Solar Cell Inspired by Plants

SUMMARY

This is a lab-based activity in which young people are introduced to the idea that energy can be harnessed from solar cells whose design has been inspired by plants, or more specifically, the process of photosynthesis.

GOALS

- To provide students with a concrete example and hands-on activity illustrating a Nature-inspired technology highly relevant to today's technological challenges.

OBJECTIVES

- Students will understand the differences between silicon-based and dye-sensitized solar cells.
- Students will see first-hand how solar energy can be converted into electrical energy using solar cells.
- Students will feel empowered to construct their own dye-sensitized solar cells out of basic materials.

AGE BANDS

K-12; see Extensions (p. 4)

MATERIALS

- See document entitled, "Blackberry Solar Cell Lab." To conduct this activity, you can order the slide kit from the non-profit organization, Beyond Benign (info@beyondbenign.org).

__Biomimicry__ is learning from, and then adapting Nature's best ideas to solving human technological challenges, in order to create a healthier, more sustainable planet.

BACKGROUND INFORMATION

History

Creating electricity from the sun has been a technological aspiration of humanity's for over a century. A nineteen year-old first discovered the "photovoltaic effect", the phenomenon of electrical current being generated when light shines on certain materials configured in particular ways. Alexandre-Edmond Becquerel (March 24, 1820 – May 11, 1891) was a French physicist who studied the solar spectrum, magnetism, electricity, and optics. He discovered the photovoltaic effect while working in his father's lab in 1839.

Since the discovery of the photovoltaic effect some 160 years ago, the overriding goal in solar cell innovation has been to increase the solar energy conversion efficiency (i.e., the percentage of photons striking a surface that are ultimately converted into electricity). To that end, humans have been steadily experimenting with materials and their configuration to increase the solar energy conversion efficiency, primarily using silicon materials, but also cadmium telluride, copper-indium selenide, and gallium arsenide.

Less appreciated in historical treatments of solar cell development is that the photovoltaic effect was actually first discovered by photosynthesizing bacteria, the precursors to

VOCABULARY BOX

Photovoltaic effect: the phenomena of electricity being created when certain materials are exposed to light.

Solar energy conversion efficiency: the percentage of photons which are converted into electrical current in a solar cell.

Photosynthesis: the process by which plants and some microbes convert solar energy into chemical energy and ultimately food (e.g., plant sugars).

DSSCs: Dye-sensitized solar cells, a solar cell technology that includes elements that emulate photosynthesis.

LEARNING FROM NATURE

BACKGROUND INFORMATION (cont'd)

plants, over 2.8 billion years ago (see image, right). Interestingly, photosynthesis did not serve as the basis for solar cell innovation until the late 1970s, some 140 years after Becquerel's discovery. These early attempts had very low conversion efficiency (< 1%). In 1991, Michael Grätzel and Brian O'Regan experimented with and successfully created a solar cell technology explicitly modeled on photosynthesis, called the dye-sensitized solar cell (DSSC), that had with relatively high solar energy conversion efficiency.

Pre-Cambrian stromatolites in the Siyeh Formation, Glacier National Park. Stromatolites are the fossilized remains of mats of microorganisms, such as cyanobacteria, who were capable of photosynthesis. Cyanobacteria are thought to be the precursor to chloroplasts in photosynthetic plants.

The first two steps of photosynthesis involve capturing photons released from the sun and using that energy to create a flow of electrons. From there, photosynthesis involves using that electrical energy to create chemical energy, from which ultimately the products of photosynthesis are created (e.g., sugars to feed the plant). It is the first two steps of photosynthesis which DSSC technology has mimicked, capturing photons and using that energy to create a flow of electrons (since ultimately the flow of electrons, or electricity, is the purpose of the technology).

Performance

Environmental comparisons

Silicon remains the primary material comprising today's solar cells. Silicon is the second most abundant mineral in the earth's crust (after oxygen), making up about one-quarter of the earth's crust by mass. However, it rarely exists in a pure state, most commonly being bound with oxygen to make silica, or silica sand. While its abundance helps, silicon is the main component in solar cells primarily because it remains a good conductor of electricity even after it has been heated. In order for silicon to be used for solar cells, it must be heavily heated to separate it from oxygen so that it can be further processed.

While solar energy created by solar cells is popularly considered a "clean" technology, this is a comparison between solar energy and fossil fuels during energy generation. The upstream manufacturing of silicon-based solar cells, in fact, entails a number of environmental (as well as social) hazards. For example, in the production of silicon-based solar cells, toxic by-products such as silicon tetrachloride are created and often dumped in the environment, to the detriment of humans and other organisms (for a review, see http://www.etoxics.org/site/DocServer/Silicon_Valley_Toxics_Coalition_-_Toward_a_Just_and_Sust.pdf?docID=821).

LEARNING FROM NATURE

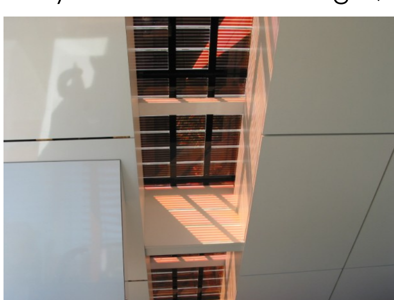
BACKGROUND INFORMATION (cont'd)

In addition, silicon-based solar cells use a great deal of energy to produce, energy that typically comes from polluting fossil fuels. Processing silica (SiO_2) to produce silicon is an energy-intensive process. At current efficiencies, it takes one to two years for a conventional solar cell to generate as much energy as was used to make the silicon it contains. Except for a couple of manufacturing centers that themselves run on solar cells, the energy to create solar cells generally comes from fossil fuels.

Dye-sensitive solar cells are basically composed of a dye that absorbs incoming photons from the sun (the analog to chlorophyll in plants), a high-surface-area matrix into which electrons knocked loose from the dye flow (an analog to the high-surface-area thylakoid membranes inside leaves), and an electrolyte solution that replaces lost electrons back to the absorbent dye so the cycle can continue. DSSCs are generally considered much more environmentally benign than conventional silicon-based solar cells to produce, using non-toxic materials and requiring little energy to manufacture.*

Energy generation

Solar energy conversion efficiency (the percentage of photons striking the solar collection surface that ultimately are converted into electricity) is an important parameter in comparisons of energy generation between different solar energy technologies. Silicon-based solar cells currently demonstrate higher efficiencies than DSSCs (e.g., 12-15% in commercially-available silicon-based solar cells, compared with 11% in DSSCs). However, DSSCs have at least four major advantages over silicon-based solar cells in terms of the overall amount of energy they can produce: (1) they can operate in low-light conditions, such as on cloudy days and in indirect sunlight, (2) they operate efficiently over a wide range of temperature conditions (silicon-based solar cells lose efficiency as they heat up), (3) they are much less expensive to produce, and (4) they can be constructed using a wide-variety of materials, including flexible materials (see images, left). The result of these advantages is that DSSCs consistently produce energy over a wide range of environmental conditions, they are inexpensive so that more surface area can be covered by them for an equivalent cost, and they can be integrated readily into a building "skin", such as in windows.



Dye-sensitive solar cells such as these created by DyeSol can be flexible, and incorporated into building skins (such as skylights). Images courtesy of DyeSol.

* While the materials used in DSSCs is widely considered less toxic than those of conventional photovoltaics, it still deserves critical attention. See, for e.g., http://cancerres.aacrjournals.org/cgi/content/abstract/0008-5472.CAN-09-2496v1

ACTIVITY

DURATION: 30-50 minute class period; longer if desired

PROCEDURE

1. Give students a basic introduction to silicon-based and dye-sensitized solar cells using the information contained in this lesson plan. An effective sequence is to introduce the environmental impacts of silicon-based solar cell production, then pose the question, What other models for solar cells might there be? And then introduce plant-inspired solar cell concepts.
2. Engage your students with the discussion questions provided (see below).
3. Conduct the lab in the document entitled "Blackberry Solar Cell Lab" (the lab procedure begins on page 4 until page 6; make sure you have already ordered a slide kit, e.g., from Beyond Benign. You may contact Beyond Benign at http://www.beyondbenign.org/contact/contact.html).

EXTENSION

◊ This lab can be done with younger students without providing as much background about different types of solar cells and their comparison. Teachers may elect demonstrating the lab rather than having students physically participate. Just seeing that blackberry juice can result in the creation of electricity, and relating this technology to the natural technology used by plants to derive energy from the sun, is of interest to and value for students in primary grades.

◊ The Blackberry Solar Cell Lab document contains good extensions for older students, that use the lab as a springboard to discuss Green Chemistry principles.

DISCUSSION

Consider this timeline of major highlights in solar energy technology:

2.8-3.5 billion years ago: Cyanobacteria discover photosynthesis.

1839: Alexandre-Edmond Becquerel discovers the photovoltaic effect.

1883: Charles Fritts creates the first solar cell.

1941: Russel Ohl creates silicon-based solar cells.

1954: Bell Labs creates silicon-based solar cells with 6% efficiency, becoming practical for use (e.g., in space applications).

1991: Michael Grätzel and Brian O'Regan invent a dye-sensitized solar cell with relatively high conversion efficiency, inspired by photosynthetic plants.

Discussion questions:

◊ Why did some 140 years pass from the discovery of the photovoltaic effect to when inventors began exploring making solar cells modeled on photosynthesis?

◊ Why is solar energy conversion efficiency not the only factor to consider when comparing the performance of silicon-based solar cells to DSSCs? What else is important when assessing performance?

◊ What would you guess the term 'ecological performance' means? What are its implications?

ADDITIONAL MATERIAL

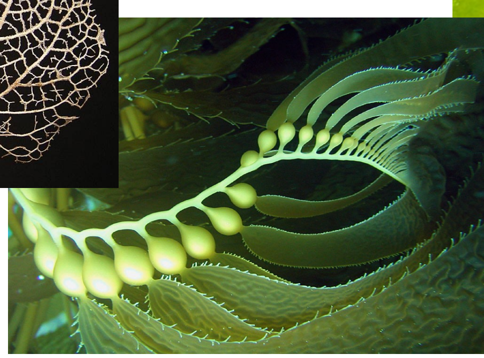
Photosynthesis: A well-adapted technology

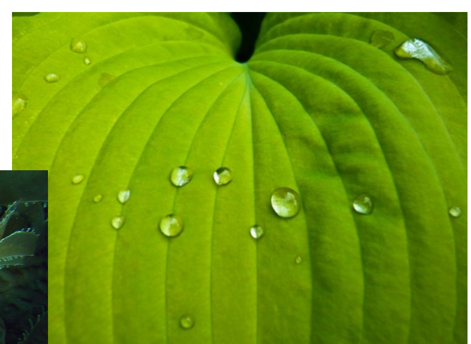
When you look at a leaf, you are looking at an extremely well-adapted solar energy technology. The photosynthesis that occurs in leaves originated in organisms that date back roughly 2.8 – 3.5 billion years, making it one of the oldest technologies on Earth. This technology successfully converts photons striking the Earth from 93 million miles away into electrical and finally chemical energy, enabling the construction of chemical molecules that otherwise would not exist on the planet, and upon which virtually all life depends.

Although large amounts of solar energy reach the earth's surface overall, the concentration of solar energy at the earth's surface (energy/unit area) is relatively low. Plants utilize this energy on-site, for their own benefit. They have evolved to be able to do all of the things they need to do (e.g., grow, reproduce, etc.) with the energy available to them from the sun on a daily basis on one spot of the planet. Because plants have been able to meet all of their energetic needs this way, they are one of the most successful kinds of organism on the planet, evident by the fact that plants cover most of the planet's surface (including oceans, when photosynthesizing marine organisms are considered).

Plants are able to create their "solar panels" relatively inexpensively, so much so that in seasonal climates they regularly shed their leaves and rebuild them the following year using a clean, low-power energy source; out of locally-available and life-friendly materials; and which decompose into nutrients that sustain soil organisms whose by-products ultimately support the continuing growth of plants.

What else could plants teach us?





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