Secondary phases developed from layered lithium nickel cobalt manganese oxide (NMC) cathode material waste:

Environmental mineralogy implications for advancing NMC recycling methodologies

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Introduction

Increasing trends in:
(1) energy storage requirements
(2) need to decrease Co consumption for layered $LiCoO_2$ cathodes for **LIB**,
resulted in Ni–rich Mn–bearing cathode alternatives, layered **$Li(Ni_{1-x-y}Co_xMn_y)O_2$** (**NMC**), $0 \leq x+y \leq 1$ [1].

Material
NMC scrap waste

NMC aging
Atmospheric conditions

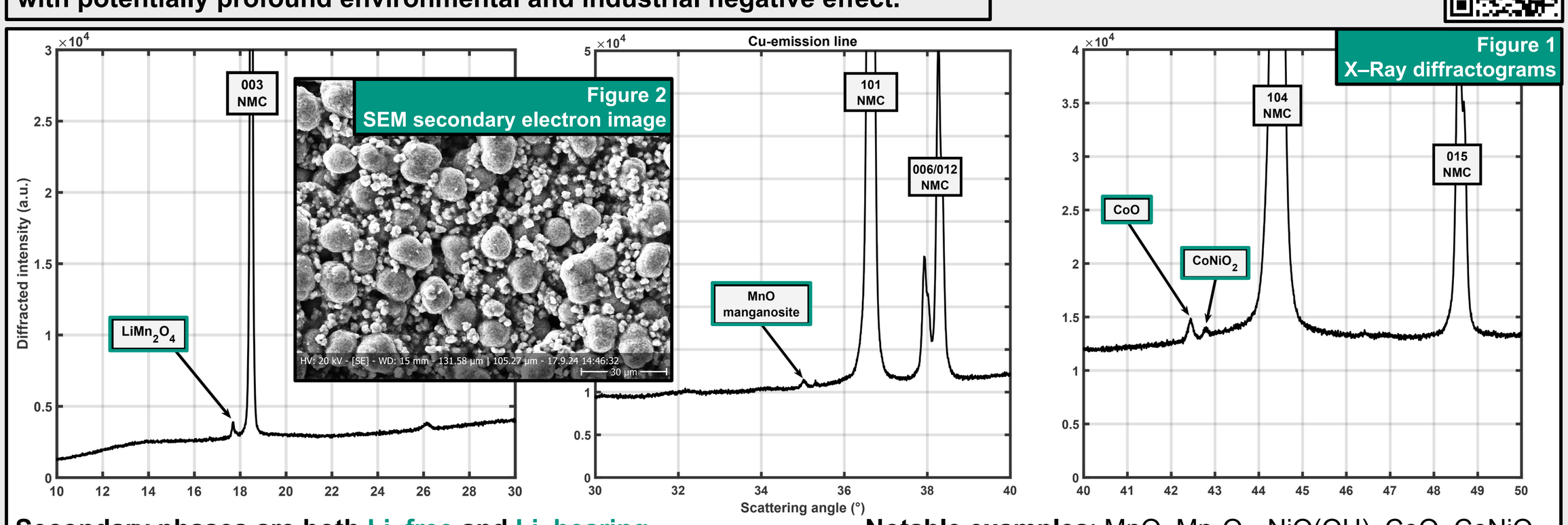
Methods
- XRD
- SEM–EDS
- ICP–OES

Motivation

Nearly **40% of total cathode materials** produced in 2025 are to be attributed to **NMC** [2].
Efforts in cathode–related:
- ❑ **sustainable recycling**,
- ❑ **regeneration strategies**,
- ❑ **targeted repurposing**.

Study Aim

Deeper understanding of NMC aging mechanisms and related processes with potentially profound environmental and industrial negative effect.



Secondary phases are both Li–free and Li–bearing.

Notable examples: MnO, Mn_3O_4, NiO(OH), CoO, $CoNiO_2$, mixed/intergrown 3:5 or 5:3 CoO·NiO oxides, $LiMn_2O_4$, $LiMn_3O_4$.

Implications of Cathode Aging–Degradation

- **Environmentally harmful**
  - **Uncontrolled waste disposal**
  - **Favoring metal mobility conditions**
- **Industrial context**
  - **Occupational safety and health**
  - **Cost–intensive recycling processes**

Conclusions – Outlook

- The secondary phases are assumed to be **grown on NMC particle surface** (Figure 2).
- The typical atmosphere as a set of reaction–controlling conditions generally seems to **favor low–valence metal oxyhydroxide products** (examples in Figure 1).
- In **surficial** geochemical environments, **metal mobility** with further **oxidation** of the low–valence compounds and **complexation** of the respective Ni– and Co–oxyanions is expected. This results in relatively rapid **environmental dispersion**, and potentially **higher bioavailability** [3].
- Implementing recycling methodologies in **non–pristine** material, where **secondary phases** can **disrupt** the hydrometallurgical solution chemistry.

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Project DiRecReg

Acknowledgements
Funding under BMBF–Projekts:03XP0553C