Decoding Lithium Transformation Mechanisms in Biological Systems for Green Extraction and Waste Remediation

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Project Highlights:

- Multidisciplinary research integrating fieldwork, advanced molecular analysis, microscopy, and spectroscopy techniques to study biological lithium interactions.
- Aims to unravel biochemical pathways of lithium transformations and geochemical cycling in microorganisms and hyperaccumulating plants.
- Findings will drive the development of eco-friendly lithium biomining strategies, with global applications for lithium recovery and environmental remediation.

Overview:

Lithium (Li), the lightest metal element, has become an essential resource in the 21st century, critical for achieving sustainability goals and reducing greenhouse gas emissions. Its prominent role in lithium-ion batteries for electric vehicles and renewable energy storage has amplified demand (Ambrose and Kendall, 2020, Speirs et al., 2014). With global lithium needs projected to surpass $50 billion by 2030, developing efficient and environmentally sustainable extraction methods is crucial (Graham et al., 2021). Traditional extraction methods, such as hard rock mining and brine evaporation, are not only resource-intensive but also contribute significantly to environmental degradation (Mousavinezhad et al., 2024).

While newer technologies, like direct lithium extraction (DLE) — as utilised by Cornish Lithium in the UK to extract lithium from geothermal brine — show promise, they still raise considerable environmental concerns (Rentier et al., 2024, Farahbakhsh et al., 2024). Therefore, alternative approaches are needed that minimise ecological impact while meeting growing demand.

Biological processes, particularly those involving microorganisms and plants, offer a promising, eco-friendly solution for lithium recovery and waste remediation (Brune and Bayer, 2012). Certain microorganisms can bioleach lithium from mineral matrices (Zhao et al., 2023), while some plants show potential for hyperaccumulating lithium from contaminated soils (Miletić et al., 2024). These biologically based methods could lead to more sustainable lithium mining and environmental cleanup, with lower energy requirements and greater cost efficiency. **However, despite their promise, the underlying mechanisms driving lithium transformation and uptake in these systems remain poorly understood.**

The goal of this project is to systematically explore the mechanistic pathways that define lithium interactions with microorganisms and plants, particularly in relation to bioleaching, uptake, and chemical speciation transformations. By unravelling these complex interactions, the study seeks to refine bio-based lithium extraction methods and advance sustainable strategies for lithium recovery and environmental remediation.

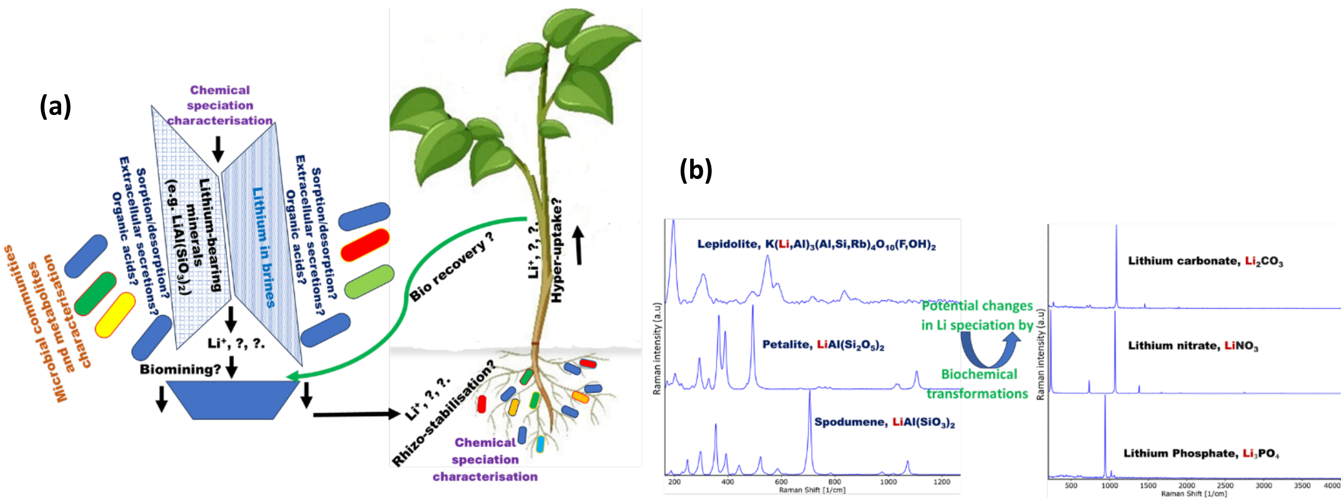

Figure 1: Illustration of (a) the project, depicting interactions between biological systems and lithium within mineral ores and brine, highlighting applications for recovery from contaminated sites, and (b) potential biochemically induced changes in lithium speciation as revealed by Raman spectroscopy. Raman spectra were collected at the UK CoreMiS facility.

Methodology:

1. **Literature Review**: A comprehensive review of existing research on lithium geochemistry, biomining, and bioremediation will be conducted. This will provide a foundational understanding of current knowledge gaps and help guide experimental design.

2. **Fieldwork and Sampling**: Fieldwork will involve the collection of lithium-rich samples from diverse sources, including lithium-bearing rocks, brine pools, and lithium-contaminated waste sites. These samples will be used to study natural microbial and plant interactions with lithium under different environmental conditions, enabling an analysis of real-world lithium bioavailability.

3. **Metagenomics, Transcriptomics and Metabolomics**: These analyses will be utilised to identify the microbial communities within the samples. This will uncover specific genes, enzymes, and metabolites associated with lithium transformation. By examining microbial genomes and expression profiles, the project will identify the key microbial contributors and molecular processes involved in lithium biogeochemistry.

4. **Advanced Micro-Spectroscopy with Ionomics and Isotope Tracing**: A novel correlative micro-spectroscopic approach will be developed to investigate biological lithium. This will be combined with ionomics and isotope tracing to monitor lithium speciation, bioavailability, and uptake.

Possible Timeline

Year 1: Conduct a comprehensive review of lithium geochemistry and biomining. Refine research questions and experimental design. Select field sites and prepare sampling protocols. Collect lithium-rich samples from rocks, brine, and waste sites. Sequence microbial communities and identify lithium-related genes and pathways.

Year 2: Conduct experiments on lithium uptake in hyperaccumulating plants. Perform ionomics to analyse lithium in plant tissues. Track lithium in microbial systems using isotope tracing analysis. Develop a novel micro-spectroscopic approach to study lithium transformations in microbial and plant systems.

Year 3: Integrate findings into mechanistic models of lithium biogeochemistry. Test engineered biological systems for enhanced lithium recovery and remediation. Complete thesis writing and submit for examination. Finalise and submit manuscripts for peer-reviewed publication.

Training and skills:

TARGET researchers will participate in a minimum of 40 days training over the 3.5 years of study composed of:

- an annual one-week workshop dedicated to their year group, and tailored to that cohort's needs in terms of skills development – *for the first three years of their study*;
- an annual all-TARGET workshop with cross-year interactions, advanced training and opportunities to specialise in particular areas – *all years of study*;
- a number of one-day workshops;
- additional online events and in-person workshops attached to relevant conferences.

The student will receive specialized training in field sampling and experimental design, as well as in plant and microbial culturing. They will also learn advanced molecular biology techniques, mass spectrometry, and morphological-chemical characterization techniques using electron microscopy, including Electron Energy Loss Spectroscopy (EELS) and Energy Dispersive X-ray Spectroscopy (EDX). Additionally, training will encompass Raman and Fourier Transform Infrared (FTIR) spectroscopy.

Partners and collaboration (including CASE):

The student will be based at the School of Earth and Environment, University of Leeds, and will spend time at the Camborne School of Mines, University of Exeter. There, they will engage in mining education and collaborate with ongoing research on lithium geochemistry, gaining access to geological lithium samples from the UK and Canada. The student will also have access to the UK Centre for Correlative Microscopy and Spectroscopy at the UK Centre for Ecology and Hydrology, which houses advanced facilities, including a correlative Raman Imaging Scanning Electron Energy Dispersive Spectroscopy (RISE-EDS) system (*http://www.ceh.ac.uk/coremis)*. This equipment will be integral for investigating lithium chemical transformations within this project.

Further details:

Please visit https://target.le.ac.uk/ for additional details on how to apply.

For more information about this project, please contact GboAde@ceh.ac.uk

Further reading:

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