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ARTIFICIAL PHOTOSYNTHESIS ENERGY

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ABSTRACT

Artificial photosynthesis is a chemical process that replicates the natural process of photosynthesis, a process that converts sunlight, water, and carbon dioxide into carbohydrates and oxygen. The term is commonly used to refer to any scheme for capturing and storing the energy from sunlight in the chemical bonds of a fuel (a solar fuel). Photocatalytic water splitting converts water into protons (and eventually hydrogen) and oxygen, and is a main research area in artificial photosynthesis. Light-driven carbon dioxide reduction is another studied process, replicating natural carbon fixation.Research developed in this field encompasses design and assembly of devices (and their components) for the direct production of solar fuels, photoelectrochemistry and its application in fuel cells, and engineering of enzymes and photoautotrophic microorganisms for microbial biofuel and biohydrogen production from sunlight. Many, if not most, of the artificial approaches are bio-inspired, i.e., they rely on biomimetics .Since the 1950s scientists have been developing systems to produce solar fuels using artificial photosynthesis, natural photosynthesis and thermo chemical routes. The term is commonly used to refer to any scheme for capturing and storing the energy from sunlight in the chemical bonds of a fuel (a solar fuel). Photo catalytic water splitting converts water into protons (and eventually hydrogen) and oxygen, and is a main research area in artificial photosynthesis. Light-driven carbon dioxide reduction is another studied process, replicating natural carbon fixation.Research developed in this field encompasses design and assembly of devices (and their components) for the direct production of solar fuels, photo electrochemistry and its application in fuel cells, and engineering of enzymes and photoautotrophic microorganisms for microbial biofuel and biohydrogen production from sunlight. Many, if not most, of the artificial approaches are bio-inspired, i.e., they rely on biomimetics.

Keywords: Artificial photosynthesis, energy

Introduction

By making a solar photovoltaic material more resilient, researchers may have found a way to make artificial photosynthesis—that is, using sunlight to make fuel—cheap enough to compete with fossil fuels. For several decades, scientists have pursued the possibility of producing solar fuels in the laboratory. There are three approaches: Artificial photosynthesis in which systems made by human beings mimic the natural process, also called artificial leaves; Natural photosynthesis; and Thermo chemical approaches. Natural photosynthesis in plants is not very efficient in converting solar energy to chemical energy. Most plants have an efficiency of less than 1 per cent. With potential conversion rates of 5-10% photosynthesis in algae or cyan bacteria is more efficient. The theoretical limit for artificial photosynthesis is around 40%, and conversion rates of 18-20% seem achievable. Over the last ten years the drive to develop systems that produce solar fuels on large scale has been an area of increasingly intense research activity in the United States, Europe and East Asia. It is also now attracting commercial interest in the form of spin-off companies such as Sun Catalytic that was founded to commercialize a low-cost catalyst developed by Professor Daniel Nocera. The company raised venture capital and landed an ARPA-E grant for a material that can produce hydrogen from water directly from solar energy [1] [2].

Scientists have made significant progress in producing two very important types of fuels: Hydrogen can be used as a transport fuel, and is also an important feedstock for industry. Hydrogen can be produced by splitting water using sunlight. Carbon-based fuels such as methane and carbon monoxide. These are key feedstock for making a wide range of industrial products including fertilizers, pharmaceuticals, plastics and synthetic liquid fuels. Carbon-based fuels can be produced using sunlight, carbon dioxide and water. Carbon monoxide is used with hydrogen as synthesis gas. How solar fuels will change future energy options the route from laboratory prototype systems to commercial technologies is still long. However, if the production of solar fuels is achieved on a large scale, it would not only transform our sustainable energy options by providing alternatives to fossil fuels for transport, industry and electricity generation, it could also transform the energy infrastructure.

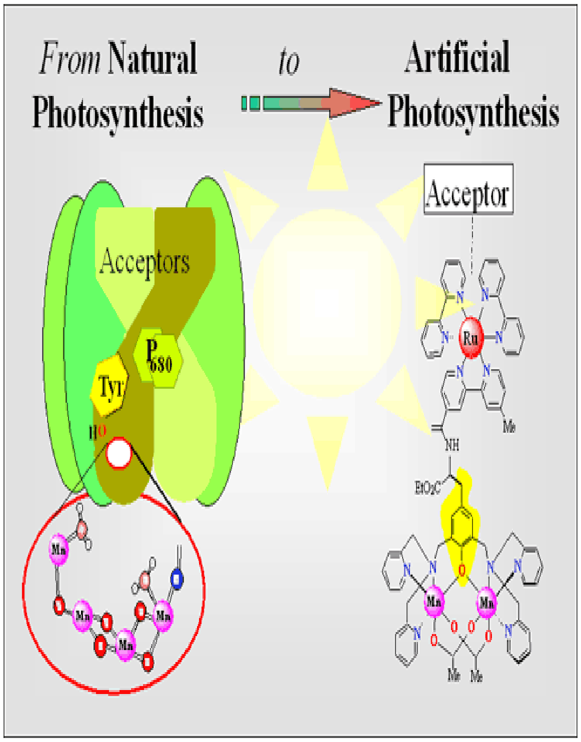

Figure 1 (www.kemi.uu.se)(In artificial photosynthesis, solar energy is harvested by a Rutenium center and is used to form a valuable product)(Project design showing a synthetic Ru-Mn complex and Photosystem II. The Figure high lights some principles that are followed in the project. In Photosystem II, chlorophylls harvest energy in light (green antenna and P680) and use this energy to drive photosynhesis. In particular a complex of 4 Mn-ions and a Tyrosine interact to oxidize water. In the Artificial molecules a Rutenium center is linked via a tyrosine analogue to a bi-nuclear Mn-center intended to accomplish water oxidation.[3])

Scientific approaches to producing solar fuels

Solar fuels refer to the process where energy from the sun is captured and stored in the chemical bonds of a material. Photosynthesis is the blueprint for this procedure. For over half a century, scientists have pursued the possibility of producing solar fuels. There are three main approaches

1- Artificial photosynthesis

2- Natural photosynthesis

3- Thermo chemical approaches

Artificial photosynthesis

Artificial photosynthesis refers to the construction of a bio-inspired device that directly converts energy from the sun into fuel. Such a device will almost certainly use the same basic steps as used in photosynthesis: light harvesting, charge separation, water splitting and fuel production. This is a very active field of research. Such a device can, potentially, yield a much higher efficiency compared to other methods of solar-to-fuel conversion: in theory up to 42 %.[5]

Artificial photosynthesis requires the expertise of all of these communities working together to address key challenges such as:

1- Integrating the different processes and materials involved, from capturing and channeling sunlight through to producing a chemical fuel; identifying inexpensive catalysts.

2- Developing ways to avoid the system degrading quickly because of exposure to sunlight.

Plants have had millions of years to improve upon photosynthesis, and most green plants are fairly efficient at it, locking down up to 6 percent of the solar energy that strikes a leaf's surface. Modern solar PV systems can achieve three times higher efficiency. Nonetheless, artificial systems that mimic natural photosynthesis typically don't provide direct electrical output, as does solar PV. Instead, they use readily available water sources to create a stream of hydrogen that can be stored and burned as fuel. Exploring natural photosynthesis helps tease out the secrets plants have as model systems for larger fuel production.

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In artificial photosynthesis, scientists are essentially conducting the same fundamental process that occurs in natural photosynthesis but with simpler nanostructures. The fabrication of these nanostructures has only recently been possible due to breakthroughs in nanotechnology in the areas of imaging and manipulation. With the core processes in photosynthesis being light gathering, charge separation, and recombination, the goal of scientists has been to create efficient synthetic nanostructures that can function as antennae and reaction centers.

While current artificial photosynthesis methods are far less efficient than the natural process, there has been continued progress in the field. One of the reasons that the technology is being pursued is that, compared to current solar panel technology, molecular nanoparticles are cheaper, lighter, and more environmentally sound. Aside from providing a renewable energy source and eliminating our reliance on rapidly diminishing fossil fuels, it has also been suggested that artificial photosynthesis on a large industrial scale could reverse global warming since the process consumes carbon dioxide and releases oxygen. With the potential of such beneficial impacts on the environment and our energy supply, continued research into combining nanotechnology and natural processes should remain a central goal.

If the smartest energy source is one that's abundant, cheap and clean, then plants are a lot smarter than humans. Over billions of years, they developed perhaps the most efficient power supply in the world: photosynthesis, or the conversion of sunlight, carbon dioxide and water into usable fuel, emitting useful oxygen in the process

In the case of plants (as well as algae and some bacteria), "usable fuel" is carbohydrates, proteins and fats. Humans, on the other hand, are looking for liquid fuel to power cars and electricity to run refrigerators. But that doesn't mean we can't look to photosynthesis to solve our dirty-, expensive-, dwindling-energy woes. For years, scientists have been trying to come up with a way to use the same energy system that plants do but with an altered end output.

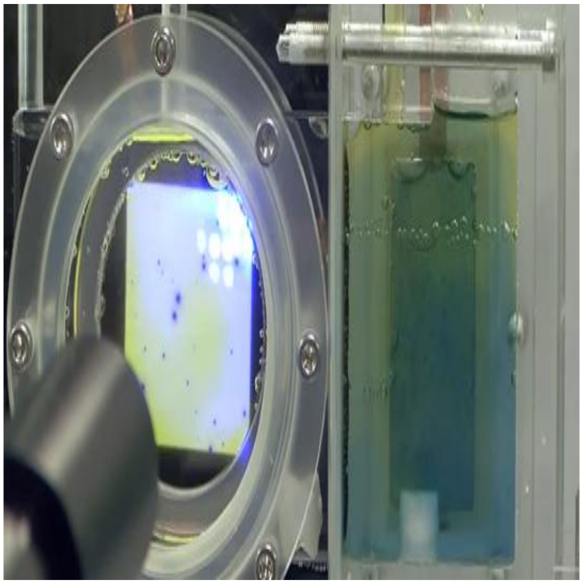

Figure 2 (hight3ch.com) (An Artificial Photosynthesis System developed by Panasonic could solve global warming and energy issues. Efficiency levels on a par with plants have been achieved, with CO2 being converted into useful organic substances. In the future, Panasonic hopes to operate artificial photosynthesis plants, which would absorb CO2 from factories and produce ethanol.)

Using nothing but sunlight as the energy input, plants perform massive energy conversions, turning 1,102 billion tons (1,000 billion metric tons) of CO2 into organic matter, i.e., energy for animals in the form of food, every year [6]. And that's only using 3 percent of the sunlight that reaches Earth [7].The energy available in sunlight is an untapped resource we've only begun to really getting a handle on. Current photovoltaic-cell technology, typically a semiconductor-based system, is expensive, not terribly efficient, and only does instant conversions from sunlight to electricity the energy output isn't stored for a rainy day (although that could be changing. But an artificial photosynthesis system or a photo electrochemical cell that mimics what happens in plants could potentially create an endless, relatively inexpensive supply of all the clean "gas" and electricity we need to power our lives -- and in a storable form, too.

Modern civilization is dependent upon fossil fuels, a nonrenewable energy source originally provided by the storage of solar energy. Fossil fuel dependence has severe consequences including energy security issues and greenhouse gas emissions. The consequences of fossil fuel dependence could be avoided by fuel-producing artificial systems that mimic natural photosynthesis, directly converting solar energy to fuel. This review describes the three key components of solar energy conversion in photosynthesis: light harvesting, charge separation, and catalysis. These processes are compared in natural and artificial systems. Such a comparison can assist in understanding the general principles of photosynthesis and in developing working devices including photo electrochemical cells for solar energy conversion.

Advantages of solar fuel production through artificial photosynthesis include:

- The solar energy can be immediately converted and stored. In photovoltaic cells, sunlight is converted into electricity and then converted again into chemical energy for storage, with some necessary loss of energy associated with the second conversion.

- The byproducts of these reactions are environmentally friendly. Artificially photosynthesized fuel would be a carbon-neutral source of energy, which could be used for transportation or homes.

Disadvantages include:

- Materials used for artificial photosynthesis often corrode in water, so they may be less stable than photovoltaics over long periods of time. Most hydrogen catalysts are very sensitive to oxygen, being inactivated or degraded in its presence; also, photodamage may occur over time.[8] [9]

- The overall cost is not yet advantageous enough to compete with fossil fuels as a commercially viable source of energy [10].

A concern usually addressed in catalyst design is efficiency, in particular how much of the incident light can be used in a system in practice. This is comparable with photosynthetic efficiency, where light-to-chemical-energy conversion is measured. Photosynthetic organisms are able to collect about 50% of incident solar radiation,[11] but photochemical cells could use materials absorbing a wider range of solar radiation. It is however not straightforward to compare overall fuel production between natural and artificial systems: for example, plants have a theoretical threshold of 12% efficiency of glucose formation from photosynthesis, while a carbon reducing catalyst may go beyond this value. [11] However, plants are efficient in using CO2 at atmospheric concentrations, something that artificial catalysts still cannot perform.

Discussion

Energy is the most important issue facing the world in the 21st century. Currently the World still relies heavily on nonrenewable fossil fuels. Solar energy has attracted increasing interest, yet we still lack practical, robust working devices for harvesting natural sunlight. Solid–state solar cells are among the very few devices that are commercially available for converting solar energy to electricity. Dye–sensitized solar cells have emerged as promising alternatives to expensive solid–state solar cells. Another highly desirable use for solar energy is powering fuel generation by water splitting, where chemical fuels (e.g. H2) can be produced and stored. While some successful examples have been reported in the literature using heterogeneous photo catalysts for visible light driven water splitting [12], photo electrochemical synthesis cells offer advantages such as the effective separation of redox equivalents for solar fuel production. The design of such cells will benefit from a molecular understanding of artificial photosynthetic systems. There has been rapid progress in mimicking natural photosynthesis and an exploding body of research in this area holds much promise for improving our understanding of the natural system and reducing the costs of solar energy conversion. Knowledge gained from research in photosynthesis will greatly facilitate the development of efficient devices leading to the production of affordable and energy-rich fuels from natural sunlight. Grand challenges remain including the discovery of inexpensive, robust, and efficient water–oxidation catalysts. In addition, limited success has been achieved in coupling single–photon charge separation with well–defined homogenous catalysts. A variety of research groups have prepared artificial reaction center molecules. These systems contain a chromophore, such as a porphyrin, covalently linked to one or more electron acceptors, such as fullerenes or quinones, and secondary electron donors. Following the excitation of the chromophore, photoinduced electron transfer generates a primary charge-separated state. Electron transfer chains spatially separate the redox equivalents and reduce electronic coupling, slowing recombination of the charge-separated state to the point that catalysts can use the stored energy for fuel production. Antenna systems, employing a variety of chromophores that absorb light throughout the visible spectrum, have been coupled to artificial reaction centers and have incorporated control and photoprotective processes borrowed from photosynthesis. Although attempts at artificial photosynthesis fall short of the efficiencies necessary for practical application, they illustrate that solar fuel production inspired by natural photosynthesis is achievable in the laboratory. More research will be needed to identify the most promising artificial photosynthetic systems and realize their potential.

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