THE NORTHERNMOST UNIVERSITY of Technology in Scandinavia

Batterifondsprogrammet

Energimyndigheten

Recycling of discarded Li-Ion batteries (LIBs)

Nordic Recycling Day VIII
27th of September 2017

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Outline

- Introduction to Li-ion battery market
- Li-ion battery composition and recycling
- Project: Recycling of spent Li-ion batteries

Introduction - Where are LIBs used?

- Li-ion batteries are used in many applications
- Increasing political and consumer focus on climate change
  - Increase electric vehicle (EV) production
  - Increased lithium-ion battery (LIB) production

Photo: Ssuaphoto

Introduction - Where are LIBs used?

- Li-ion batteries are used in many applications
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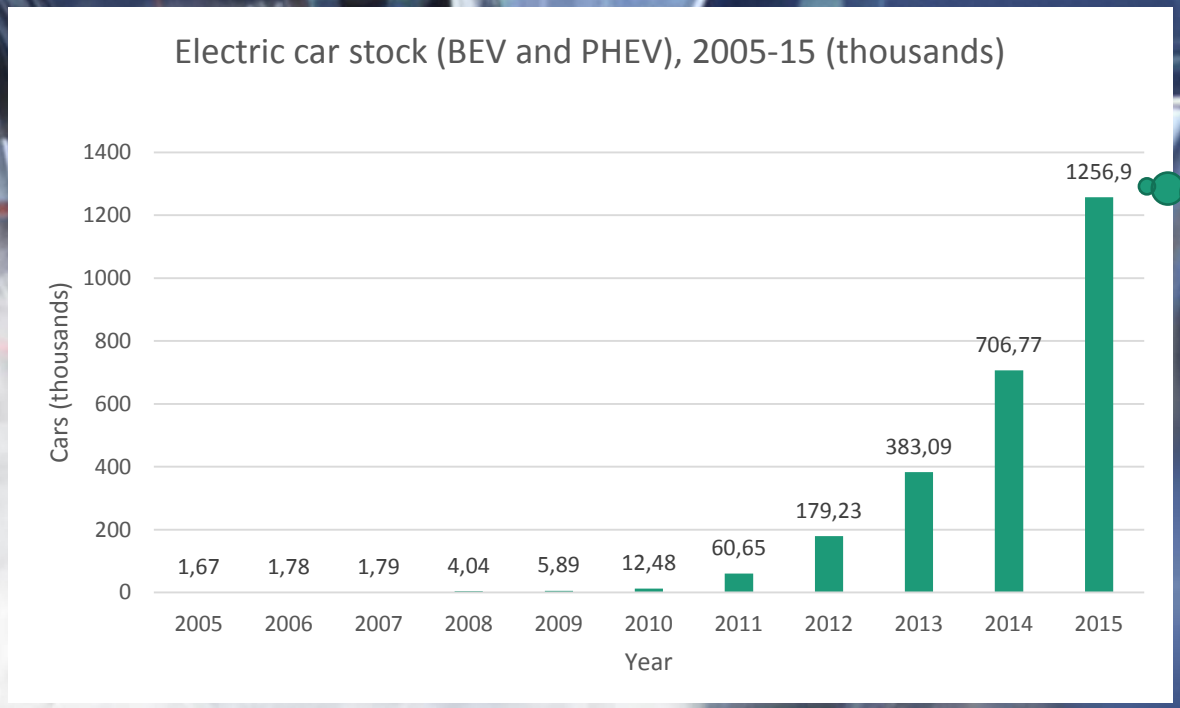


Almost 0.9% of car market

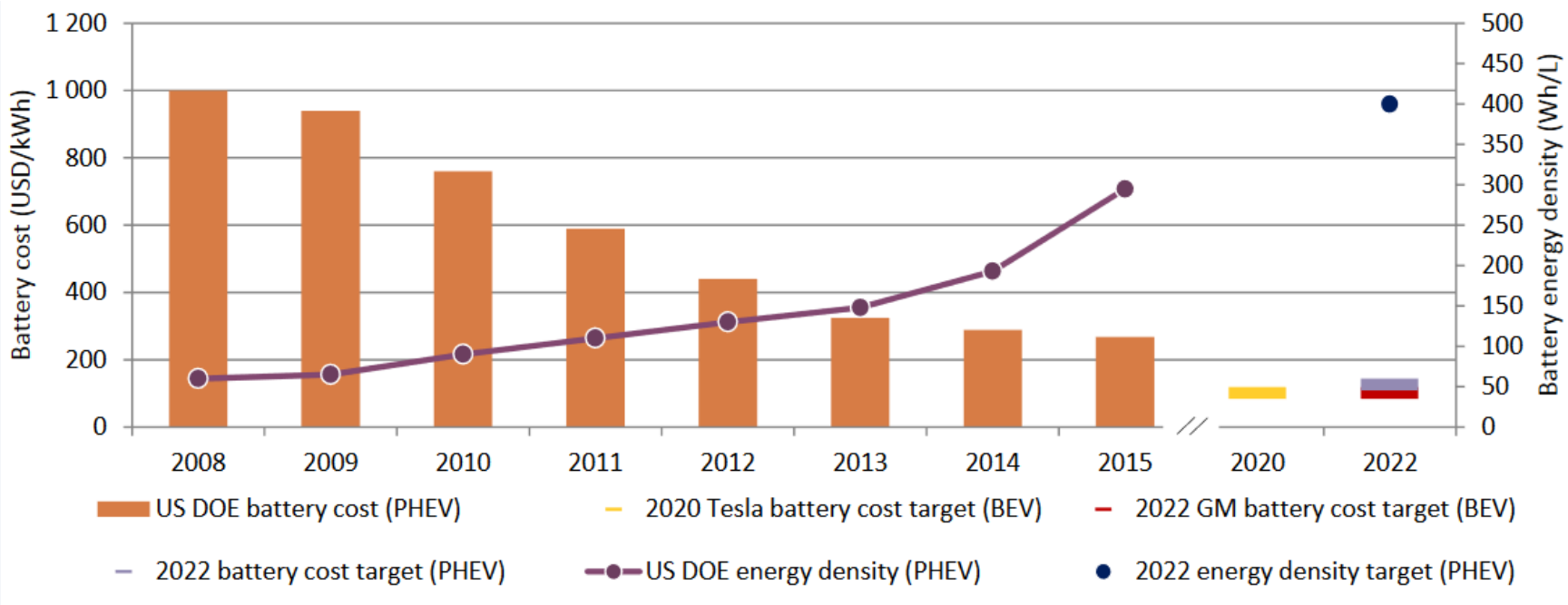
Source: © OECD/IEA 2016, *Global EV Outlook 2016*, IEA Publishing

Photo: Ssuaphoto

Introduction - Why LIBs?

- LIB is an important technology for electric vehicle (EV) – high specific power, energy density and lifetime
- Ongoing development of battery composition

Development of battery energy density and cost



Source: © OECD/IEA 2016, *Global EV Outlook 2016*, IEA Publishing

Introduction - Why

Energy density:
30-50 Wh/kg Lead acid battery
110-160 Wh/kg Li-ion battery

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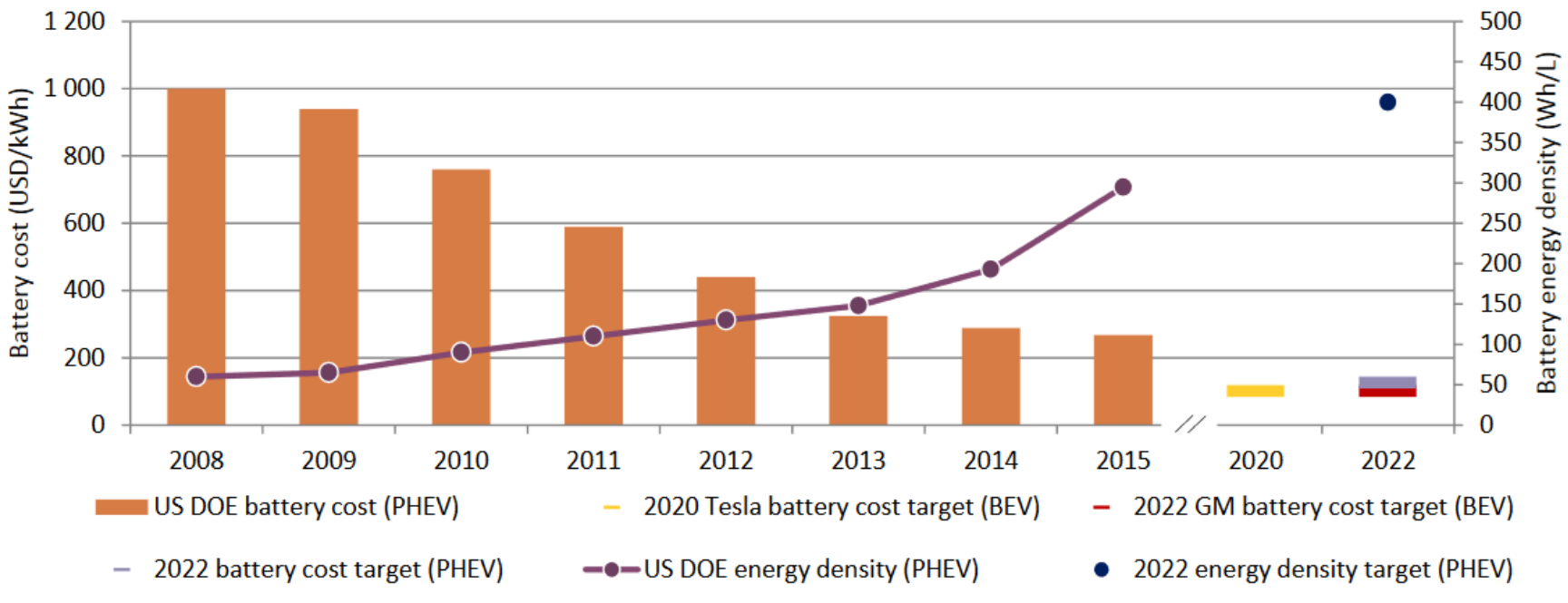
Development of battery energy density and cost



Source: © OECD/IEA 2016, *Global EV Outlook 2016*, IEA Publishing

LIB composition – What's inside?

- Cathode
  - Lithium metal oxide, $LiMeO_2$, graphite and PVDF binder on **Al-foil**
  - Metals used: i.e. **Co, Ni**, Mn, Al, Fe
- Anode
  - Carbon and PVDF binder on **Cu-foil**
- Electrolyte
  - Li salts and organic solvents (flammable).
- Casing
  - **Steel (Fe, Cr, Ni), Al**
- Complex material to recycle

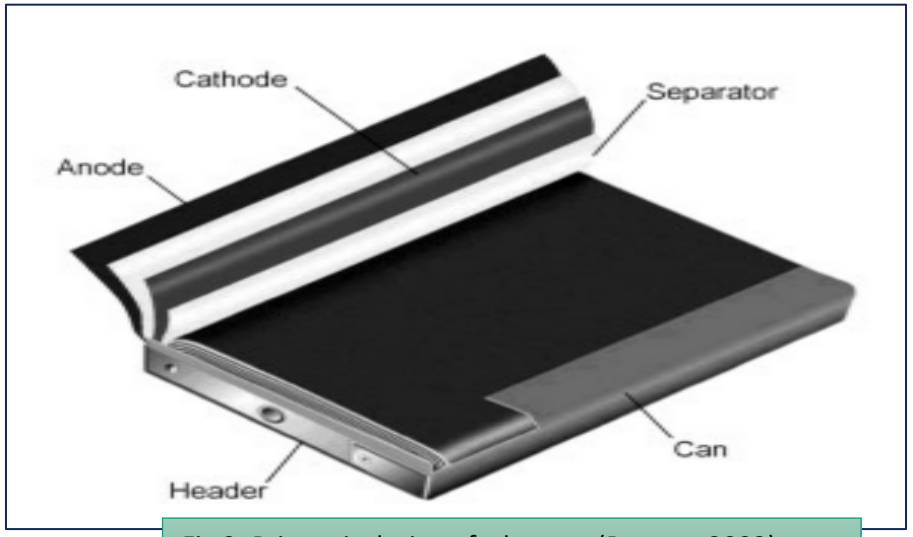
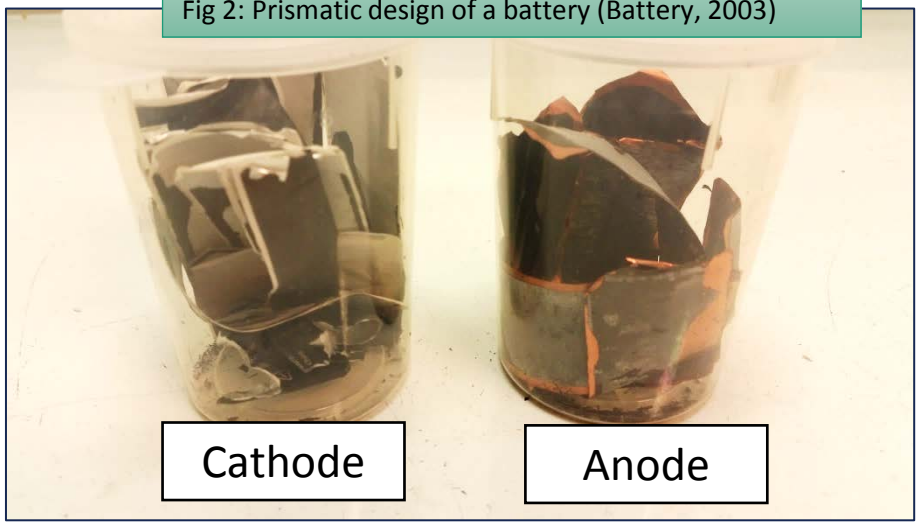


Fig 2: Prismatic design of a battery (Battery, 2003)



LIB recycling – challenges!

- Existing high temperature recycling process
  - Based on Co and Ni recovery
- Short circuiting / thermal runaway
  - Need of pre-treatment
- Battery chemistries
  - Development of cathode active material
  - What to recycle in the future?

System Electrodes	NCA Graphite	LFP(phosphate) Graphite	MS (spinel) Graphite
Positive (Cathode)	$LiNi_{0.8}Co_{0.15}Al_{0.05}O_2$	$LiFePO_4$	$LiMn_2O_4$

Recycling of spent LIBs project

Recap:

- Increasing volumes of end of life LIBs
- Ongoing development of battery chemistry
- Recycling in existing processes

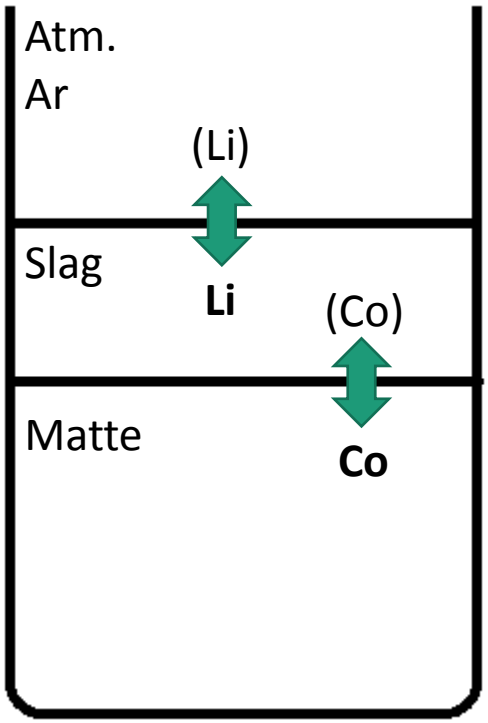
Aim:

- **To investigate thermochemical feasibility of the processes – FactSage**
- **To recycle spent LIBs in copper pyrometallurgical process**
  - Distribution of Li and Co between phases

Cu-system

- Slag: Fe_2SiO_4 + (CaO)
- Matte: Cu_2S
- Metal: Cu

FactSage results



Li to gas phase:

- T increase >1300°C
- CaO addition
- <$logPO_2$ (-10)

Co to matte phase:

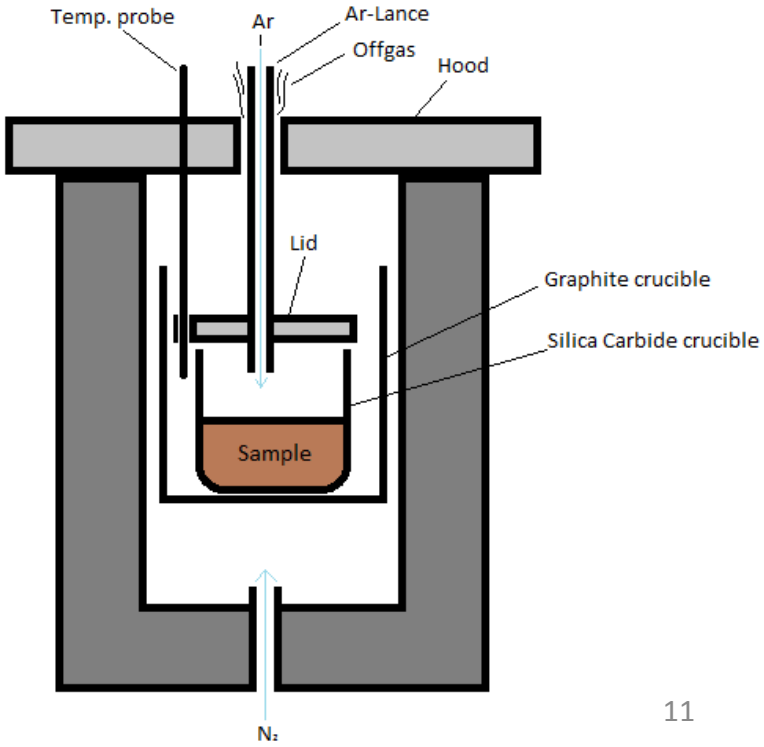
- CaO addition
- <$logPO_2$(-10)

Validation with experimental work!

Experimental method

Parameter	Low value	Middle value	High value
Temperature	1250°C	1350°C	1450°C
Fe/SiO_2	1	1.3	1.6
CaO addition	0 wt.%	5 wt.%	10 wt.%

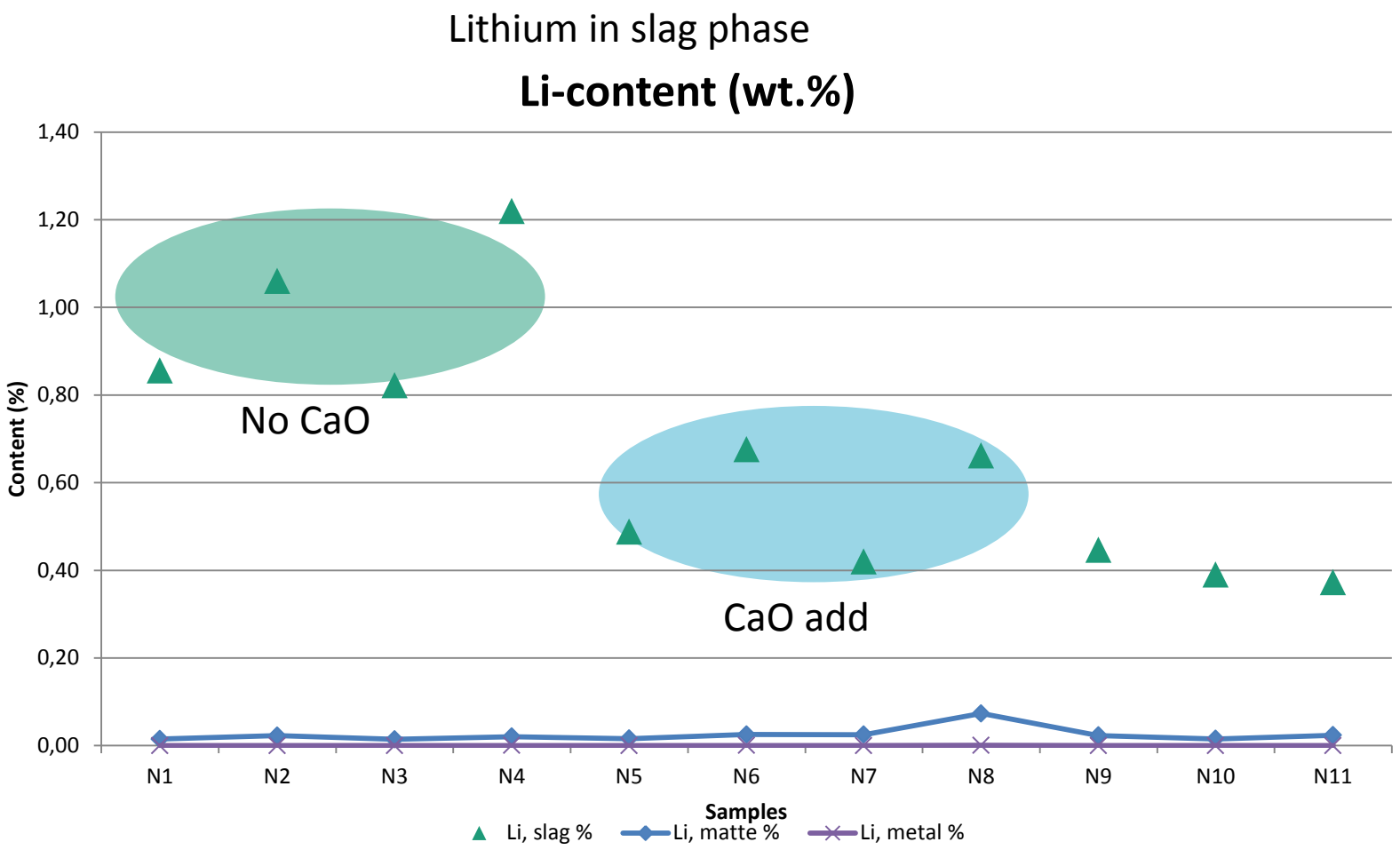
- Inert atmosphere



Sample

- Slag, Fe_2SiO_4 50g
- Matte, Cu_2S 75g
- Metal, Cu 25g
- 5% $LiCoO_2$ (constant)
- CaO addition

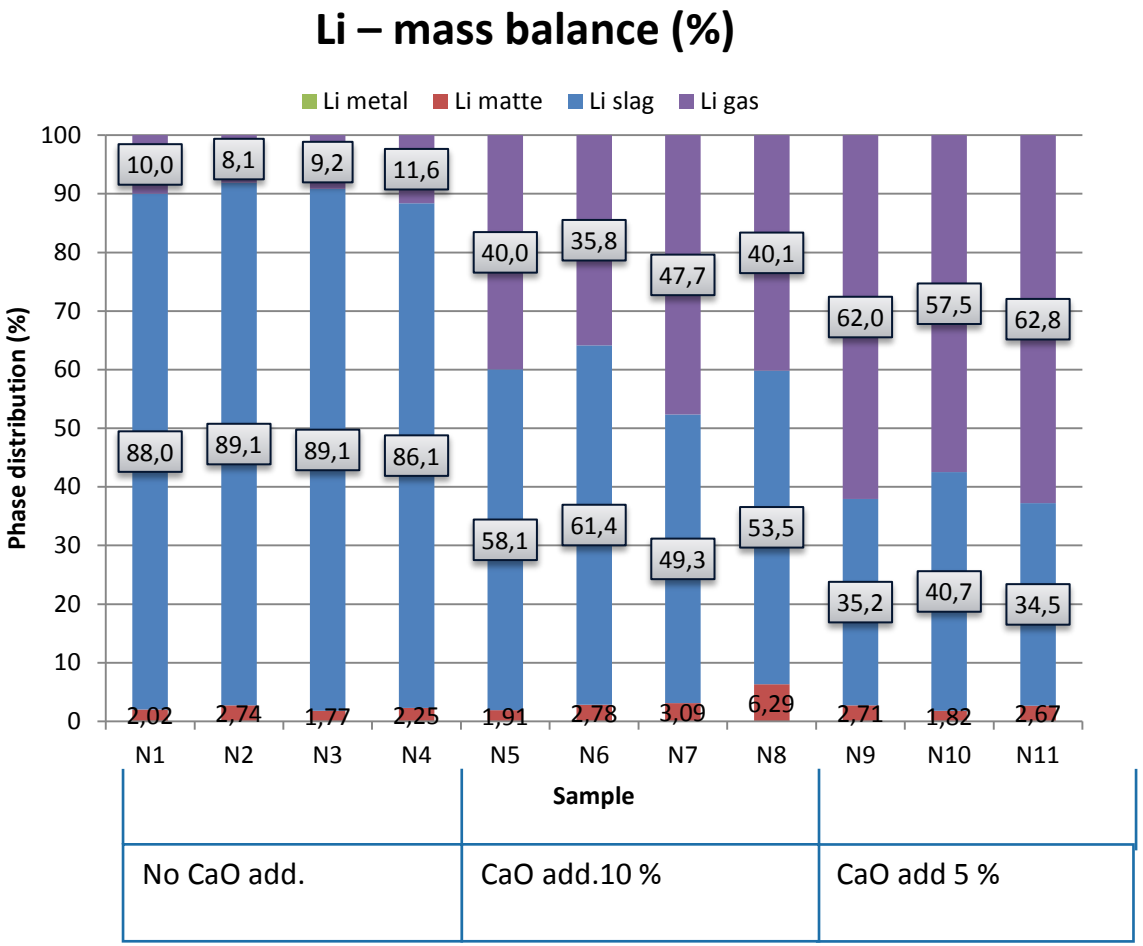
Experiment results – Li - CaO add



Experimental results – Li mass bal.

- No CaO addition
  - 88% Li in slag
- CaO addition 10%
  - 35% Li loss
- CaO addition 5%
  - 56% Li loss

- No/small effect of Fe/SiO_2 ratio

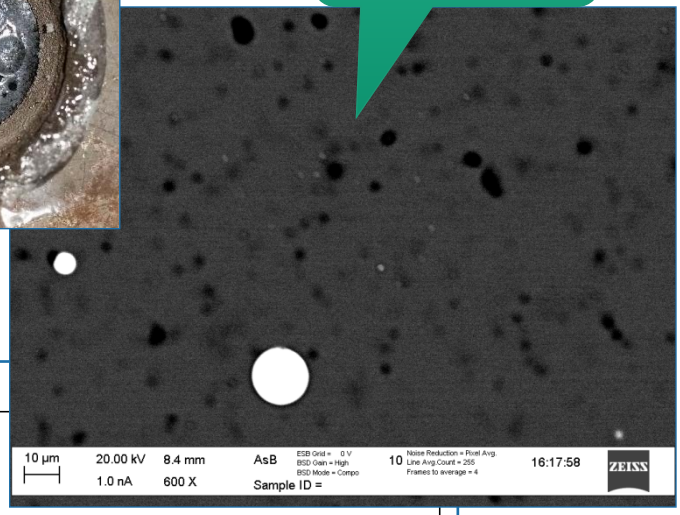


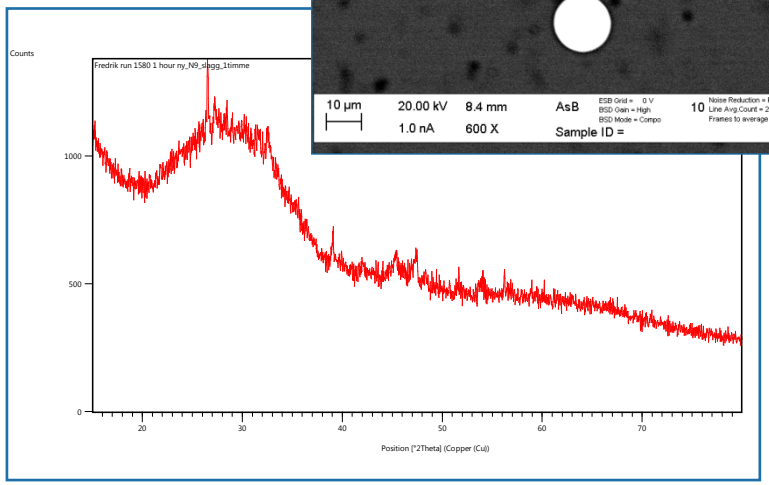
Experimental results – Li

- Middle-point samples N9-N11

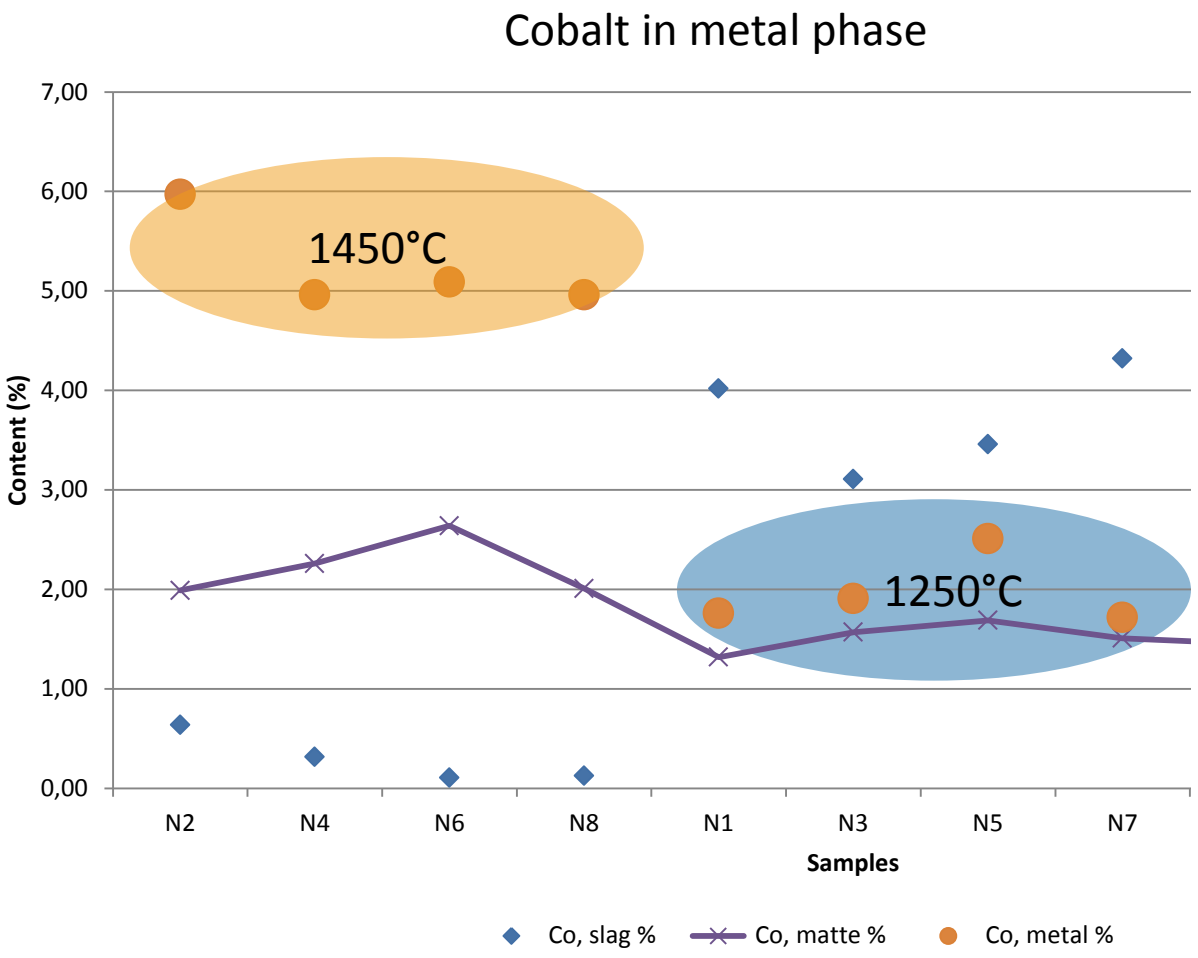
Conditions
- T 1350°C
- Fe/SiO_2 1.3
- CaO add 5%

- Glassy amorphous slag
- Verified by XRD and SEM
- Consistent for all 3 samples
- Most of Li reported as loss (58-63 mass%)

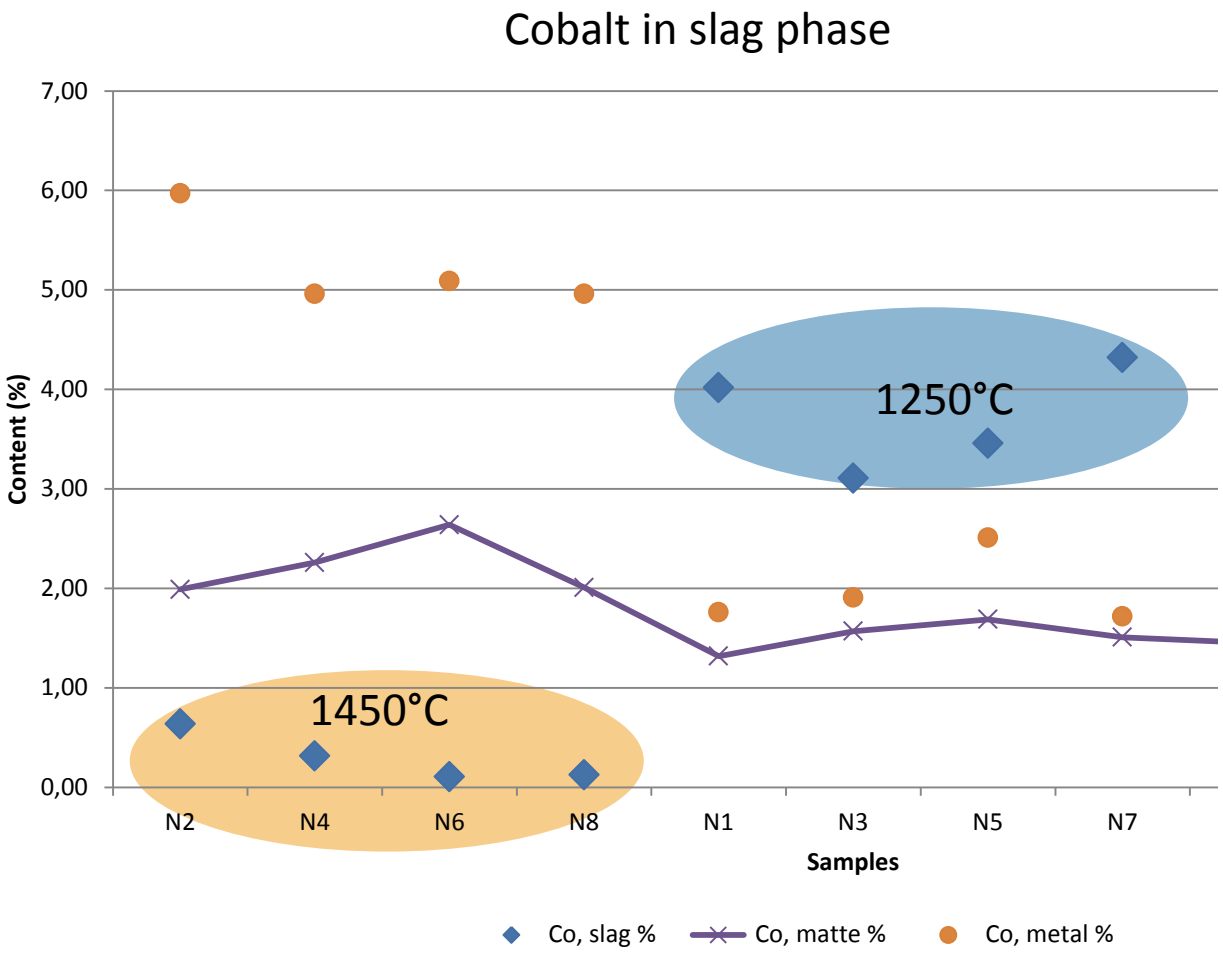




Experiment results – Co - Temp

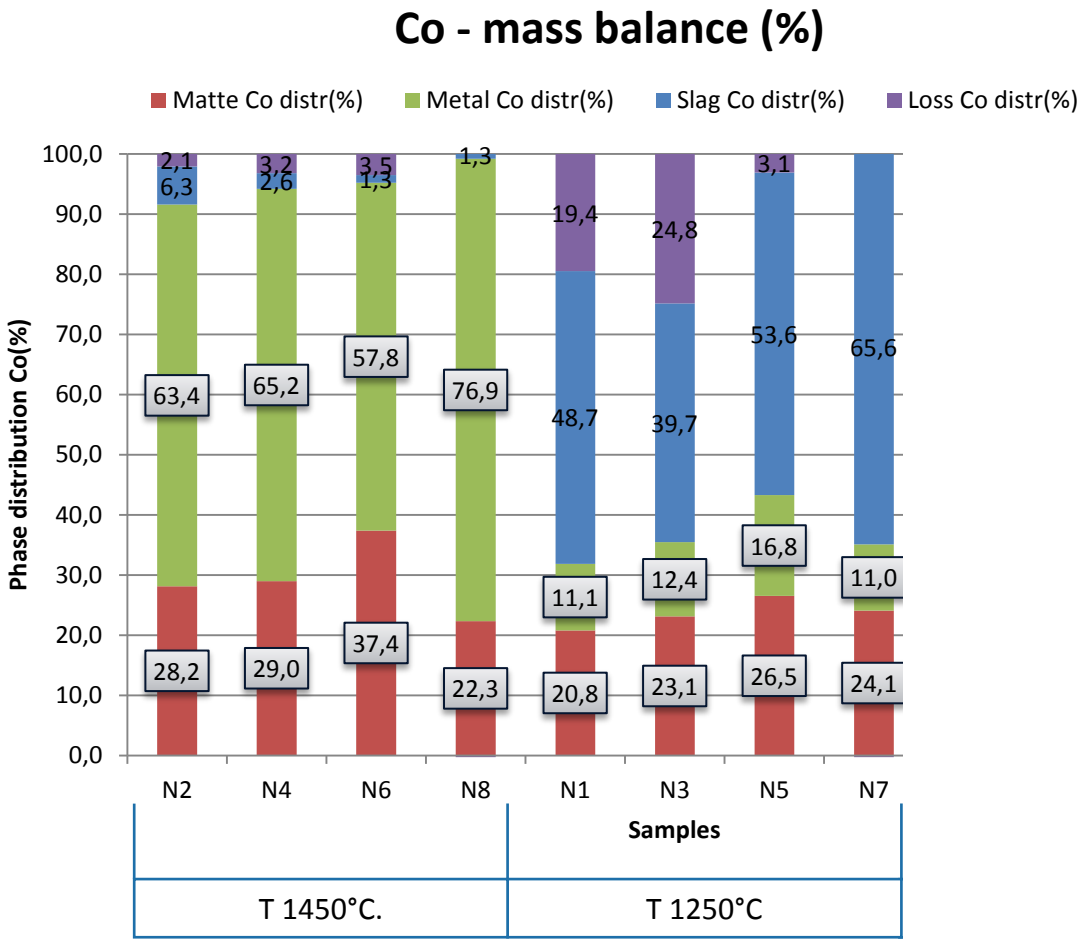


Experiment results – Co - Temp



Experimental results – Co mass bal.

- 1450°C
  - 66% Co in metal
- 1250°C
  - 52% Co in slag
- No/small effect of Fe/SiO_2 ratio and CaO add



Summary

- Li is distributed between slag and gaseous phases (loss)
  - CaO addition reduces the amount of Li reported to the slag phase
- Co is distributed between slag, matte and metal(mainly) phases
  - Co is at 1250^{o}C dissolved into the main slag phase
  - Co is at 1450^{o}C in the metal phase and as diffused metal droplets in the slag and matte phase
- Co in matte phase as inclusions (metal droplets) – no dissolution.

Further work

- Investigate the influence of adding other metals as Al, Mn, Ni to the system
- Further investigation with spent LIBs instead of $LiCoO_2$ addition to the Cu-system
- Pre-treatment of batteries, physical separation

Thank you for your attention!

Project partners:

Stena Recycling AB

KTH

Chalmers