

Monitoring and Accessing Cellular Photosynthesis Electrical Energy for Bioelectricity

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Objective: Plants have developed sophisticated solar energy capture mechanisms that may be adapted to be less expensive or perform better than current photovoltaic solar energy collectors. An electrical potential difference exists after solar energy splits water into oxygen, protons, and electrons in the chloroplast of photosynthetic cells. The investigators will explore the possibility of capturing electricity directly from living biological cells by inserting nano-scale electrodes into their chloroplasts.

Background: The photosynthetic apparatus, housed in the chloroplasts of photosynthetic eukaryotic cells, uses light energy to oxidize water and generate a charge separation across the thylakoid membranes, as shown schematically Figure 1. This apparatus is comprised of two photosystems, designated PS I and PS II, and a series of electron carriers including plastoquinone, plastocyanin, the cytochrome b_6/f complex, and ferredoxin. Light absorption by the photosystems splits water to produce oxygen, protons, and high energy electrons that are normally used to reduce carbon dioxide in the atmosphere. The oxygen and protons are generated in the thylakoid lumen on the oxidizing side of PS II. The electrons derived from the reaction center of PS II are transferred to PS I through a series of electron carriers. Excitation of PS I causes electron transfer to ferredoxin, a mobile electron carrier located on the stromal surface of the thylakoid membranes. This energy carrier may be the source from which high energy electrons can most readily be captured by nano-probes.

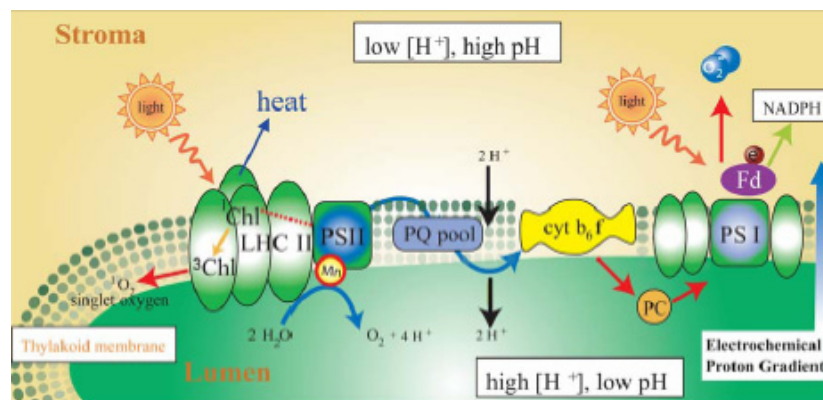


Figure 1: Electron transfer steps in photosynthesis

Approach: The geometry of *C. reinhardtii* cells and their mutant derivations make them good candidates for the exploration of bioelectricity with electrodes (see Figure 2). The cell has a

single cup-shaped chloroplast that can occupy nearly half of the volume of the cytoplasm. Furthermore, the chloroplast contains an extensive array of stacked and unstacked thylakoid membranes. The stacking features as well as the extent of thylakoid membranes present in the chloroplast can be controlled by the intensity of light in which the organism is grown. Therefore, the chloroplast stroma and the lumen of the thylakoid membranes offer targets that are sufficiently large for localization of electrodes.

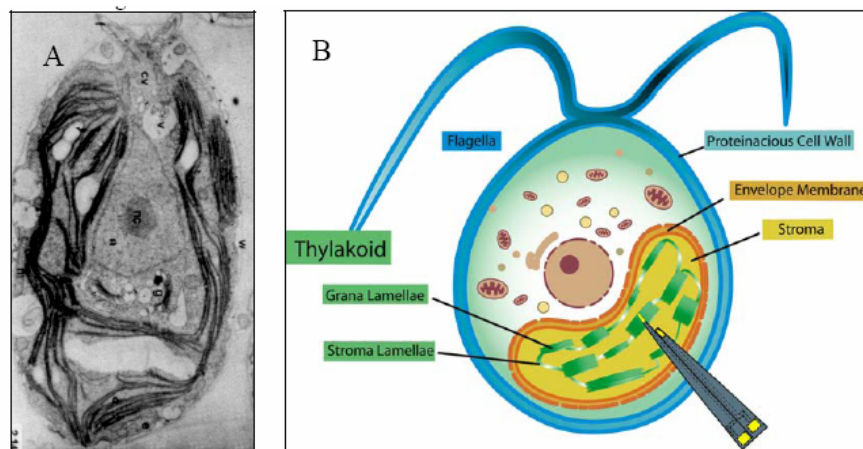


Figure 2: A) *C. reinhardtii* electron microscope image; B) Schematic depicting *C. reinhardtii* anatomy with an inserted probe spanning the stroma and the lumen of the grana thylakoid membranes.

Micrometer long, high-aspect-ratio electrochemical probes with silicon based tips will be developed. These probes will serve as a sensor to monitor electrochemical reactions inside the cell and as an electron collector and donor in the stroma and thylakoid for the extraction of bioelectricity. Micro-manipulators or an atomic force microscope (AFM) will be used to position the probes.

Generation of bioelectricity will occur by placing the anodic electrode in the stroma of the chloroplast and the cathodic electrode in the lumen, as shown in Figure 2B. The anode will accept high energy electrons from the reduced electron carrier ferredoxin, pass them through an external circuit to capture electrical energy, and combine them with protons and oxygen to produce water. The cell voltage is estimated to be about 1.1 V.

Once energy can be extracted from single cells, efforts will be expanded to create cell arrays. Collections of cells pre-oriented by a light stimulus would be embedded in a hydrogel matrix layer for ease of manipulation. This layer will be assembled with a micro-probe electrode array linked to the cells chloroplasts. Electricity generated by panels of these oriented populations of algal cells could contribute to clean bioenergy production.

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