Technology Offer

ATP Production from Electricity

A new-to-nature electrobiological module powering ATP synthesis directly from electrons

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Harnessing electrical energy to power biology, researchers at the Max Planck Institute for Terrestrial Microbiology have developed the AAA cycle — a membrane-free, four-enzyme cascade that converts electrons directly into ATP. Operating at −0.6 V with up to 47% faradaic efficiency, this modular system enables continuous ATP regeneration for cell-free protein synthesis, biocatalysis, and metabolic engineering — without sacrificial co-substrates or complex membranes.

Background

Electrical energy is a clean, programmable input that could directly power biological work if converted efficiently into biochemical currency. Yet the regeneration of ATP, the universal energy carrier for biosynthesis, information processing, and homeostasis, has been a long-standing challenge. Conventionally, ATP regeneration relies on membrane-bound phosphorylation or sacrificial small-molecule donors that add complexity and waste. Existing ATP regeneration in cell-free systems suffers from cost, by-product accumulation, or limited scalability, constraining continuous operations and integration with electrosynthesis. Bridging electrochemistry and biocatalysis therefore requires routes that interface electrodes with enzyme networks while maintaining high efficiency, stability, and control over reaction conditions.

Technology

Researchers from the Max-Planck-Institute for terrestrial microbiology have developed a new-to-nature electrobiological module, converting electrical energy into ATP. The so-called acid/aldehyde-ATP (AAA) cycle couples an electrochemical reductant to a four-enzyme, membrane-free cascade that converts a carboxylic acid to an acyl phosphate and then to ATP via a carboxylic acid kinase. The inventors have already realized a propionate-based version, which operates from -0.6 V vs. standard hydrogen Electrode (SHE) with continuous ATP regeneration and faradaic efficiencies up to 47%, and is compatible with IVT/IVTT and acyl-phosphate-driven chemistry.

Advantages

- Minimal, membrane-free ATP module using a defined four-enzyme cascade
- Electricity-to-ATP conversion at −0.6 V with up to 47% faradaic efficiency
- Deployable with cell-free transcription/translation and ATP-coupled biocatalysis
- Tunable enzyme/electron-carrier sets; integrates with electrochemical cells

Applications

Continuous ATP supply for in vitro protein/RNA synthesis, metabolic prototyping, electrobio-catalytic synthesis (e.g., glucose-6-phosphate), and energy/information storage workflows.

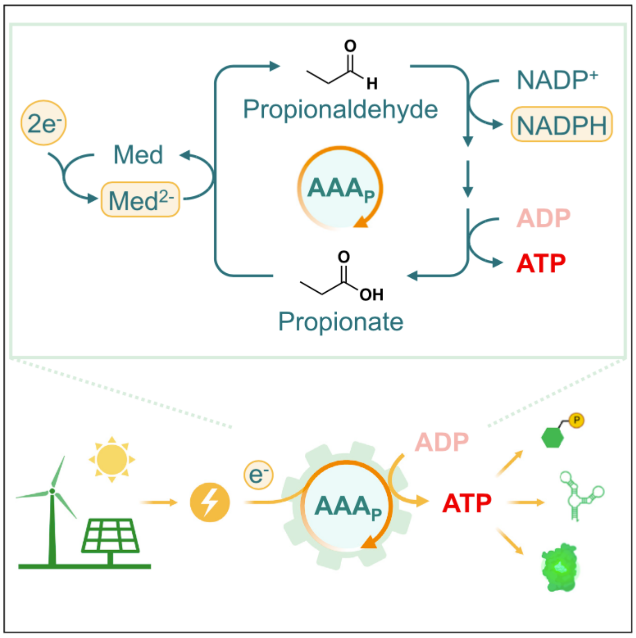

__Figure 1__ The AAA cycle: Continuous production of the biological energy carrier ATP from electricity (Luo et al. 2023).

Publication

Luo et al., ATP production from electricity with a new-to-nature electrobiological module, Joule, 2023; DOI: **10.1016/j.joule.2023.07.012**

Patent Information

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