Biophotovoltaics

Energy from algae

Alex Driver
Paolo Bombelli

Conventional solar cells are based on silicon.

Could these giant lily-pads be the green power station of the future? The image above is an artist's impression of what a biophotovoltaic power station might look like. ***Alex Driver*** *and* ***Paolo Bombelli*** *of Cambridge University explain.*

Key words
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The Sun is the ultimate source of energy for almost all life on Earth and harnessing this energy is one of the great scientific and technological challenges. Traditional fossil fuels are considered to be the main contributor to the greenhouse effect; they are subject to a large political risk and destined to run out. Conversely, solar energy is virtually carbon-free, extremely abundant and available worldwide.

Nature has clearly demonstrated that it is possible to harness solar energy through the process of photosynthesis. The photosynthetic production of biomass is not a very energy-efficient process – plants use only about 0.25% of the energy of the sunlight that falls on them. Despite this, it is estimated that the Earth's photosynthetic organisms convert more than ten times as much energy per year as current human energy consumption.

A number of synthetic techniques have also been developed to try to emulate the photosynthetic process; the most successful of these are solar cells based on the photovoltaic effect in which sunlight releases electrons in a solid material, thus creating a useful voltage. Unlike photosynthetic organisms, solar cells are able to convert energy with a high efficiency (10-15%). However, the technology is based on the use of expensive, high purity semiconductor materials.

In order to exploit the advantages of both the biological and synthetic approaches, a technology is required which makes use of the high energy-conversion efficiency of the synthetic systems whilst keeping the merits of a low-cost biological approach. With the cooperation of four Cambridge University departments (see About the authors on page 15), a novel method for harnessing solar energy which does just this has been developed.

Biological solar cells

Biophotovoltaic (BPV) devices are biological solar cells that generate electricity from the photosynthetic activity of living microorganisms such as algae. When light falls on the algae, a series of reactions take place which split water into protons (hydrogen ions, H^+), electrons and oxygen. These are vital ingredients for transforming carbon dioxide and other inorganic materials into things like carbohydrates and proteins which allow the algae to grow. Biophotovoltaic devices exploit this charge separation to generate electrical energy. This is achieved by placing the algae inside one of two electrode-containing chambers separated by a membrane that only allows protons to pass through it, as shown in Figure 1. Electrons produced during photosynthesis flow through an external circuit in order to re-combine with protons and oxygen at the reductive electrode (cathode) to form water. The resultant current flowing in the external circuit can be used to power electronic devices.

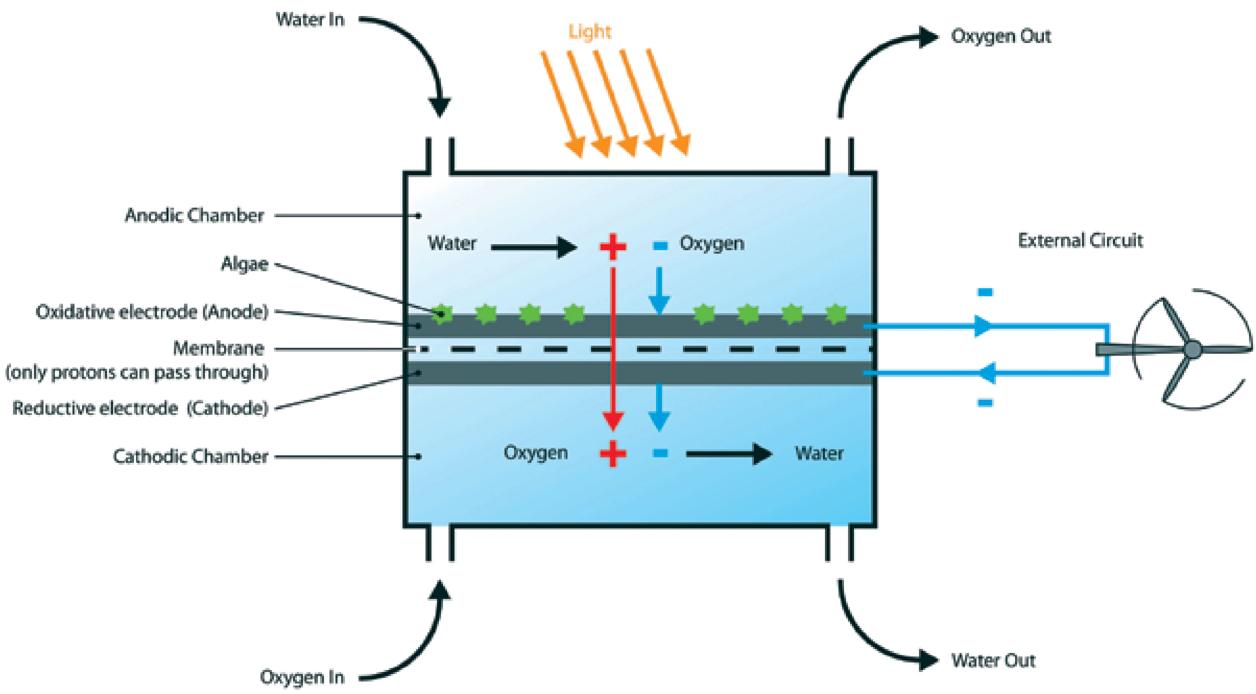


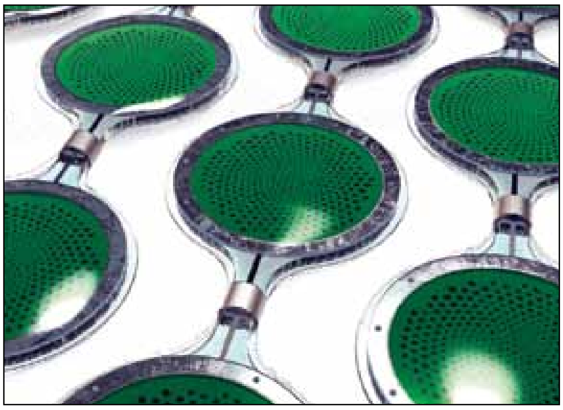
Figure 1 *A schematic diagram of a biophotovoltaic device*

Current research into biophotovoltaics exploits a wide range of techniques including electrochemistry, micro-fabrication, chemical synthesis, molecular biology and numerical simulation. The first BPV devices have recently been constructed and tested in the laboratory, but a great deal of research is required in order to develop biophotovoltaics into a commercially viable technology. Future research will focus on developing a fundamental understanding of the processes occurring within the devices. This knowledge will then be applied to the optimisation of both the synthetic and biological device components.

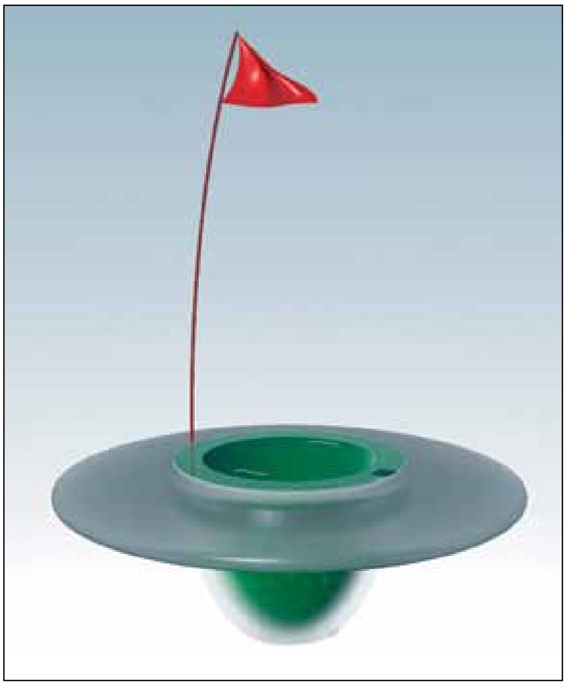
Manufacturing targets

Although they probably going to be less efficient, low-cost BPV devices are likely to become competitive alternatives to silicon-based photovoltaic cells within in the next 5-10 years. The long term target is to produce economical devices with low manufacturing costs and excellent energy conversion efficiency. With this in mind, the scientific team agreed to take part in a collaborative project with designers from the university's Institute for Manufacturing to look into the future to suggest a range of applications of BPV technology.

The designers had a brainstorming session with the scientific team, during which the scientists answered the designers' technical questions, and the group generated a range of ideas for possible products. These included a biophotovoltaic solar panel, a near-shore generator that harvests desalinated water, and a garden table that generates and stores enough energy during the day to power a light in the evening.



An array of biophotovoltaic solar panels



A floating biophotovoltaic generator, designed to produce desalinated water

Biological power

The team also came up with the idea of an offshore biophotovoltaic power station consisting of several vast floating 'lily pads' coated in algae. The power output per unit area of a BPV power station would ideally match that of an equivalently-sized offshore wind farm (5-6 watts per square metre) which should be enough to exploit this technology commercially. Such a power station would even generate energy during the night as a result of excess electrons being stored inside the plant cells during daylight hours.

Following this session, the scientific team asked the designers to build a prototype of the biophotovoltaic solar panel. They produced a 3D computer model of the device which they used to manufacture and assemble the components in the engineering department's workshop. The device, shown in Figure 2, operates on the principle outlined in Figure 1.

An array of these devices would be placed on a roof to provide a portion of the building's power requirements. The advantages of this device that are that it is environmentally friendly and easy to manufacture, at least compared with conventional solar panels. Algae, the bio-electrical catalysts, require only water and sunlight to survive and generate energy. The oxygen produced at the anode escapes into the atmosphere whilst the water produced at the cathode can be harvested or left to evaporate. No harmful chemical waste is produced during the process and once exhausted the devices should be easy to recycle.

Other possible uses of BPV technology include water desalination, the co-generation of chemicals (e.g. formic acid which can be used as a fuel) and the production of hydrogen.

The prototype and concepts have proved to be invaluable in communicating the potential of the technology to colleagues, potential investors and members of the public.

Alex Driver and Paolo Bombelli work at the University of Cambridge.

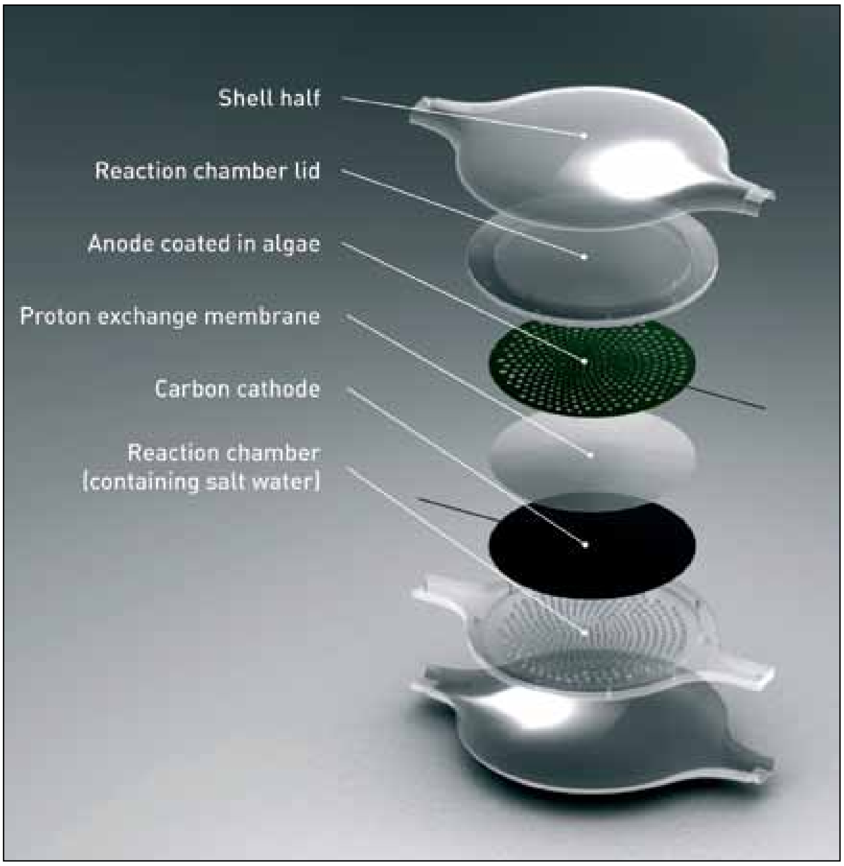


Figure 2 *A biophotovoltaic solar panel prototype, and an exploded view showing how it is contructed.*

About the authors

Alex Driver is a Research Associate at Cambridge University's Institute for Manufacturing. Alex has a background in mechanical engineering and industrial design and is currently researching the potential role of industrial design in scientific research.

Paolo Bombelli is a Research Associate at Cambridge University's Department of Chemical Engineering and Biotechnology. Paolo has a background in plant biology and photosynthesis. He has been working on the development of biological solar panels since 2002 and is currently investigating the wider application of biology in achieving renewable and sustainable sources of energy.

Scientific research is carried out, for the most part, by teams of individuals from a variety of different fields. The work on biophotovoltaics has been based in four departments and involved 14 scientists, designers and engineers. The University of Cambridge departments involved in this work are:

Department of Chemical Engineering and Biotechnology, Department of Biochemistry, Department of Plant Sciences, and the Institute for Manufacturing in the Department of Engineering