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Recycling of Lithium-Ion Batteries by Solar Pyrometallurgy

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The Problem: A Growing Waste Stream & Critical Material Scarcity

The global battery market is growing fast.

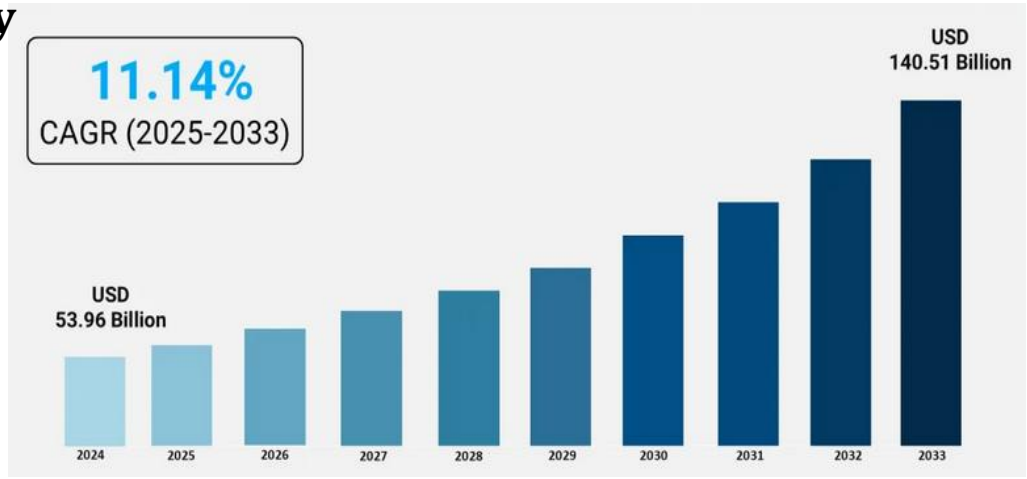
Market Growth: 54 → 140 billions USD (2024 → 2033)

Critical Materials Dependency:

- ✓ Cobalt: 98% reserves in DR Congo.
- ✓ Lithium: Concentrated in "Lithium Triangle" (Chile, Argentina, Bolivia)
- ✓ Nickel: 50% production in Indonesia

Limitations of Conventional Recycling:

- ✓ **Pyrometallurgy**: Lithium loss in slags (>80%) and high energy consumption.
- ✓ **Hydrometallurgy**: Generation of hazardous effluents
- ✓ **Direct Recycling**: Limited to specific chemistries



Lithium-ion Battery Materials Market (2024–2033) – Billion USD

In the DR Congo, workers—including children and their families—face unsafe conditions.

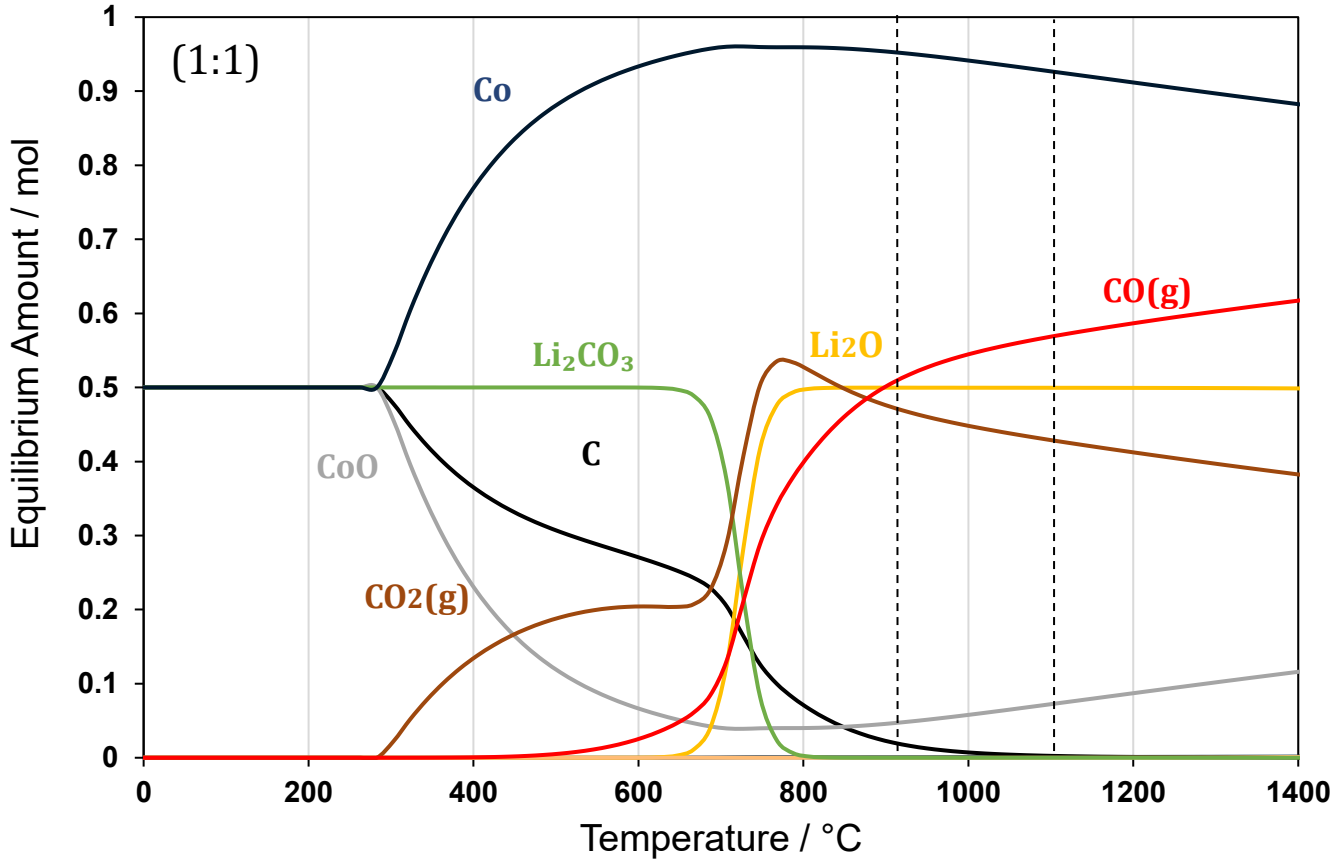
Our Solution: Solar Pyrometallurgy

- ✓ Use concentrated solar energy as a renewable heat source.
- ✓ Target zero operational CO_2 emissions.
- ✓ Enable direct and simplified recovery of metals.
- ✓ Explore carbothermal reduction of $LiCoO_2$ under inert atmosphere.

Simulation – Thermodynamic Equilibrium

System: $LiCoO_2$ – carbon under inert atmosphere (1 bar N_2)
Molar ratio: $LiCoO_2$:C = 1:1

Low temperature (< 300 °C): The system remains stable. Li_2CO_3 and CoO are the most stable phases.
Intermediate temperature (300–700 °C): Li_2CO_3 decomposes into Li_2O and CO_2(g), and cobalt is reduced to metallic Co^0.
High temperature (800–1100 °C): Metallic cobalt (Co^0) is maximized, while lithium is mainly present as lithium oxide (Li_2O).



The Solar Process & Experimental Setup

Methodology: Concentrated Solar Energy for Carbothermal Reduction

Operating Principle

25 m² heliostat tracks and redirects solar radiation

Parabolic concentrator (2 m diameter) focuses the radiation to reach 900-1100°C on the sample at the focus

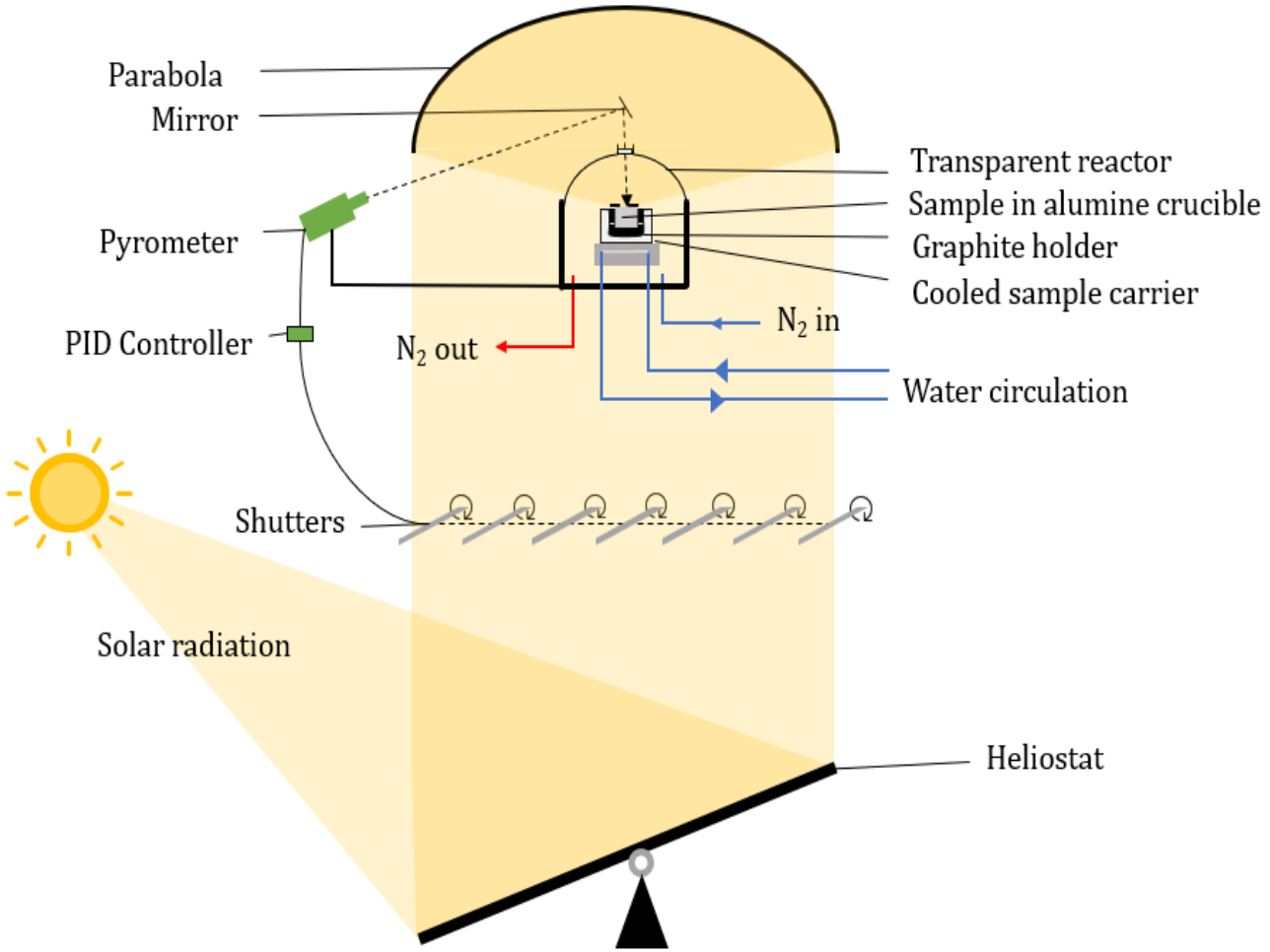
The sample is surrounded by an **inert N_2 atmosphere**

Experimental Procedure

Pre-treatment: Vacuum + 3 N_2 purges (1 bar, 0.7 L/min, 15 min)

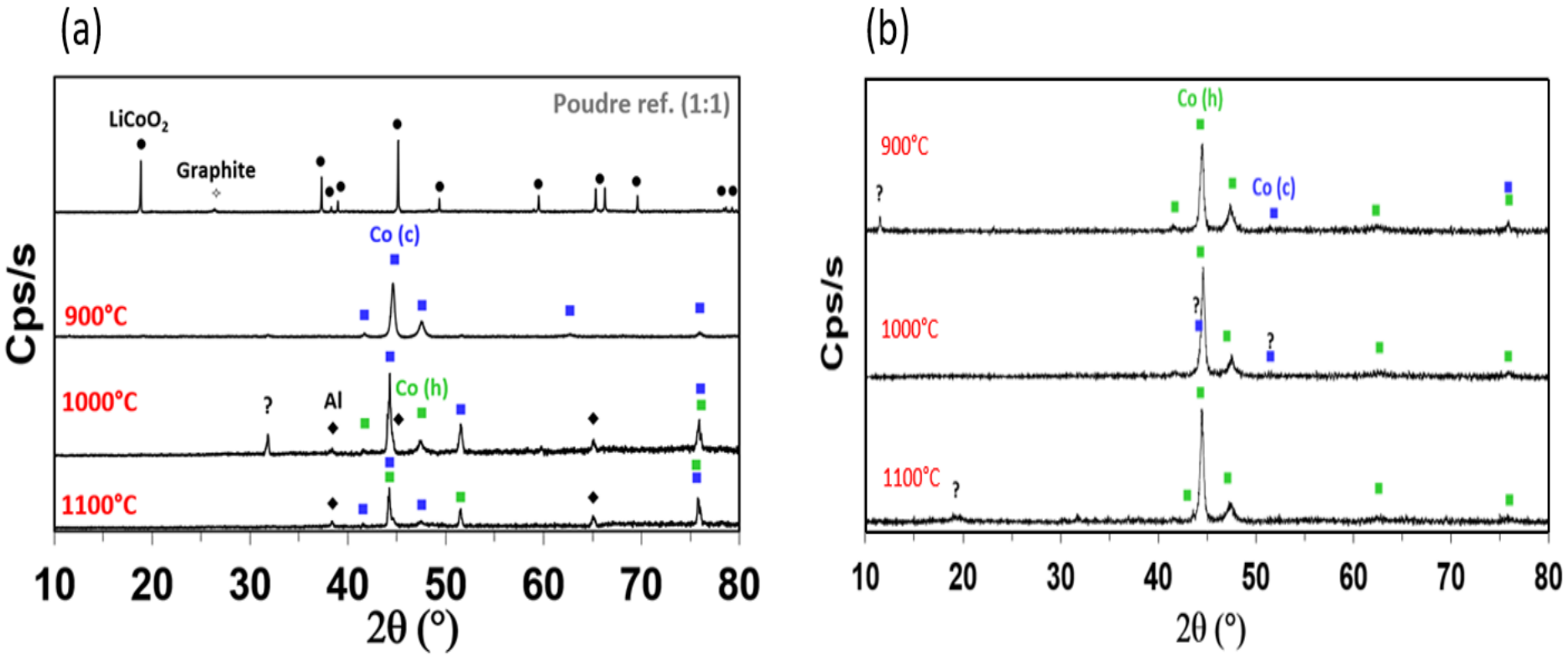
Heating: 50°C/min to target T (900, 1000, 1100°C), hold 45 min

Cooling: 50°C/min



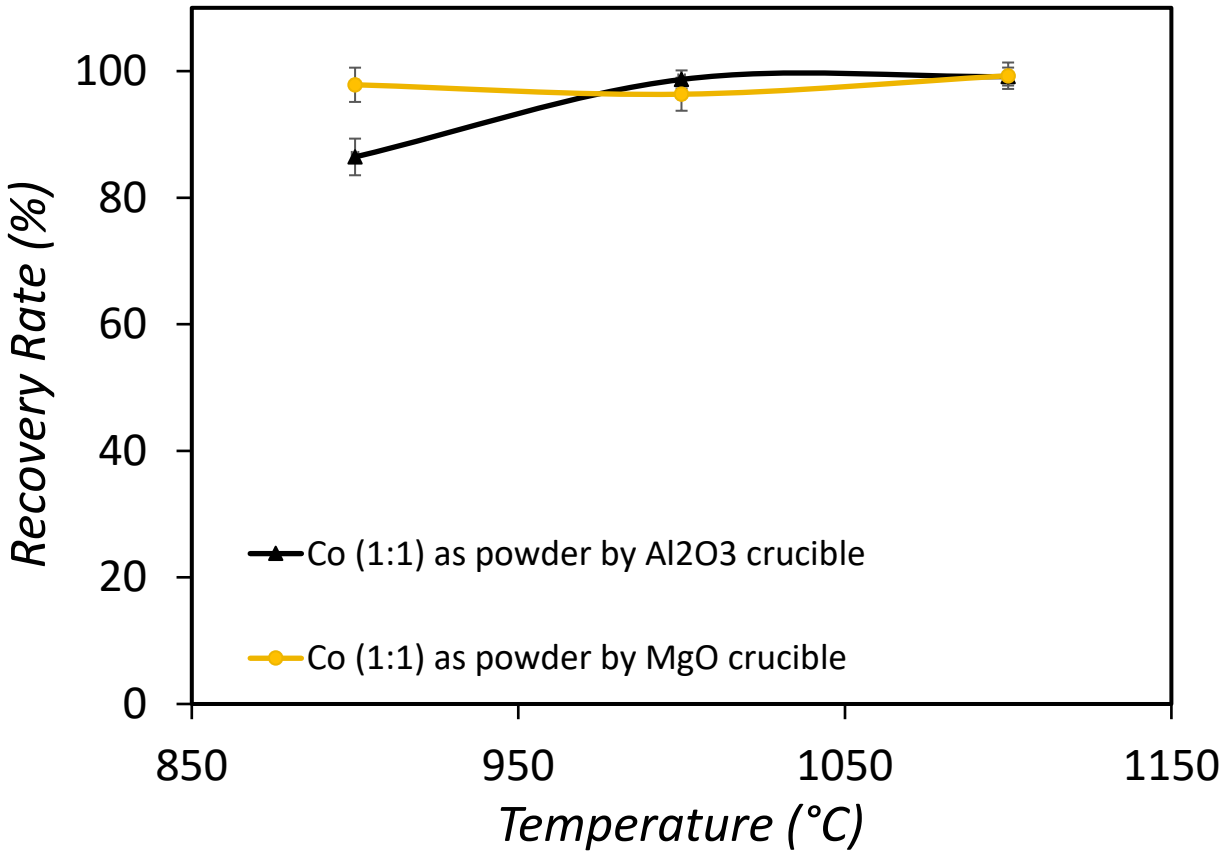
Experimental Results - XRD Analysis

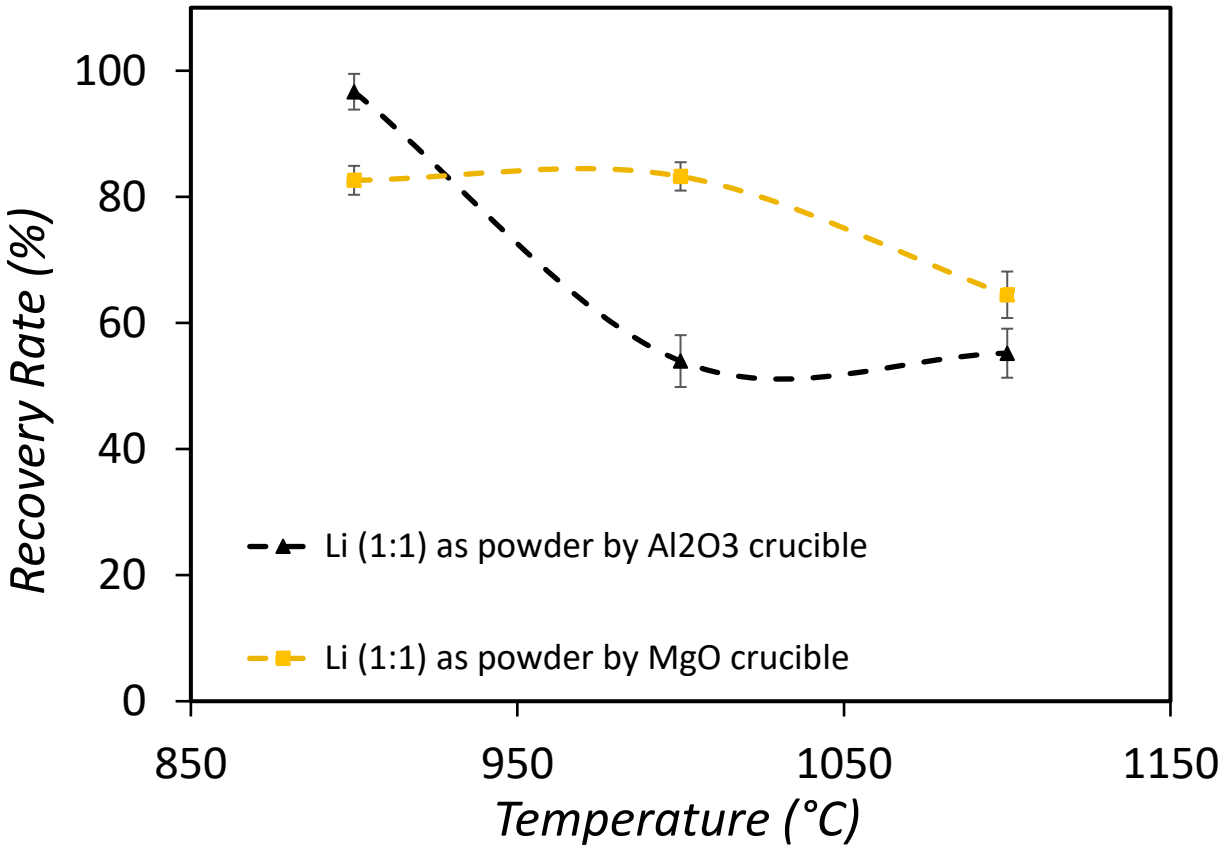
Influence of crucible composition



Comparative XRD patterns of (1:1) using different crucible materials (a) with Al_2O_3 crucible (b) with MgO crucible.

Experimental Results – ICP-OES Analysis

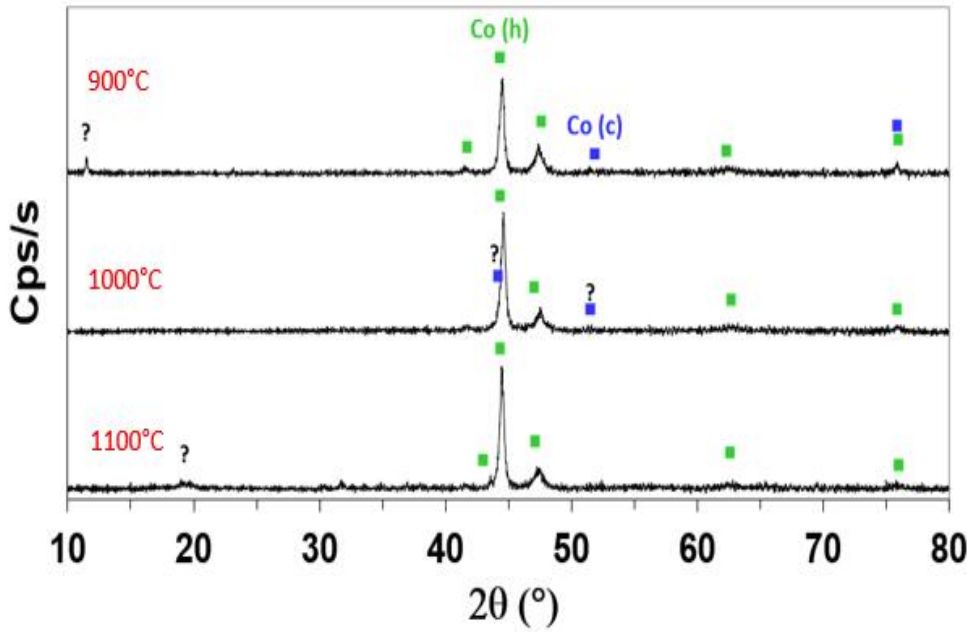


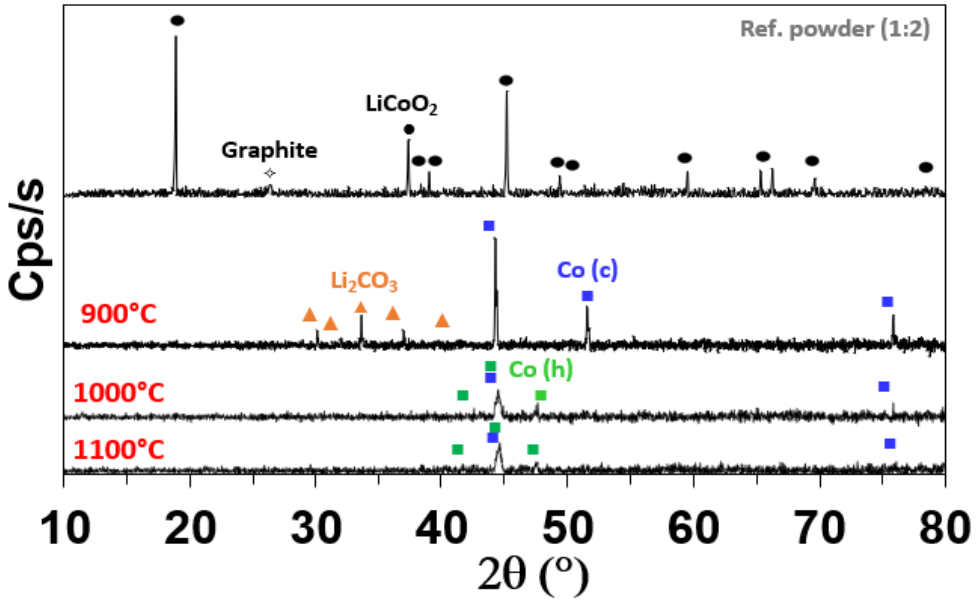


Recovery rates of cobalt and lithium for samples with molar ratio (1:1) using an Al2O3 crucible

Experimental Results - XRD Analysis

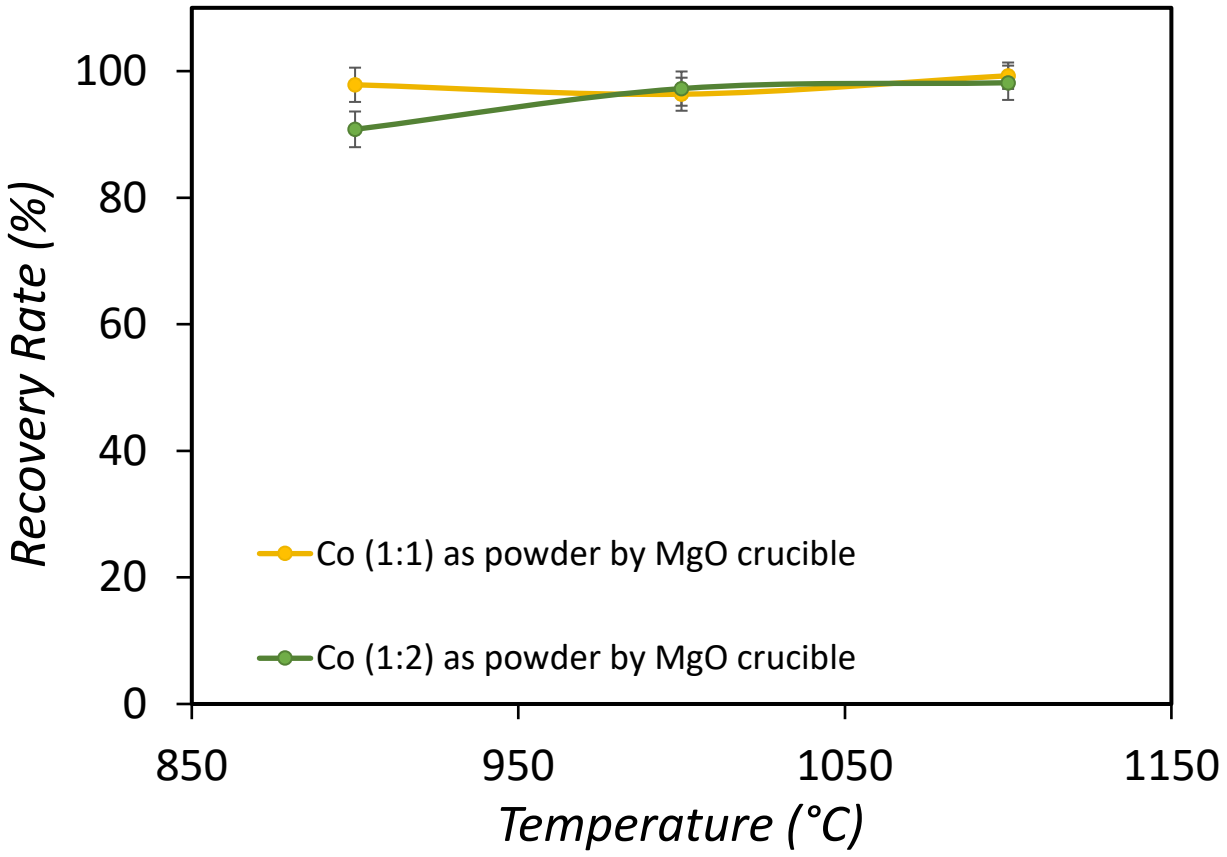
Influence of the Oxide/Graphite Ratio

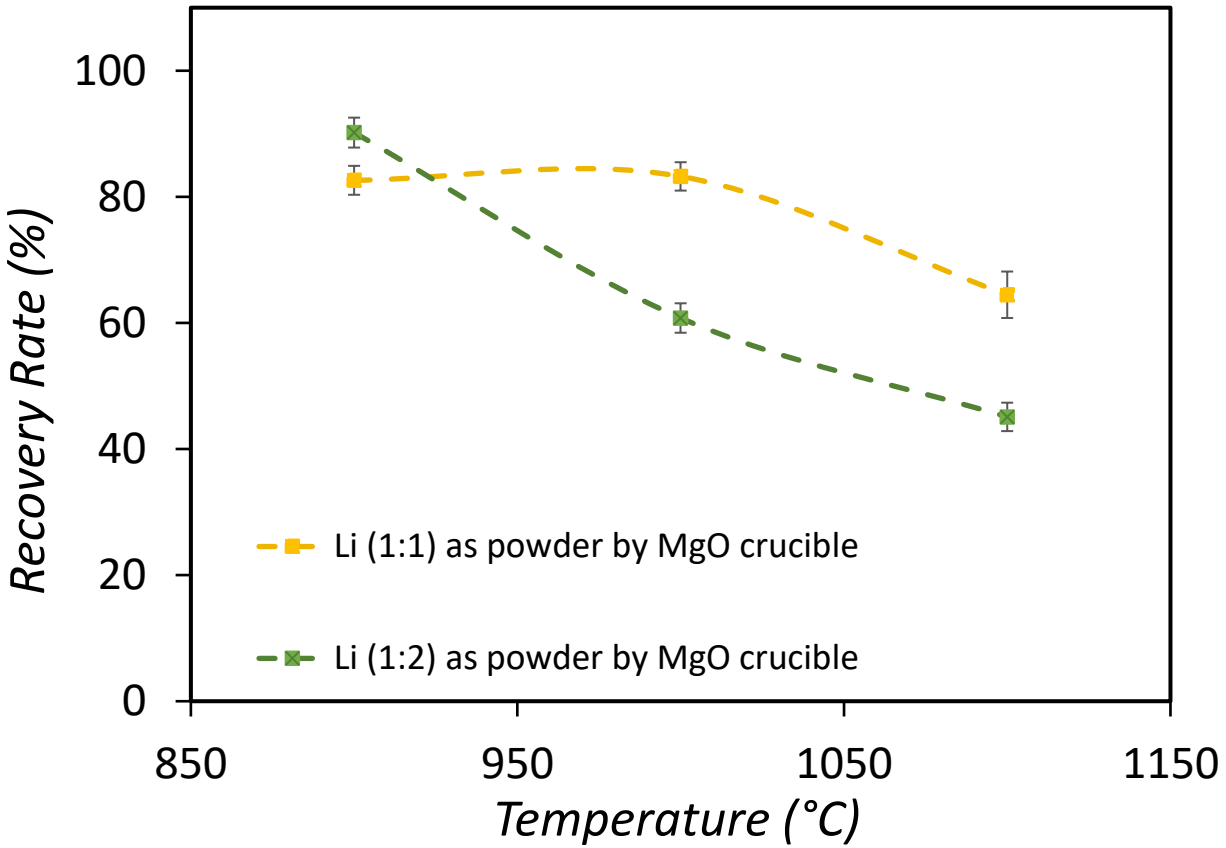




XRD results of (1:2) used MgO crucible for different temperatures.

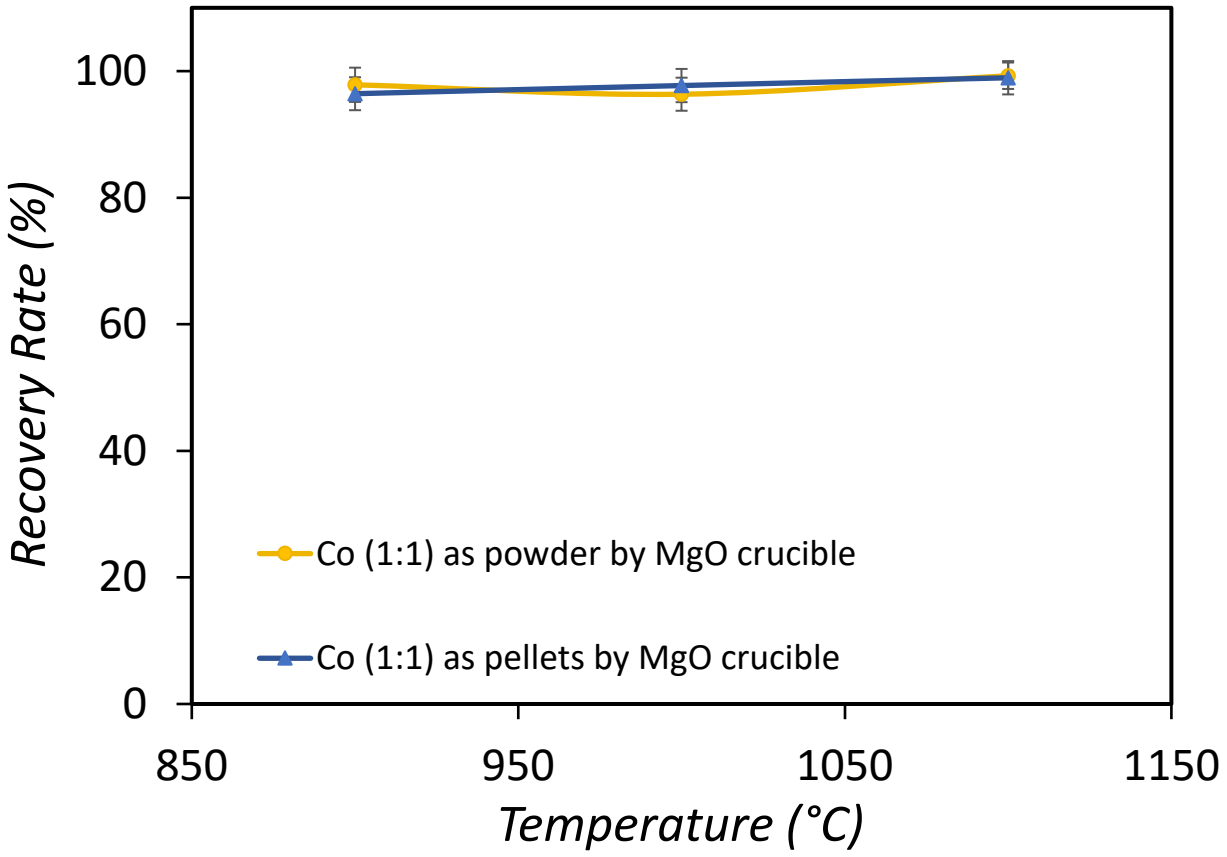
Experimental Results - ICP-OES Analysis

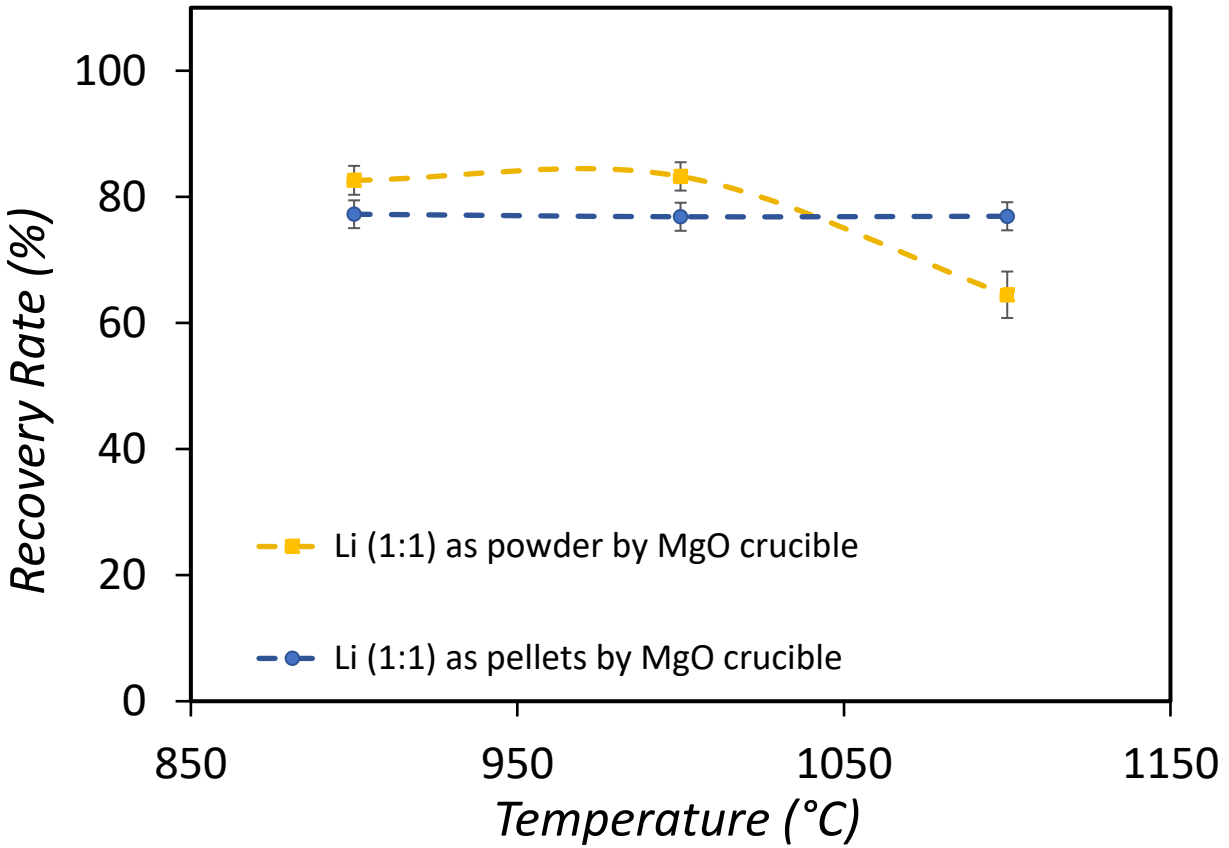




ICP-OES results for different ratios of recovery rate of Co and Li as powder with a different molar ratio (1:1) and (1:2) using a MgO crucible

Experimental Results - ICP-OES Analysis



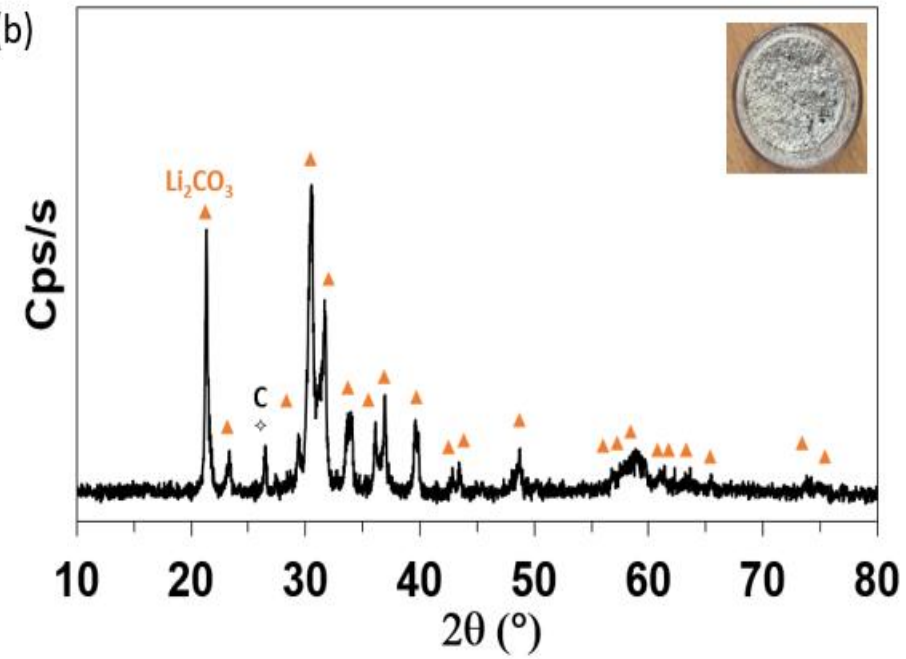


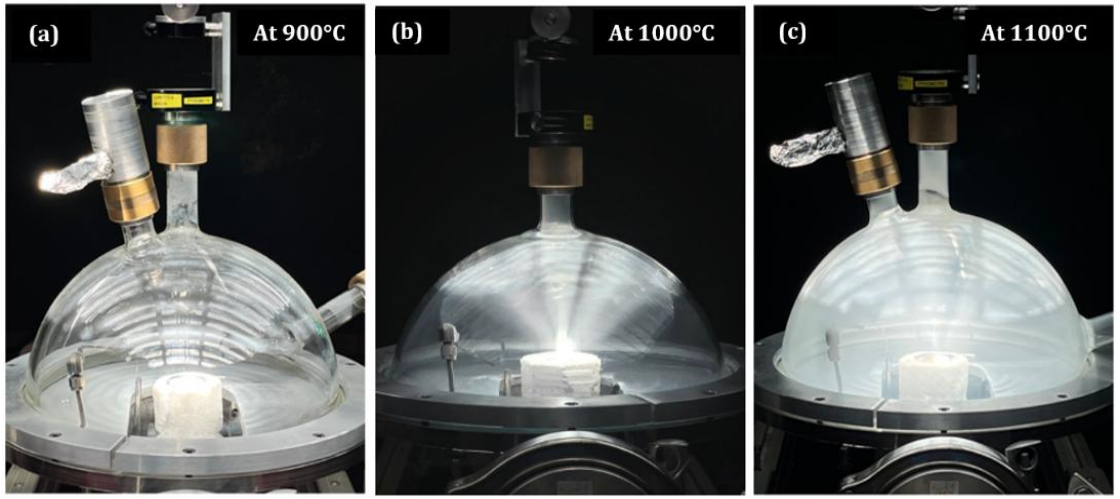
Experimental Results - XRD Analysis

Analysis of reactor deposits after treatment at 1100°C for 45 minutes with 1:1 molar ratio

(a)

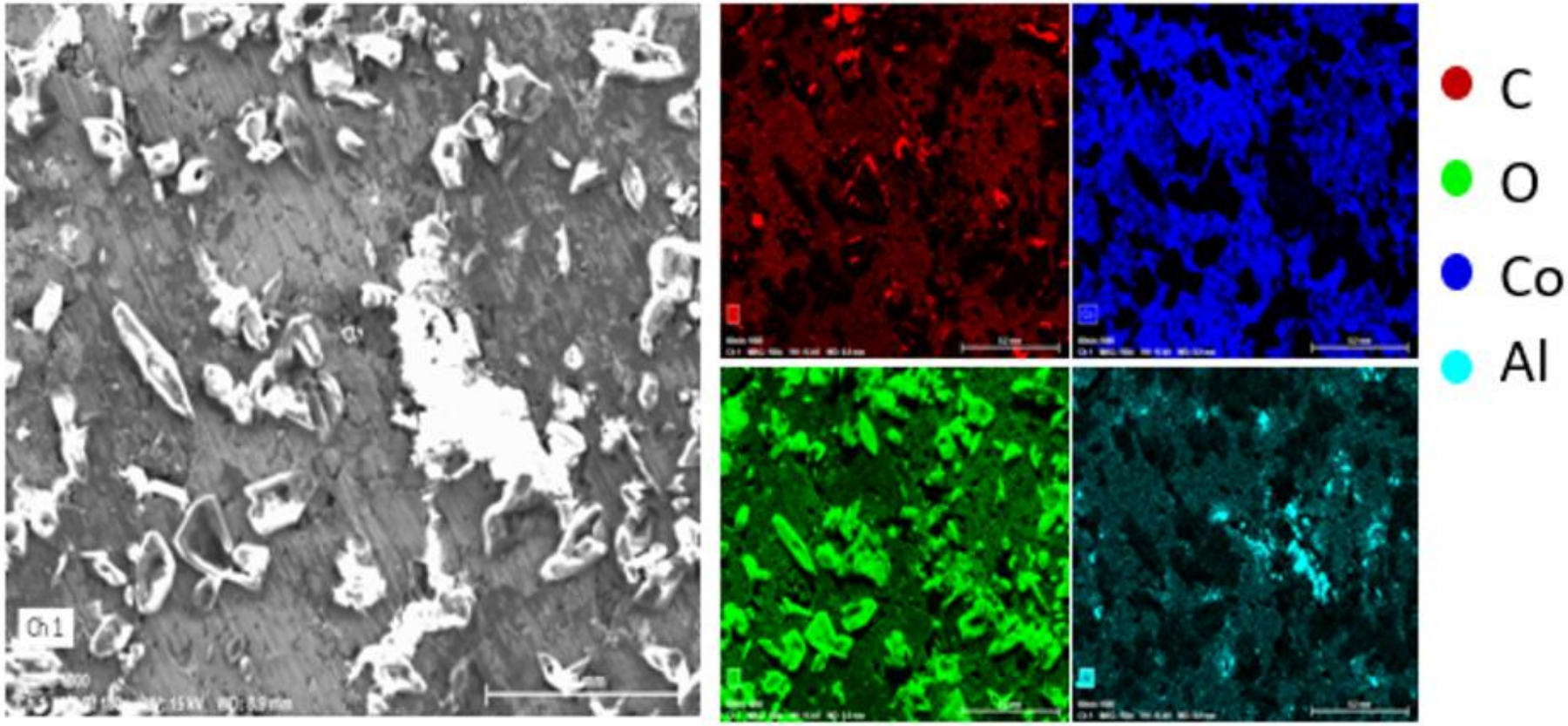
(b)





SEM mapping

Interaction of the sample at 1000 °C for 45 min in an Al_2O_3 crucible



Next Steps

Application to complex materials: Extend the process to NMC and NCA cathodes.
Scale-up from lab to pilot scale: Develop a pilot process capable of recycling 1 kg of material using 30 kW of concentrated solar energy.

Acknowledgments & Questions

Thank you for your attention! Any questions?

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