Finnish Institute of Occupational Health

Lithium-ion battery's life cycle: safety risks and risk management at workplaces

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IN COOPERATION WITH

Gaiker
MEMBER OF
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& TECHNOLOGY ALLIANCE

Työsuojelurahasto
Arbetarskyddsfonden
The Finnish Work Environment Fund

OSALAN
Laneko Segurtasun eta Osasunerako Euskal Erakundea
Instituto Vasco de Seguridad y Salud Laborales

About the project

The objective of the study is

- To determine the Li-ion battery's value chain
- To specify the risks and potential impact for health, safety and environment
- Produce guidance and good practices for improving occupational safety

Funding

Finnish Work Environment Fund, FIOH

OSALAN, GAIKER

Budget

350 000€

Co-operation

Finnish Institute of Occupational Health

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Workplaces from Finland and Spain

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Structure of the project

WP1 EHS management, Framing the issue

- Identification of the operators in the overall life cycle of Li-Ion batteries
- Description of the occupational safety risk management
- Identification of key materials in the production of Li-Ion batteries
- Overall picture of the Li-Ion batteries

WP2 Life cycle assessment

- Determination of the material flows over the life cycle
- Life Cycle Assessment of Li-Ion batteries

WP3 Critical occupational risk factors

- Hazard assessment of materials
- Assessment of workers exposure to chemicals
- Safety risk assessment

WP4 Performance in value chain

- Development of a guidance and best practices for occupational safety along the life cycle of Li-Ion batteries
- Publications and events

Identification of the value chain in Finland and Spain

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Production and Integration

Mining and Extraction of Raw Materials	Battery Chemical Production	pCAM and CAM Production	Cell/ Battery Production	Battery Integration and End Users	Recycling and End of Life
Example of the value chain in Finland					
Boliden Kevitsa Terrafame Ltd Keliber Oy Fin Cobalt Oy Minerals AB Latitude 66 Cobalt Posio Mawson Gold Ltd. Beowulf Mining	Boliden Harjavalta Nornickel Harjavalta Terrafame Ltd. Boliden Kokkola Umicore Finland Oy Keliber Oy	Umicore Finland Oy BASF Battey Materials Finland Oy Finnish Minerals Group	Valmet Automotive Oy Celltech Solutions Oy Geyser Batteries Oy	Linkker Oy Sandvic Mining & Construction Oy Avant Techno Oy Cargotec Finland Oy Wartsila Ovj Merus Power Ovj Fortum Ovj Nokia Ovj Mitsubishi Logisnext Europe Inex Partners	Fortum Ovj Akkuser Oy
Example of the value chain in Spain					
CLC Alcoa, etc. Tecnología Extremeña de Litio Recursos Minerales de Galicia Lithium Iberia Phi4Tech	Phi4tech		Cegasa Millor Batteries Amopack Alterity Hoppecke Batteries Master Battery Endurance Motive Saft Enix Power Solutions Phi4tech Ford LG IDEC Group	PSA Group	Endesa

■ Actual and Approved Projects
■ Proposed/thought Projects

Identification and selection of key materials

Cathode	Advantages	Disadvantages
NMC-811	Higher specific capacity (25 % higher than NMC-111) Higher electronic conductivity and ionic diffusivity Lower cost	It still has Co Surface reactivity
Graphene for LIBs, SIBs and LIs	High electrical and thermal conductivities Unique electronic structure Large surface area	Needs more investigation to increase potential industrial applications
CNT	Increased electronic conductivity, charge/discharge rate, and higher structural flexibility High chemical resistant and low flammability	The growing use has raised concerns about their potential impact on human health and the environment

Anode	Advantages	Disadvantages
LTO	Improved safety "zero strain"	Significantly lower energy density due to its halved specific capacity comparing with graphite, and the reduced voltage windows of the cell Low intrinsic electronic conductivity and low Li+ diffusion coefficient and therefore performs poorly at high rates
Graphene for LIBs, SIBs and Lis	High electrical and thermal conductivities Unique electronic structure Large surface area	Needs more investigation to increase potential industrial applications
Graphite	Avoid the short-circuiting due to the dendrites that Lithium metal can form and that can start a thermal run-away reaction	Poor rate capability Lithium dendrite problems upon overchanging

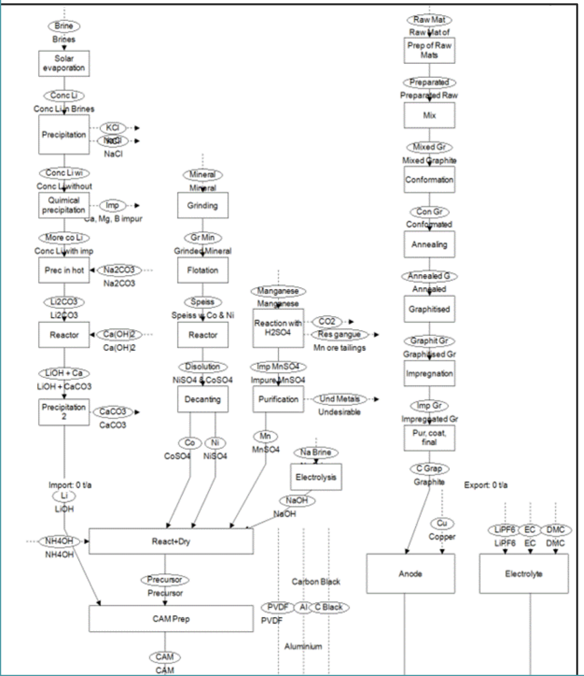
Electrolyte salts
Lithium hexafluorophosphate ($LiPF_6$)
Solvents
Dimethyl carbonate (DMC)
Ethyl methyl carbonate (EMC)
Diethyl carbonate (DEC)
Ethylene carbonate (EC)
Additives
Fluoroethylene carbonate (FEC)
Vinylene carbonate (VC)

Material flows and life cycle assessment

Raw Materials → Components → Assembly → Use → End of Life

Material Flow Assessment over the life cycle based on specific case study

Battery type
Application
Overall life cycle stages
Potential release points



Quantitative results:

- ***Inputs/outputs***
- ***Release points***
- ***Recovery rates***

Life Cycle Assessment

Inputs:
- Material inputs and outputs from MFA
- Additional resource consumption (eg. Energy)
- Waste treatment processes

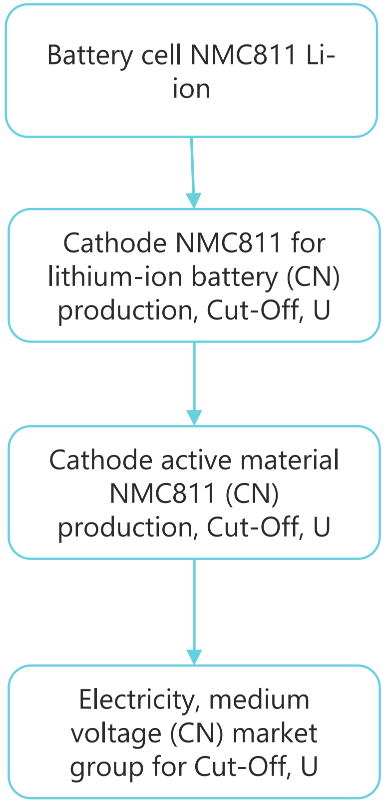
Quantitative results: contribution to different impact categories

- ***Global Warming Potential***
- ***Ecotoxicity***
- ***Toxicity***
- ***Acidification***
- ***Eutrophication***
- ***Resource Depletion***

Life cycle assessment: Impact on global warming potential

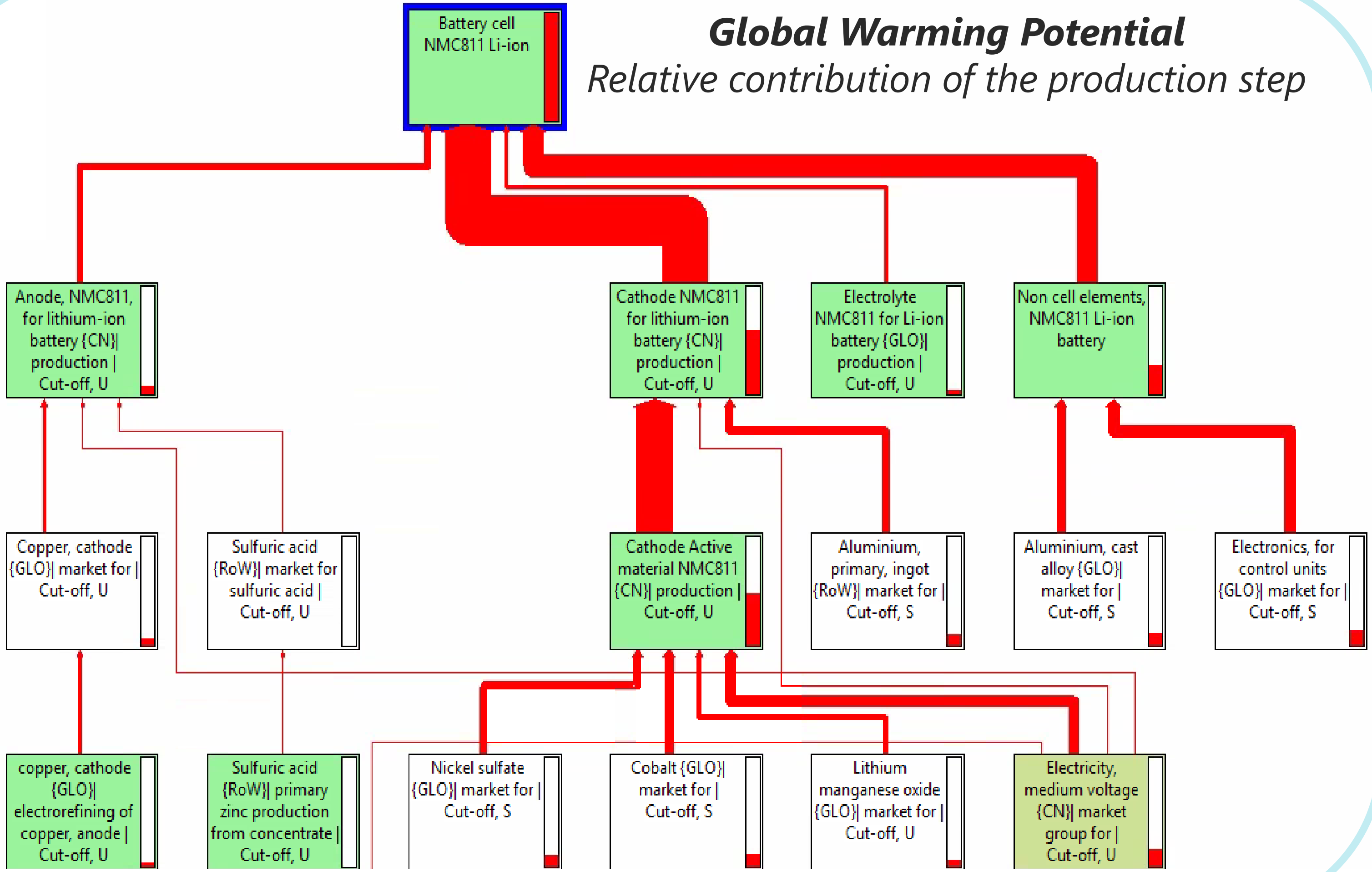
- **Production phase:** key processes modelled, and Impact Category indicators calculated
- **End of Life phase:** under development
- **Use phase** (including accidental releases): next step

The most impactful route for the Global Waring Potential example:



Global Warming Potential

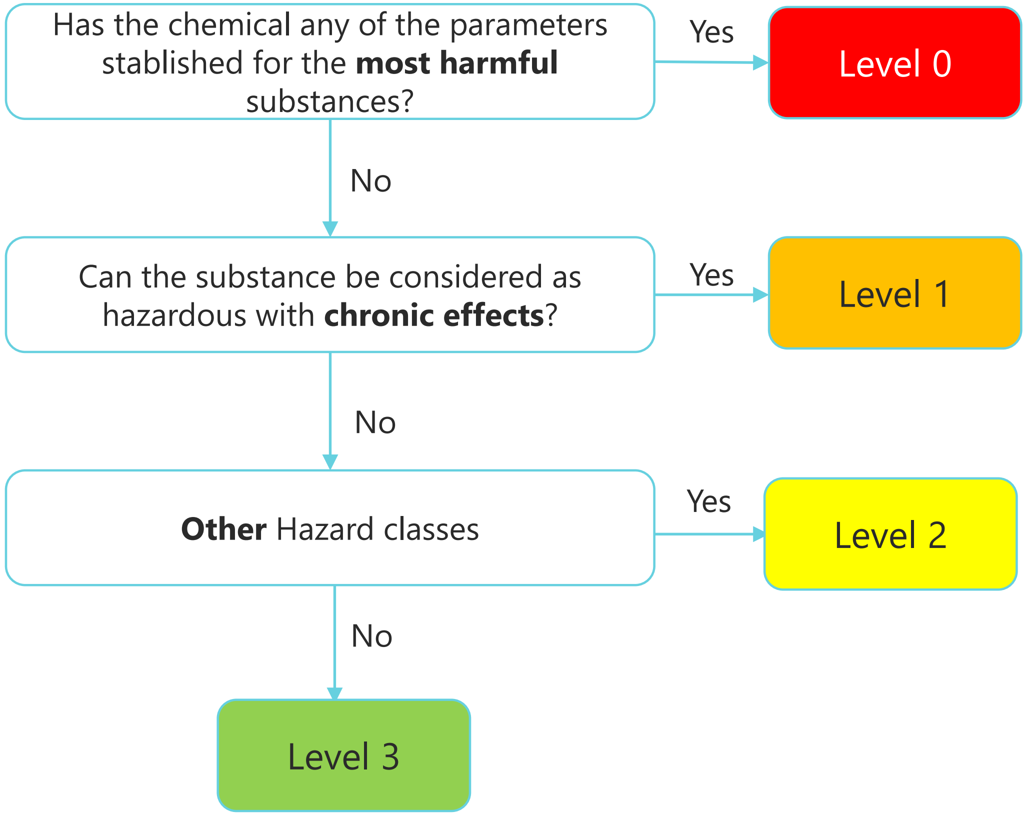
Relative contribution of the production step



Hazard assessment of materials

- Classification of chemical hazards using the Globally Harmonized System of Classification and Labelling of Chemicals (GHS)

- Three hazard levels have been considered:
  - **Most harmful** substances (level 0):
    - Carcinogenic (1A-1B).
    - Mutagenic (1A-1B)
    - Reproductive toxicity (1A and 1B).
    - Respiratory sensitizer (1).
  - Hazardous substances with **chronic effects**. Level 1
  - **Other** Hazard classes. Level 2
    if the substance has no GHS hazard statements or has few hazard statements with a low concern within it.
  - No hazard. Level 3



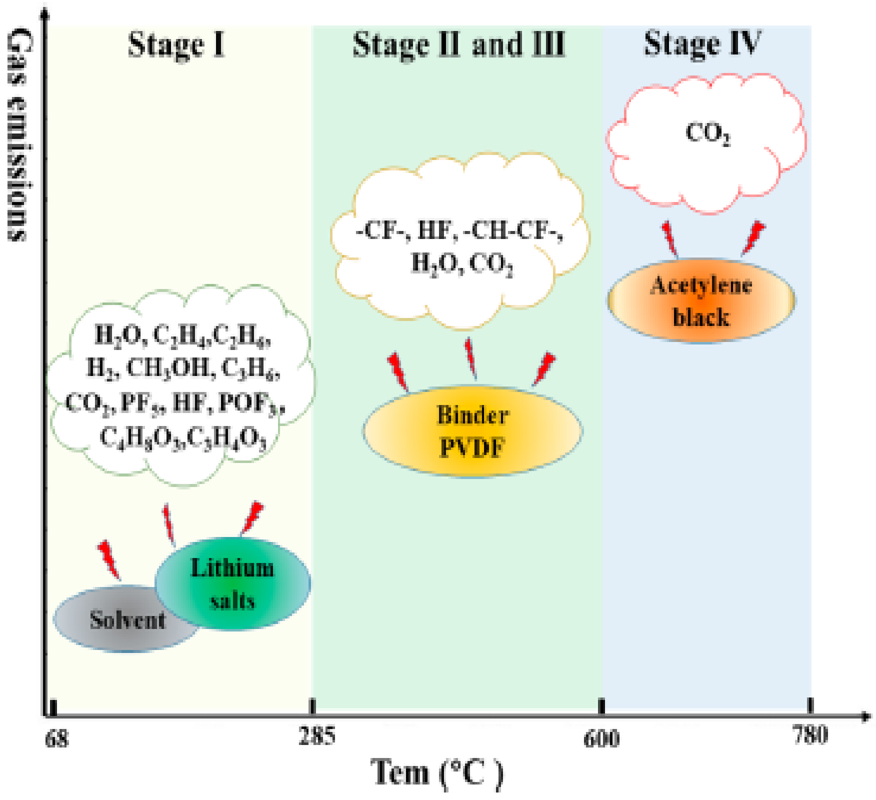
Hazard assessment of materials

Hazard	Mining and extraction of materials	Battery Chemical Production	pCam and Cam Production	Cell/Battery production	Battery integration and end users	Recycling and end of Life
	Cobalt Nickel	Nickel Sulfate Nickel Hydroxide Cobalt Hydroxide Cobalt sulphate	Ni-Mn-Co (8:1:1) Ammonium Hydroxide	Ni-Mn-Co (8:1:1) Carbon Black Lithium Hexafluorophosphate	Hydrogen Fluoride	Cobalt Nickel
	Manganese Lithium Aluminum	Ni-Mn-Co (1:1:1) Hydrogen peroxide Manganese Sulphate Lithium Hydroxide Sulfuric Acid Sodium Hydroxide	Lithium Hydroxide Lithium Carbonate Sodium Sulphate	N-Methyl-2-pyrrolidine EC DMC PVDF	Carbon Monoxide Methane Ethylene Lithium Hydroxide Hydrogen	LIF PF_5 DMC EC
	Copper	Sodium Sulphate Manganese Oxide Trimanganese Tetraoxide Manganese Hydroxide Lithium Sulphate	Graphite	Aluminum Graphite Copper PP PE Steel PET		PCl_5

Value chain of LIBs

Hazard assessment of materials, Gas emissions in accidents

- The most typical accident is related with temperature.
- When an accident occurs the Battery releases different gases.



	Hazard via inhalation route	Hazard via dermal route	Hazard via oral route	Hazard for the eyes
HF	Systemic effects: - DNEL = 0,03 mg/m^3 Local effects: - DNEL = 0,2 mg/m^3 (long term exp) - DNEL = 1,25 mg/m^3	Systemic effetcts: - no-threshold effect Local effects: - no-threshold effect	Systemic effects: - DNEL = 0,01 mg/kg bw/day	
LiOH	Systemic effects: - DNEL = 6,21 mg/m^3 (long term exp) - No hazard (acute/short term exp) Local effects: - Low hazard	Systemic effects: - DNEL = 41,35 mg/kg bw/day (long term exp) - No hazard (acute/short term exp) Local effects: - Medium hazard	Systemic effects: - DNEL = 4,13 mg/kg bw/day (long term exp) - DNEL = 12,4 mg/kg bw/day (short term exp)	Local effects: - Medium hazard
	Environmental Occupational Exposure Limit Values in Spain			
CH_4	1000 ppm			
C_2H_4	200 ppm			
	OSHA PEL 8-hour TWA (ST) STEL (C) Ceiling Peak	**NIOSH REL** Up to 10-hour TWA (ST) STEL (C) Ceiling	**ACGIH TLV©** 8-hour TWA (ST) STEL (C) Ceiling	**CAL/OSHA PEL** 8-hour TWA (ST) STEL (C) Ceiling Peak
CO	PEL-TWA: 50 ppm (55 mg/m^3)	REL-TWA: 35 ppm (40 mg/m^3) REL-C: 200 ppm (229 mg/m^3)	TLV-TWA: 25 ppm	PEL-TWA: 25 ppm (29 mg/m^3) PEL-STEL: 200 ppm

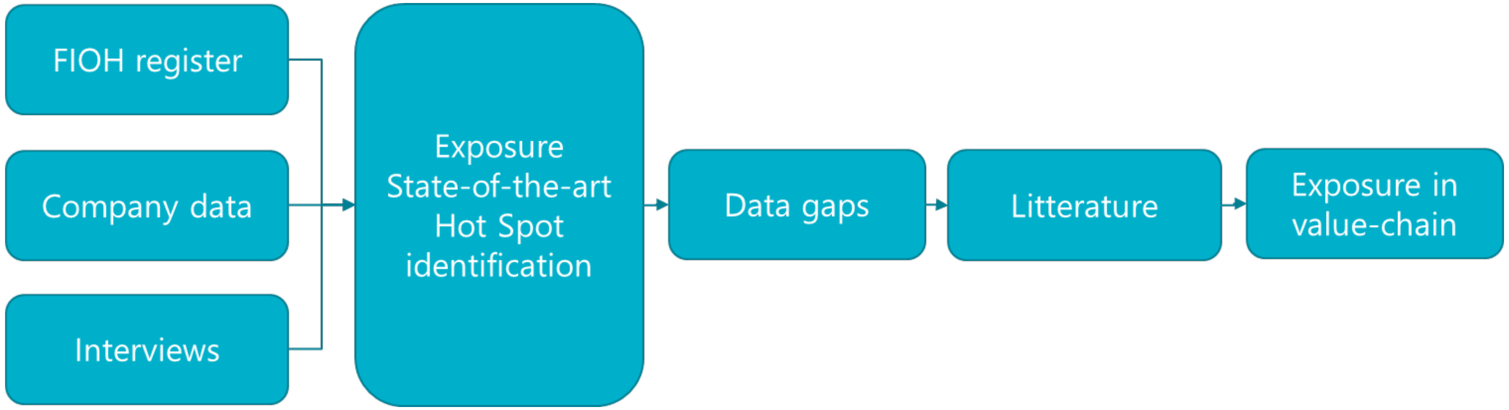
PF5 is rather short lived. The toxicity of HF and the derivate hydrofluoric acid is well known while there is no toxicity data available for POF_3, which is a reactive intermediate that will either react with other organic materials or with water finally generating HF. Judging from its chlorine analogy $POCl_3$/HCl, **POF_3 may even be more toxic than HF** (Larsson, Andersson, Blomqvist, & Mellander, 2017) .

Worker exposure to chemicals in value chain
(in progress,…)

	Hazard	Exposure potential								
Substance	Inherent hazard potential (CLP)	Mining and concentrate production	Metal refining	Maintenance	Battery Chemical production	pCAM and CAM production	Cell and Battery production	Battery integration and end users	Transport	Recyling and End of Life
Ni compounds	Carc 1A									
Co compounds	Repr 1B									
Mn compounds	STOT RE2									
Li compounds	Repr 1B									
Nickel Cobalt Manganese Hydroxide	Carc 1A									
H_2SO_4	Skin Cor. 1B									
LiPF6	STOT RE1									
Graphite										
Solvents (EMC,EC)	STOT RE2, Flam. Liq. 2									

Exposure	Air sampling criteria	BM criteria
High risk	>100% OEL	5% > Action level
Moderate risk	10-100% OEL	Non-exposed < BM < Action level
No/low risk	<10 % OEL	75% < Non-exposed
Data gap		
Not relevant		

Hazard	JRC SSbD hazard based criteria
Most harmful	Criterion S1
Chronic effects	Criterion S2
Other hazards	Criterion S3
Not classified	
Data gap	



Safety risk assessment in value chain (in progress...)

	Mining	Refining and chemical production	Battery integration	End users (forklift)	Transportation	Recycling and End of life
Risk assessment (batteries, battery chemicals)						
Safety observation (batteries, battery chemicals)						
Communication, safety co-operation in the value chain						
Accidents						
Preparedness, competence (batteries, battery chemicals)						

	high risk
	moderate risk
	low/no risk
	data gap

Safety management

Interviews (30 in Finland and 3 in Spain)

- Diverse safety management practices
- Long traditions for risk assessment
- Few near-misses concernig Li-ion batteries or battery chemicals
- Need for preparedness is recognized, information is needed
- Safety information follows the product and materials
- Co-operation is ongoing with fire and rescue department
- Communication requires more attention between value chain partners

Next steps

1) Complete the data gathering
2) Finalize MFA and LCA and hazard potential for End of Life
3) Model impacts from potential accidents in LCA
4) Visit the target companies
5) Join the data
6) Prepare the risk table
7) Prepare the guidance
8) Dissemination

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Thank You!

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