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Bionic Generation: A New Approach To Power Generation Reviewed.

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ABSTRACT

Photosynthesis has long been looked at as the gold standard for turning sunlight into energy and it only makes sense to look to plants for inspiration when building a new clean technology. Harvard and many other labs have been working on artificial leaves for years. Usually the result is a solar technology that when submerged in water or connected to a water source can split the water molecules into oxygen and hydrogen for use in a fuel cell. Last year, Harvard debuted their bionic leaf which goes beyond that and turns sunlight into liquid fuel. The system uses solar energy to split the water molecules, but also contains a hydrogen-eating bacterium that produces liquid fuel The new system converts sunlight into biomass at an efficiency of 10 percent, which is 10 times better than the one percent achieved by the fastest growing plants. The bionic leaf 2.0, they're using doesn't produce the reactive oxygen, making the system far more efficient and the new system can now produce many more fuels like Isobutanol, Isopentanol and PHB, a bio-plastic precursor.

Keywords: photosynthesis ,bionic leaves , electrolysis, power generation, catalyst.

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I. INTRODUCTION

BIONIC LEAF Scientists in U.S have beaten nature at its own game by creating a bio-mimic of leaf i.e. “BIONIC LEAF” that uses sunlight to create biomass. They released a new Artificial Photosynthesis System BIONIC LEAF 2.0. This technology uses sunlight to split water molecules & feed the hydrogen to bacteria which then produces liquid fuels. This is a “TRUE ARTIFICIAL PHOTOSYNTHESIS SYSTEM”. Professor Nocera designed a leaf which was made from a silicon strip coated with catalysts on both sides. This leaf produces oxygen & hydrogen from sunlight. Thus, these artificial leaves take solar energy & convert it into hydrogen which is further used in fuel cells. Researchers’ have designed a bionic leaf that not only uses solar energy to produce oxygen & hydrogen but it feeds this hydrogen to bacteria which are then engineered to make isopropanol. The hydrogen produced is channelled through a chamber filled with a bacterium called “Ralstonia Eutropha

IDEA BEHIND BIONIC LEAF The fundamental idea is to reverse combustion and use a remnant of fossil fuel burning—The CO2 piling up in the atmosphere—to build renewable fuels, just as plants do. But the bionic leaf will not compete on price anytime soon with the fossil fuels dug out of the ground, especially because the microbes do not yet make a lot of fuel quickly. The largest bionic leaf to date is in a one-litre pot, although the team has not discovered any limits to making it bigger**.** By knitting fuels out of the excess CO2 in the air, this new bioreactor could help mitigate planet-warming pollution problems while bringing cleaner fuels to people who do not currently have access to modern energy."By integrating the technology of biology and organic chemistry there is a very powerful path forward where you take the best of both worlds," he adds. "I took air plus sunlight plus water and I made stuff out of it, and I did it 10 times better than nature. That makes me feel good."Nocera says.

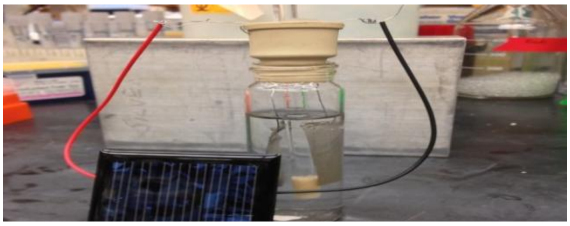

Figure 1.2 Practical Bionic Leaf 2.0

By breaking photosynthesis down into reactions, it becomes very clear that one reaction is the heart of it: water splitting. Water splitting is the process by which water is broken down into hydrogen gas (H2) and oxygen gas (O2). Luckily for us, Harvard University professor Daniel Nocera has already produced a catalyst, the “artificial leaf”, that is capable of breaking water into its component elements. While there are many water-splitting catalysts available, the artificial leaf is special for several reasons: it’s made of cheap materials, it operates at neutral pH (i.e. tap water), and it can be operated by ordinary solar panels. Therefore, an artificial leaf catalyst is capable of splitting water from one of the most abundant energy sources in the world: sunlight. The artificial leaf catalyst converts solar energy to H2 and O2 gasses. These are attractive fuels in principle but lack the infrastructure to be widely adopted in the near future. For example, without hydrogen filling stations for cars or hydrogen pipelines into homes, it’s difficult to imagine hydrogen rapidly replacing fossil fuels.

1.2.1 Microbe power

We decided to combine a futuristic fuel – hydrogen – with what can be considered old news: bacteria. The soil bacterium Ralstonia eutropha is an organism capable of growing mainly from H2 and carbon dioxide. We figured it would be possible to use the hydrogen generated from the artificial leaf to drive the growth of Ralstonia. And from that bacteria’s growth, we could get our desired product: a liquid fuel or chemical. Dubbed the “bionic leaf”, this system converts sunlight shining on a solar panel to electricity. Electricity travels to a glass vial containing liquid where both Ralstonia and the water-splitting catalyst are immersed. The electricity drives the catalyst to generate O2 and H2, which Ralstonia consumes along with bubbled carbon dioxide to grow. In the lab, we piped in carbon dioxide from a tank; in a commercial situation, we could use carbon dioxide emissions from a polluter, such as a power plant. Just like plants, the bionic leaf converts sunlight into “biomass” or, biological material. Here, we produced the alcohol isopropanol, a compound which can be used for the production of fuels. Where many terrestrial plants convert sunlight to biomass at an efficiency of about 1%, the bionic leaf does so at an efficiency of up to 3.2%. The key to this efficiency is the increased light harvest from solar panels to drive water splitting. The solar photovoltaic panels act as a sort of amplifier, increasing the amount of solar energy delivered to the bacteria-growth medium than what a typical plant can harvest. In addition to increased efficiency, this setup bridges the strengths of each technology. Solar panels are great at harvesting sunlight but storing energy is a challenge. Also, panels aren’t really designed to produce chemicals. Microbes, in contrast, can produce a wide range of high-value compounds but require constant “food” to grow - in this case, hydrogen, sunlight and CO2. By combining these technologies, solar energy produces the necessary molecules our Ralstonia require to grow and produce chemicals.

1.2.2 Potential for potential energy

After reconstructing photosynthesis, we set out to prove that the bionic leaf could be used to synthesize, or produce, chemicals. To do this, we used an Isopropanol-synthesizing Ralstonia strain engineered by Tony Sinskey’s lab at MIT. Our results provided the first proof-of-concept of solar-driven chemical synthesis for the bionic leaf. The bionic leaf was designed from the idea of personalized energy. Our current liquid fuel infrastructure – refineries, pipelines – is massive and optimized for fossil fuels and our design is unlikely to provide a comparable fuel yield in the near future. But the bionic leaf has lots of potential to perform as a decentralized source of off-grid power. One could imagine a portable, solar-powered bioreactor that is virtually impervious to physical or cyber attacks aimed at disabling a population’s power. Although replacing gasoline or diesel fuel with a solar fuel is tantalizing, the most practical application of the the bionic leaf is likely to translate as a chemical-producing box kept in your backyard. Because its only energy requirement is sunlight, the bionic leaf could also be used as a mobile energy source in countries that don’t already have a large liquid fuel infrastructure. We have only touched on the potential of the bionic leaf. Biology is truly the ultimate platform for chemical synthesis meaning there is a wide range of compounds we can theoretically produce. Ralstonia eutropha, for one, naturally produces bio plastic precursors in large quantities. With genetic engineering, one could imagine the solar-driven synthesis of drugs, materials, or high-value chemicals. The bionic leaf would then function more as a mobile lab than a fuel box. In addition to chemical synthesis, Ralstonia eutropha can also metabolize a great number of chemical pollutants. In that scenario, our current system could be modified to clean water.

1.3 How does the bionic leaf work?

You can think of a bionic leaf as a living battery that combines chemistry and biology. The process of splitting water into oxygen and hydrogen is powered by utilizing solar electricity from photovoltaic cells. Starved microbes are added to feed on the hydrogen, which converts and enables the release of carbon dioxide into the form of alcohol fuels. The first bionic leaf produced in 2015 could produce about 215 milligrams of alcohol fuel per litre of water; however, the catalyst that enabled the splitting of water molecules into hydrogen and oxygen atoms – nickel molybdenum zinc – was not compatible with the microbes as they would die of poisoning.

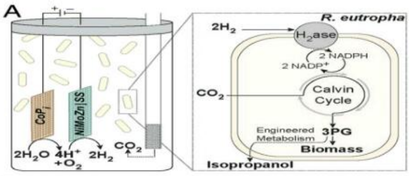

Figure 1.3 Formation of Isopropanol & Isobutanol

The Harvard team, which also includes post-doctoral researcher Dr. Chong Liu and graduate students Brendan C. Colón and Marika Ziesack, set out to find a new catalyst that would enable the splitting of water molecules without harming the microbes necessary for the experiment. The scientists found the answer in an amalgam used as a common anticorrosion agent – an alloy of phosphorus and cobalt. Phosphate in water is actually beneficial for living things – including half of the constituents of the new bionic leaf, a bacteria called Ralstonia eutropha. Running an electric current generated by photovoltaic cells into the phosphorus, cobalt and water solution splits the water molecules with the formation of the cobalt phosphide catalyst. The voltage of the photosynthesis device is also higher than needed in order to ensure the formation of the catalyst with an abundance of free electrons – without which the *Ralstonia eutropha* bacteria would perish and abruptly halt the splitting of water molecules. As a result, the catalyst never dies as the artificial system carries on creating energy. To date, the new photosynthesis device has been able to run continuously for 16 days. Furthermore, the cobalt phosphide catalyst manages to split water molecules without releasing reactive oxygen atoms, which can potentially damage DNA with the release of free radicals. The Harvard researchers have yet to figure out why that is, but it allowed the team to lower the voltage of the experiment, boosting the efficiency of bionic leaf 2.0 by a major increase. This was one of the major challenges of the first artificial photosynthesis device, bionic leaf 1.0. The nickel-molybdenum zinc alloy used as a catalyst to produce hydrogen would yield oxygen molecules stripped of their electrons. These oxygen ions would destroy the DNA of the bacteria and essentially kill it. Working around this problem, Harvard researchers had to run bionic leaf 1.0 at extremely high voltages, which dramatically lowered the efficiency of the system. But bionic leaf 2.0 does much more than match the 1% efficiency of a fast-growing natural photosynthesis system: the new artificial device has the potential to make 60 grams of Isopropanol fuel from 130 grams of carbon dioxide out of 230,000 litres of air in one kilowatt-hour of electricity. As mentioned earlier, this amounts to a vastly improved 10% efficiency. The new artificial photosynthesis system also offers the potential to generate much more than usable fuels. “The beauty of biology is it’s the world’s greatest chemist – biology can do chemistry we can’t do easily,” Pamela Silver was quoted as saying. She adds that the team now has the platform to create any downstream carbon-based molecule, and could, in theory, generate a variety of other products, making bionic leaf 2.0 extremely versatile. For instance, the Ralstonia eutropha bacteria could be used to generate a vast range of chemicals synthesized from fertilizers or other polluting sources, as well as the complex hydrocarbon molecules found in fossil fuels. In their Science paper, the Harvard team mentions they have used Ralstonia eutropha to make PHB – a molecule that can be transformed in certain types of plastics in a process initially proven by Massachusetts Institute of Technology professor Anthony Sinskey. Ultimately, the goal is to achieve reverse combustion, which would, in essence, recycle carbon dioxide waste into clean energy. A decade ago, scientists were burying the toxic by-product of fossil fuels instead of trying to efficiently convert waste back into energy. Today the Harvard team has established new grounds in taking water, sunlight, carbon dioxide and the right catalyst – in this case cobalt phosphide – to generate an alcoholic fuel. Cleaning up air by removing excess carbon dioxide could not only help contribute to the problem of global warming, but bring clean fuels to developing countries that lack the means to access modern energy.

"This science you can do in your backyard,” You don't need a multi-billion dollar massive infrastructure," Dr. Daniel Nocera says. "By integrating the technology of biology and organic chemistry there is a very powerful path forward where you take the best of both worlds," he adds. Using the principles of artificial photosynthesis, one bottle of drinking water could, in theory, provide enough energy to power an entire household in a developing country. A 10% efficiency exceeds the established 8% threshold needed to be considered for scalable and viable modern applications in today's world. Dr. Johannes Lischner, a Royal Society Fellow and Lecturer from the Faculty of Engineering, Department of Materials, Imperial College London, says this high efficiency is promising and calls the research "intriguing". He also adds that the real question is whether or not bionic leaf 2.0 will work as a real-world device. For instance, the system would likely encounter practical problems in developing countries that may not have the capabilities of accessing infrastructures necessary for storing solar energy. Another possible drawback is whether or not these biological systems could survive in harsh environments such as the Sahara desert. Dr. Daniel Nocera's goals are to bring his revolutionary technology to the developing world by working with the First 100 Watts program at Harvard, which contributed to research funding, and is also counting on the involvement of scientists from these developing nations. The Harvard team's work is also supported by the Office of Naval Research Multidisciplinary University Research Initiative Award, the Air Force Office of Scientific Research Grant, the Wyss Institute for Biologically Inspired Engineering, and the Harvard University Climate Change Solutions Fund.

II. RESULTS

Bio electrochemical Growth of R.eutropha H16 Driven by Earth- Abundant Water-Splitting Catalysts. A schematic of the system and the cell configuration used for the bio electrochemical experiments is shown in Fig. 1.

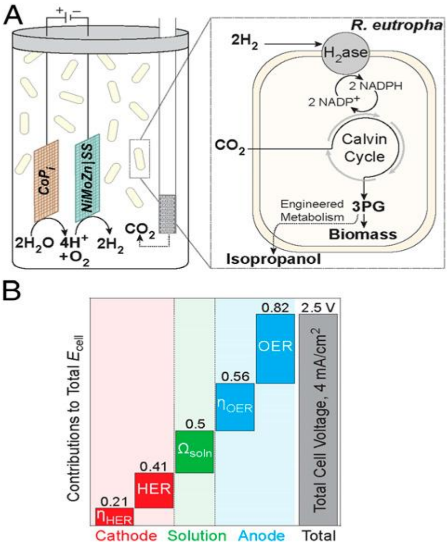

Figure 2.1 Schematic diagram of bio electrochemical cell.

(A) Water oxidation takes place at the cobalt phosphate (CoPi) anode with proton reduction taking place at the nickel molybdenum zinc (NiMoZn) or stainless-steel (SS) cathode. CO2 is continuously sparged into the cell. The wild-type (wt) bacterium Ralstonia eutropha (Re) H16 oxidizes H2 using oxygen-tolerant hydrogenases (H2ase) to generate reduced cofactors (e.g., NADPH) and ATP, and uses these to reduce CO2 to 3-phosphoglycerate (3PG) via the Calvin cycle. 3PG is then converted into biomass in wt ReH16 or may be diverted in metabolically engineered Re2133-pEG12 into isopropanol. (B) Voltage contributions from CoPi and NiMoZn water-splitting half-reactions, including overpotentials (η), and solution resistance (Ωsoln) components for a system driven at Ecell =2.5 V to achieve a current density of ∼4 mA/cm2 (averaged over 5 d).

R. eutropha was cultured in the cell using a CoPi anode and either NiMoZn electrodeposited on SS 304 mesh or plain SS mesh as a cathode. These electrodes furnished oxygen and hydrogen, respectively, which was the sole source of biological reducing equivalents. The electrolyte was a chloride-free minimal growth medium buffered at pH 7.0 with 36 mM phosphate (Materials and Methods), and the solution was saturated with gaseous CO2. The cell voltage, Ecell, was operated in the range of 1.8–3.0 V, with current densities ranging between 0.5 and 11 mA/cm2.

The potential Ecell required for water-splitting current in excess of 2 mA/cm2 was between 2.0 and 2.3 V (SI Appendix, Fig. S1), which is higher than the potentials needed for the CoPi j NiMoZn system in buffer solutions for two reasons. First, the solution resistivity of the growth medium was measured to be significantly higher (Ωsoln = 62.4 Ω) than normal water-splitting conditions owing to a relatively low overall salt concentration; the solution resistance translates to a solution voltage of ∼0.5 V at 4 mA/cm2 of current. Second, in the presence of the growth medium, the OER (ηOER) and HER (ηHER) over potentials are higher than in buffered solutions. The ηOER was determined from the Tafel plot for CoPi in the growth media (SI Appendix, Fig. S2) to be ηOER = 0.56 V vs. 0.53 V (at 4 mA/cm2) in 0.1 M KPi (pH 7.0) for typical water splitting conditions. Using the foregoing measured values and thermodynamic values for OER and HER of E°′ OER = 0.815 and E°′ OER = 0.413 V vs. NHE, respectively, at pH 7, the ηHER may be determined from the following: ηHER =Ecell −h_E°′ OER + ηOER_+Ωsoln +E°′HERi: [1]

The relative contributions of the CoPi anode, NiMoZn cathode, and solution resistivity to the overall cell potential, Ecell = 2.5 V, operating at a current density of 4 mA/cm2 is schematically summarized in Fig. 1B. We observed consistent growth of R. eutropha for Ecell ≥ 2.7 V (Fig. 2 A and B). Growth at 2.3 V is achievable after an extended lag phase, and occasionally a long lag phase is observed even at higher voltages (data not included in Fig. 2A). We note that CoPi j NiMoZn electrodes and R. eutropha were reciprocally compatible under applied potentials: CoPi and NiMoZn electrodes permitted biological growth, and conversely, biological growth did not oppose long-term catalyst function

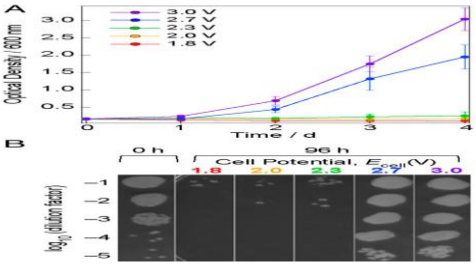

Fig.2.2 Cell growth of R.eutropha. (A) Time course of R. eutropha cell growth by monitoring OD at 600 nm, using a CoPi anode and NiMoZn cathode poised at a range of total cell potentials (Ecell); currents obtained at each of these cell potentials are shown in SI Appendix, Fig. S1. Error bars represent SEM with n = 3–5 independent experiments at each potential. (B) Spot assays of R. eutropha before starting electrolysis (0 h), and after 96 h of Electrolysis with CoPi/NiMoZn electrodes, as a function of Ecell.

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