# Cyborg Bacteria Based Solar Panel: A Promising Way towards Bioenergy

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***Abstract*-- In today's race towards finding clean renewable energy sources, solar energy has always been much focused area. While inventing numerous ways to extract solar energy most efficiently, there has been negligence towards natural and efficient way that nature has developed billions of years ago i.e. photosynthesis. This paper elaborates a way to make solar power more effective by mimicking the natural photosynthesis process more efficiently than plants. In this paper, cyborg bacteria is given focus that mimics what happens in plants and could potentially create an endless, relatively inexpensive and most importantly much efficient supply of electric power. A cyborg bacteria that converts sunlight and carbon dioxide to acetic acid by synthesizing its own tiny solar panels is the basis for artificial photosynthesis. This process is stable and self-replicating thus making this process as zero waste technology.**

***Keywords—Cyborg Bacteria, Solar panel, Bioenergy, Artificial Photosynthesis***

## INTRODUCTION:

Photosynthesisprovides energy for the vast majority of life on earth. But chlorophyll the green pigment that plants use to harvest sunlight, is relatively inefficient. The energy available in sunlight is an untapped resource that has only begun to really get a handle on. Improving natural photosynthesis can enable the sustainable production of chemicals. However neither purely artificial nor purely biological approaches seem poised to realize the potential of solar to chemical synthesis. There has been development in the approach come up whereby combination of highly efficient light harvesting of inorganic semiconductors with high specificity, low cost and self-replication and repair of bio-catalyst. Current photovoltaic – cell technology, is expensive, not terribly efficient and does only instant conversions. But an artificial photosynthesis system using cyborg bacteria that mimics what happens in plants could potentially create an endless, relatively inexpensive supply of electrical power. To enable humans capture more of the suns energy than natural photo-synthesis, bacteria can be covered in tiny, highly efficient solar panels to produce useful compounds.

This artificial photosynthesis can help provide a clean energy source by efficiently converting solar energy into large amounts of electricity.Harnessing inorganic semiconductors that can capture sunlight to organisms such as bacteria that can then use the energy to produce useful chemicals from carbon dioxide and water. To supercharge non-photosynthetic bacteria by providing them energy in the form of electrons from inorganic semiconductors, like cadmium sulfide, that are efficient light absorbers.

What is a cyborg? One might imagine Terminator-esqe half-human, half-machine hybrids or other creatures with fantastic mechanical augmentations, but we must direct our attention down to the cellular level—to cyborgian beings that are far smaller. Despite these cyborgs' underwhelming size, researchers have engineered a new biohybrid bacteria that may make a formidable impact on the solar fuel industry.1 These originally non-photosynthetic organisms are able to grow their own tiny semiconductor "solar panels" to harness solar energy and store it in the chemical bonds of acetate, an essential natural and industrial building block (1).

## WHAT IS SOLAR FUEL?

According to the Royal Society of Chemistry, more energy is delivered to Earth in one hour by the sun than all the energy that we consume through fossil fuels, nuclear energy, and other renewable sources of energy in a year (2). Plants and other photosynthetic organisms have mastered the process of capturing and storing this solar energy in chemical fuels or "solar fuels" (2). Since the 1950s, scientists have strived to mimic these processes to create more sustainable alternatives to traditional energy sources such as fossil fuels (2). Unlike the energy generated by other sources of renewable energy, like photovoltaic cells and wind turbines, the physical nature of solar fuels means that they can be much more easily stored and transported through existing distribution networks and methods.

Acetate and other carbon-based solar fuels can be used as feedstock, or raw material, for the production of many products such as fertilizers, pharmaceuticals, and plastics (2). Currently, the petrochemical industry produces much of the feedstock for these industries. However, solar fuel-derived feedstock, in addition to being more renewable, reduces the harmful greenhouse gas emissions.

## PHOTOSYNTHETIC BIOHYBRID SYSTEMS

Humans have developed incredible scientific and technological capabilities so far as to not only replicate some of the most complicated biological and chemical systems in nature but also surpass them in efficiency. Nevertheless, some processes, like the conversion of CO2 and other small atmospheric molecules to more complex organic molecules, have been more difficult to mimic (3).The reduction of, or the addition of electrons to, CO2 is surprisingly difficult. Electrons must be transferred from some catalyst, or an electron carrier, to CO2 , and new carbon-to-carbon bonds must form (3). Furthermore, as each process and chemical reaction in the biological world is highly specific in its reactants and products, scientists also have to replicate the high-accuracy selection of a single product (3). Attempts to reproduce these processes in the lab have often ended in tangles of chemical problems that seem to contradict one another, yet biological organisms have evolved so that the cell is able to incubate and facilitate a vast number of diverse reactions through a delicately-regulated chemical environment.

As a result researchers have developed photosynthetic biohybrid systems (PBSs) to take advantage of the existing biological systems that have been developed so elegantly through evolution (3). By combining these systems with high-efficiency inorganic light harvesters, they are able to enhance or induce photosynthetic capabilities in organisms (3). The key challenge of this field has been smoothly integrating the biotic and abiotic components of the PBSs. Some PBSs feed electrons collected by an inorganic light harvester to the biological part of the system, though engineering and producing nanowire arrays and intricate carbon cloths to do so can be costly (4). Other researchers have developed PBSs by isolating specific enzymes, such as hydrogenases, and combining them with semiconductor nanoparticles (4). However, whole-cell PBSs are favored due to their self-replication and self-repair capabilities (4).

Sakimoto et al., on the other hand, have been able to engineer microorganisms that not only facilitate CO2 reduction, but also synthesize their own inorganic light harvester materials (3). Sakimoto's team discovered that the introduction of Cd2+ (cadmium) ions to initially non-photosynthetic Moorella thermoacetica bacteria can induce the bio-precipitation of cadmium-sulfide (CdS) nanoparticles on the cell surface (4). The growth of these semiconductor light harvesters is able to transform the M. thermoacetica bacteria into highly efficient photosynthetic systems, producing products that are 90% acetic acid and 10% biomass (4).

Since the bacteria are able to produce their own inorganic semiconductor light harvester particles, Sakimoto et al.'s new PBS is cost-effective (4). The complex micro-fabrication techniques, high-purity reagents, and high-temperature processes are essential in synthesizing the semiconductor components in PBSs, but they are incredibly energy and resource intensive (4). Aside from the initial set-up of the system, Sakimoto et al.'s system requires very low maintenance, as the bacteria are able to remake the CdS particles even after the particles degrade (4).

## CYBORGIAN EVOLUTION

Sakimoto and colleagues aim to experiment with other semiconductor particles and bacterial species in order to optimize the efficiency of their PBS (4). Since cadmium sulfide is highly toxic, they hope to replace these nanoparticles with other less toxic semiconductor materials such as silicon (4). As other researchers strive to develop PBSs that not only reduce CO2 but also complete other crucial biological processes such as N2 fixation, Sakimoto et al.'s discovery may signify the advent of a new cyborgian evolution (3).

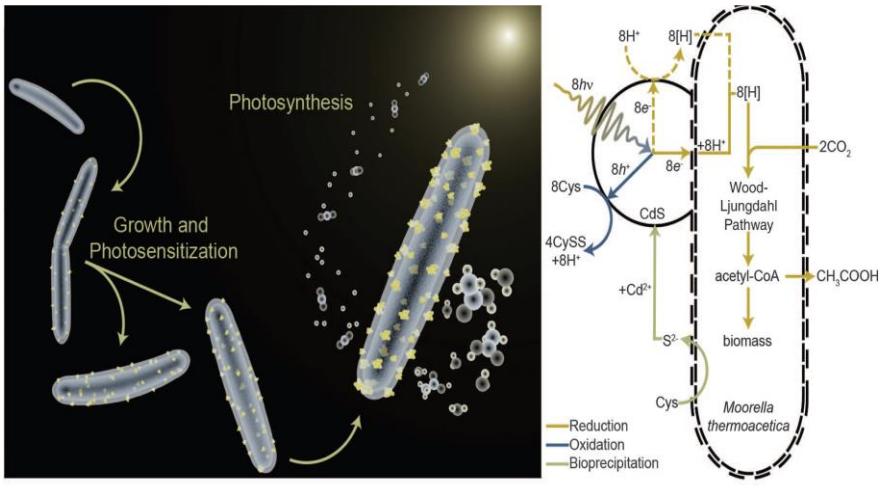


*Fig. 1. M. thermoacetica–CdS reaction schematics.*

*Fig.:1 (A)Depiction of the M. thermoacetica–CdS hybrid system, proceeding from the growth of the cells and bio precipitation (loading) of the CdS nanoparticles (shown in yellow) through photo-synthetic conversion of CO2 (center right) to acetic acid (right).*

*Fig.: (B)Pathway diagram for M. Thermoacetica- Cds system. Two possible roots to generate reducing equivalents, [H] , exist generation outside the cell (dashed line) or generation of direct electron transport to the cell (solid line). Hypo sized electron transfer pathways are presented.*

Although photosyntheticorganisms can precipitatesemiconductornanoparticles, their metabolicpathways are arguably less desirable thanthose of their nonphotosynthetic counterparts.Although gene modification of phototrophs has progressed (5), non-photosynthetic bacteria remaintheworkhorse ofsynthetic biology, offering a facileway to tailor the product diversity from CO2 reduction(6).Additionally, thermodynamic comparisonsreveal substantial energetic advantagesto photosensitizing nonphotosynthetic CO2 reduction(17). Of particular interest is the Wood-Ljungdahl pathway, through which CO2 is reducedto acetyl coenzyme A (acetyl-CoA), a commonbiosynthetic intermediate, and eventually to aceticacid, both of which can be further upgraded tohigh-value products by wild-type and geneticallyengineered organisms (8, 9).This pathway isalso used by CO2-fixing electrotrophs, enablingthe use of semiconductor photoelectrons in thisenergetically efficient biosynthetic route.We developed a hybrid system containingthe non-photosynthetic CO2-reducing bacteriumMoorella thermoacetica (ATCC 39073) and its biologicallyprecipitated CdS nanoparticles (10). CdSis a well-studied semiconductor with an appropriateband structure and is suitable for photosynthesis(11). As an acetogen and as

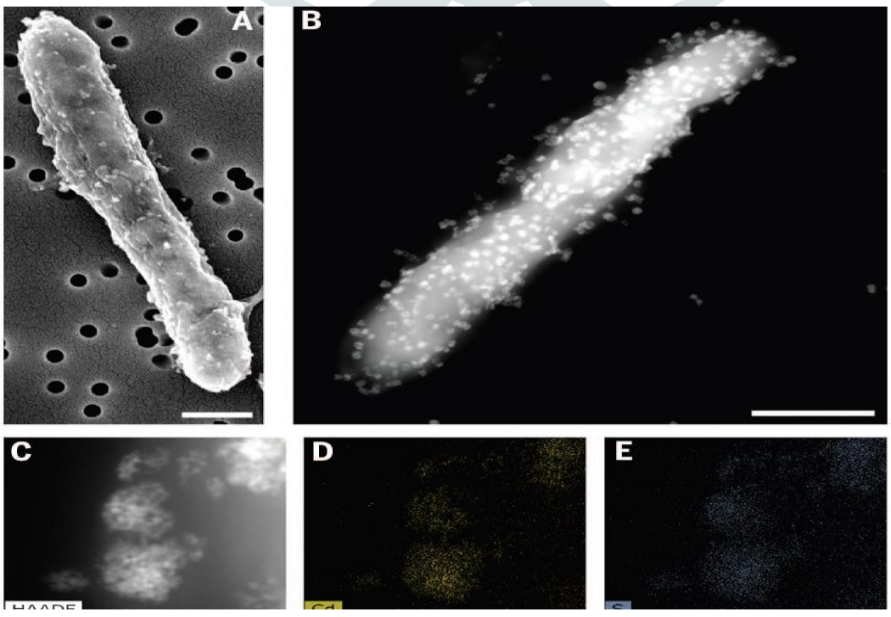

*Fig. 2. Electron microscopy of M. thermoacetica–CdS hybrids. (A) SEM image of CdS nanoparticles on M. thermoacetica. (B) High-angle annular dark field (HAADF) STEM image of a single cell, showing clusters across the entire cell surface. (C) HAADF image and EDS mapping showing clusters mainly composed of(D) cadmium and*
*(E) sulfur. Further elemental mapping is provided in fig. S3. Scale bars in (A) and (B), 500 nm; in (C) and (D), 50 nm.*

electrotrophs,M. thermoacetica serves as an ideal model organismto explore the capabilities of a hybridsystem (12). The photosynthesis of acetic acid by M. thermoaceticaand CdS is a two-step, one-pot synthesis(Fig. 1).

First, the precipitation of CdS byM. thermoacetica is triggered by the additionof Cd2+ and cysteine (Cys) as the sulfur source(10, 13). M. thermoacetica uses photogeneratedelectrons from illuminated CdS nanoparticles tocarry out photosynthesis (Fig. 1B). The absorptionof a photon, hn, by CdS produces an electron andhole pair, e– and h+. The electron generates areducing equivalent, [H] (see supplementary textand fig. S1 for elaboration of this process), that ispassed on to the Wood-Ljungdahl pathway to synthesizeacetic acid from CO2. Cysteine quenchesthe h+, leading to the oxidized disulfide form, cystine(CySS) (see supplementary text for the full setof reaction equations). The overall photosyntheticreaction is

2 CO2 + 8 Cys + 8 hn~~CH3COOH~~2H2O + 4 CySS

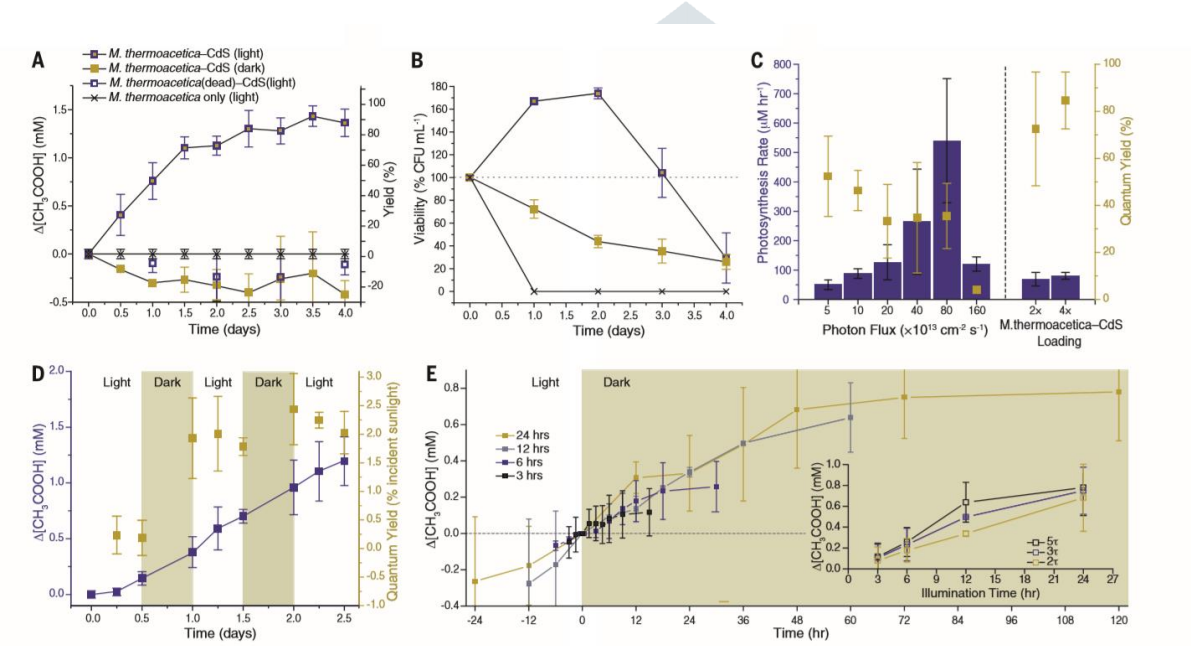


*Fig. 3. Photosynthesis behavior of M. thermoacetica–CdS hybrids. (A) Photosynthetic production of acetic acid by M. thermoacetica–CdS hybrids and deletional controls. The key applies to (A) and (B) only. (B) CFU viability assaysforM.thermoacetica–CdShybridsanddeletionalcontrols.(C)Rates of acetic acid production and quantum yields for increasing illumination intensities and M. thermoacetica–CdS concentrations. (D) Photosyntheticacetic acidproductionunder low-intensitysimulatedsunlightwithlight-dark cycles. (E) Acetic acid production under dark conditions for varying illumination times. The inset shows the relation between illumination time, t, and acetic acidyield underdarkconditionsat increasing multiplesof 't'. All points and error bars show the mean and error-propagated SD, respectively, of triplicate experiments.*

The M. thermoacetica–CdS system displays behavior that may help it to exceed the utility of natural photosynthesis. First, the quantum yield increased withhigher M. thermoacetica–CdS concentrations. The ability to tune theeffective light fluxperbacteriumbychangingtheconcentration ofthesuspensionisaconsiderableadvantageover similar light management practices in natural photosynthesis that are achieved through genetic engineeringofchloroplastexpression(14).Second, the catabolic energy loss observed during dark cyclesinnaturalphotosynthesiswasabsentinour hybridsystem,whichmaybean innatefeatureof theWood-Ljungdahlpathway,inwhichaceticacid is a waste product of normal respiration. Additionally, many plants and algae tend to store a large portion of their photosynthetic products as biomass, which requires extensive processing to produce useful chemicals. In contrast, the M. thermoacetica–CdS system directs ~90% of photosynthetic products toward acetic acid, reducing thecostof diversifying tootherchemicalproducts. This system could be improved by substitutingCys oxidation with a more beneficial oxidationreaction,suchasoxygenevolution,wastewater oxidation for water purification, or oxidative biomass conversion (15, 16). Expanding the material library available through biologically induced precipitation will increase the capacity for light absorption and raise the upper limit on semiconductor-bacteria photosynthetic efficiency. The availabilityofgeneticengineeringtoolsfor Thermoacetica (17), as well as the introduction of electro trophic and nanoparticle precipitation behavior in model bacteria such as Escherichia coli (18, 19), suggests a

potential role for synthetic biology in rationally designing such hybrid organisms. Beyondthedevelopmentofadvancedsolar- tochemicalsynthesisplatforms,thishybridorganism also has potential as a tool to study biological systems.Thenativeintegrationofsemiconductor nanoparticles with bacterial metabolic processes provides a distinctive optical tag for the study of microbial behavior, such as semiconductorbacteria electron transfer (20, 21), by providing a sensitive, noninvasive, nonchemical probe.

## Conclusion:

Solar energy has a great potential as a clean, cheap, renewable and sustainable energy source, but it must be captured and transformed into useful forms of energy as plants do. Within this paper, work is being done to unravel the fundamental principal of photosynthesis that nature has developed billions of years ago. Thus, this paper focuses on cyborg bacteria embedded solar panel which can perform photosynthesis more efficiently than plants and by interrupting light reaction and extracting electrons for converting it to electrical energy. This can be far better replacement for current inefficient photovoltaic solar panels. This paper introduces a whole new concept of converting solar energy to electrical energy directly similarly to PV solar cells but instead of semiconductor materials, self-replicating, more efficient and zero waste cyborg bacteria to be used to mimic the process that is fundamental thing on the earth since billion years and provides us energy.

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