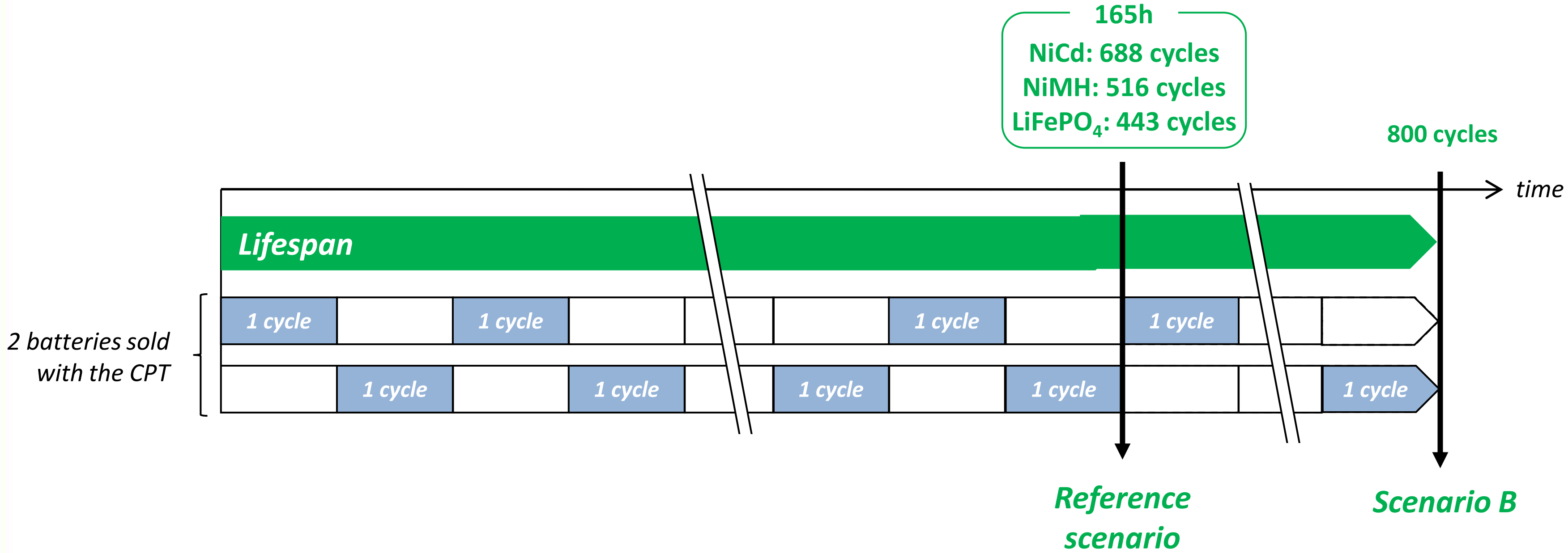
**PRELIMINARY FINDINGS**

# Comparative analysis of the LCA results

## Sensitivity analysis – Lifespan

- Sensitivity analysis on the lifespan of the batteries

| | Reference scenario | Scenario B |
|---|---|---|
| **Lifespan** | Batteries and charger stop being used after 165 hours of use | Batteries and charger stop being used after 800 cycles |



PRELIMINARY FINDINGS

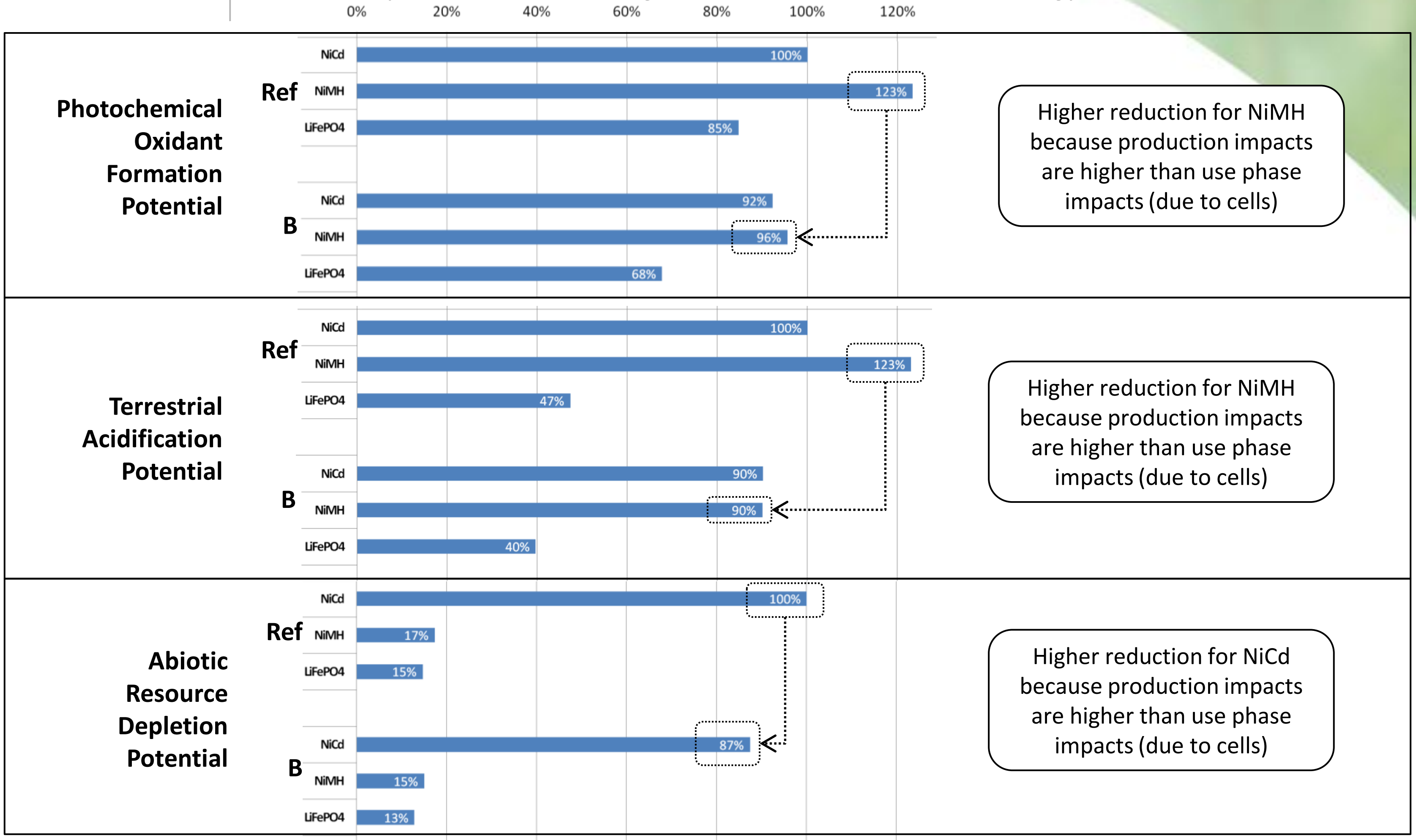
# Comparative analysis of the LCA results

## Sensitivity analysis – Lifespan (without toxicity indicators)

**Moderate sensitivity for all batteries to the extended lifespan for photochemical oxidant formation, terrestrial acidification and abiotic resource depletion**

**reference (100%): NiCd (reference scenario)**
**FU: 1kWh delivered by the battery to the CPT**

*Low sensitivity on Global Warming Potential and Cumulative Energy Demand*



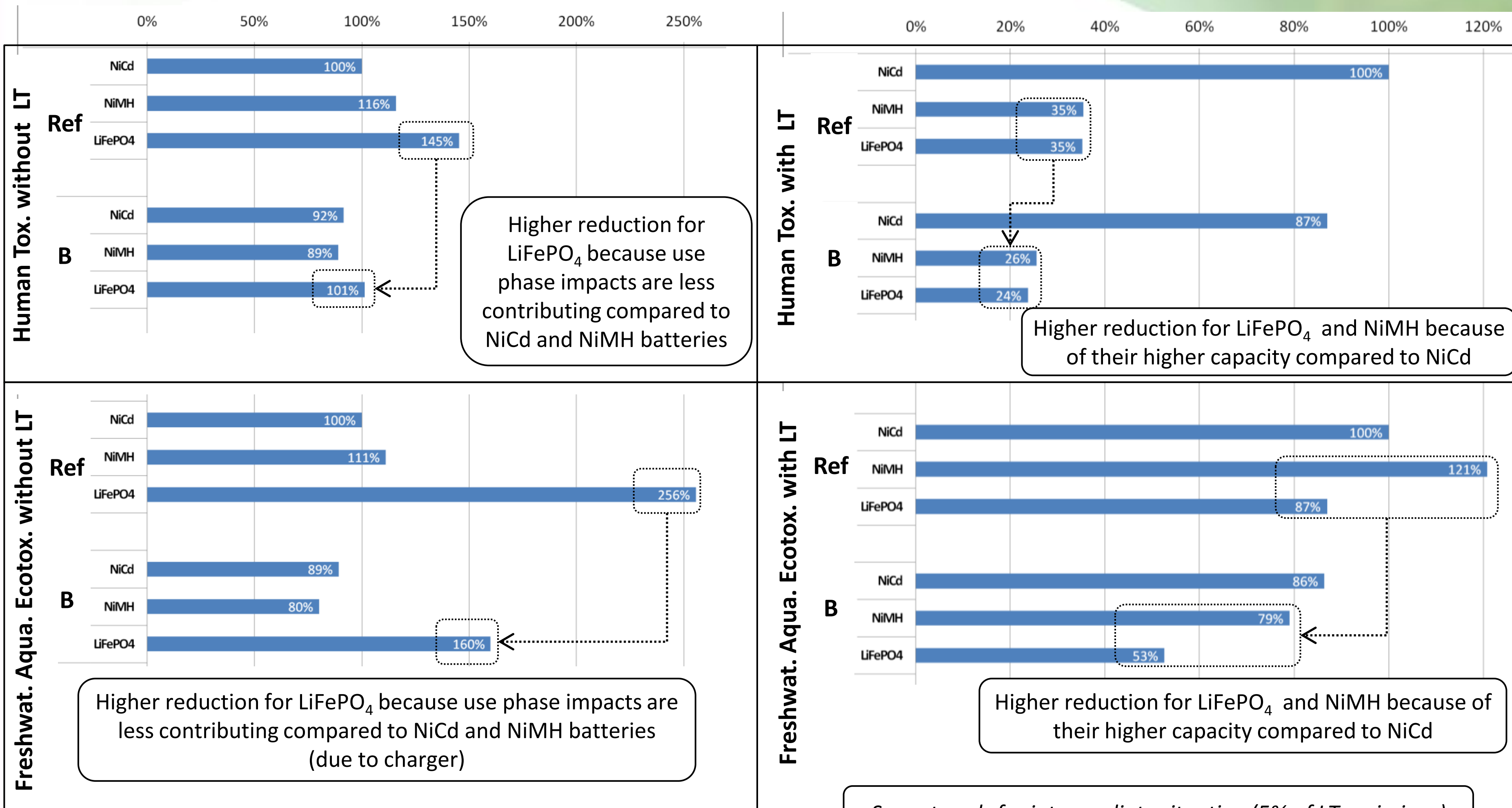
PRELIMINARY FINDINGS

# Comparative analysis of the LCA results

## Sensitivity analysis – Lifespan (toxicity indicators)

**For toxicity indicators, using the batteries until 800 cycles reduce the impacts for $LiFePO_4$ (ST and LT) and NiMH (LT)**

**reference (100%): NiCd (reference scenario)**
**FU: 1kWh delivered by the battery to the CPT**




*Same trends for intermediate situation (5% of LT emissions)*

# Content

# Preliminary findings

- No life-cycle step is predominant for all impacts indicators
- NiCd shows higher impacts for abiotic resource depletion
- Inconclusive on the fact that one battery shows environmental advantages regarding global warming potential, cumulative energy demand and photochemical oxidant formation potential
- **Batteries are ranked differently** in terms of potential impacts on human toxicity and freshwater ecotoxicity, **depending on the inclusion or exclusion of long-term emissions →** inconclusive on the superiority of one particular battery type.

**From a general point of view, inconclusive findings on the environmental superiority of one technology of battery towards the two others.**

**Thank you for your attention!**
**Any question?**