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Dynamic Electron Transfer in Magnetite Biogeobatteries: The Impact of Day/Night Cycling on Iron-Oxidising and Iron-Reducing Bacteria

STEFANIE A. HETZ AND JAMES M. BYRNE
University of Bristol

Biogeobatteries facilitate the metabolic activities of microorganisms by enabling electron transfer processes, which are essential for biogeochemical cycling. Magnetite, a mixed-valence iron oxide, has been identified as an effective biogeobattery, serving as both an electron donor and acceptor in iron (Fe) redox cycling - a critical environmental process. This study aims to explore how magnetite biogeobatteries enhance electron transfer and redox cycling between iron-oxidising and iron-reducing bacteria. We investigate the dynamics of iron transformations by employing a combination of in-operando and ex-situ techniques.

Iron-oxidising bacteria, *Rhodobacter* (*R.*) *ferrooxidans* SW2, and iron-reducing bacteria, *Geobacter* (*G.*) *sulfurreducens*, were cultured on magnetite to assess their impact on electron transfer and redox cycling. The study simulated day/night cycling to reflect the natural conditions for *R. ferrooxidans* SW2, a photoferrotrophic bacterium, to observe the effects of light on Fe-oxidation and Fe-reduction processes. During the day, *R. ferrooxidans* SW2 actively oxidises Fe(II) to Fe(III) using light energy, while at night, *G. sulfurreducens* reduces Fe(III) back to Fe(II), creating a continuous cycle of electron transfer and redox transformations. This dynamic interaction between the two bacteria enhances the efficiency and sustainability of the biogeobattery system.

Dynamic changes in iron species concentrations can indicate active iron reduction and oxidation processes. Fourier-transform infrared spectroscopy (FTIR) analysis will provide spectral changes corresponding to the transformation of iron phases. In contrast, Mössbauer spectroscopy offers detailed insights into the iron compounds' mineral structure. Magnetic susceptibility measurements will be used to monitor changes in the magnetic properties of the samples, indicating redox transformations. X-ray diffraction (XRD) will identify and quantify the crystalline phases of iron minerals. Transmission electron microscopy (TEM) will provide high-resolution images of the bacterial interactions with magnetite at the nanoscale.

The findings offer valuable insights into the potential application of magnetite biogeobatteries for sustainable energy solutions, demonstrating their capability to sustain prolonged electron transfer cycles and achieve efficient energy conversion. This research underscores the feasibility of employing magnetite biogeobatteries in environmental remediation and renewable energy technologies, thereby contributing to the advancement of sustainable and eco-friendly innovations.