Title: Can the Sun change Carbon Society to Hydrogen Society?

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Global warming is one of the biggest problems in our society. Warming means temperature rise, which causes climate change, rising sea levels, and many other unexpected phenomena. They can be the cause of many issues in our society. For example, climate change reduces food availability and affects the distribution of dangerous viruses. By rising sea levels, floods occur everywhere in the world and our habitable area becomes narrower. We need to find why global warming is happening and how to stop it.

It is now common knowledge that human activities accelerate global warming. One of the most significant and familiar factors is carbon dioxide abbreviated as CO_2. CO_2 has greenhouse effect and direct contribution to global warming. Thermal power generations, factories, and automobiles emit large amounts of CO_2 every day. Automobiles use gasoline and gasoline is made from fossil fuels. Fossil fuels are one of the main sources of CO_2 emission. There is another problem. Fossil fuels are natural resources and are going to be exhausted someday. Nevertheless, most of the energy used by human come from fossil fuels today.

To overcome these situations, various solutions are considered. One of them is hydrogen fuels. Hydrogen fuels leave only water after burning and do not emit CO_2 in principle. If all fuels were replaced by hydrogen, or if the society became hydrogen society, no more CO_2 was emitted and We might stop the progress of global warming. Unfortunately, it has not been achieved today. There are many problems with hydrogen fuels.

What are the challenges of this new energy resource? First, hydrogen is known to be difficult to store. It is a gas at standard temperature and pressure and is highly combustible. We need to find solutions for how to store and how to transport safely. Another problem, the most serious one, is that hydrogen does not exist anywhere in nature. We need to produce hydrogen if we want to use it.

There are many ways to produce hydrogen. For example, we can do this by using fossil fuels, and then CO_2

is emitted. However, this makes no sense! Here is what I mean. Hydrogen fuel is certainly a clean fuel that does not emit CO_2, but it is NOT a source of energy. We must use some kind of energy resource to produce hydrogen and hydrogen is just storing its energy. So, we have to solve the following issue. What is the clean energy source that can be used to produce hydrogen?

One of the answers is the sun. Sunlight could be used to produce hydrogen by decomposing water into oxygen and hydrogen. Is it possible?

Photocatalysts make that dream-like water decomposition reaction possible. a catalyst helps with chemical reactions that would not normally occur. The mechanism is as follows. When sunlight hits a photocatalyst, electrons (e^-) receive the energy of sunlight. This phenomenon also creates holes. Hole (h^+) is a place where electron is absent. We can regard hole as a particle with electric charge of +1, just as electron is a particle with charge of -1. Holes react with water to produce oxygen molecule O_2. Since water is H_2O, hydrogen ions H^+ remain. Then, electrons react to the remaining H^+. Finally, we can get hydrogen molecule H_2! In this way, the photocatalyst succeeds in using the energy of sunlight to produce hydrogen. And carbon C does not appear anywhere. neither CO_2 nor other harmful molecules are produced. This wonderful material is already demonstrated. By this method, can we produce enough hydrogen for the society? In fact, we can not. There are still problems with this method.

Photocatalytic water decomposition has two major issues. One is about the wavelength of light. Sunlight contains light in a broad range of wavelengths, from infrared to ultraviolet. The light that has the strongest intensity in sunlight is visible light. Generally, photocatalysts can absorb light in a small range of wavelengths. It means that the photocatalysts can use only a small part of the energy of sunlight. We want to get hydrogen efficiently, so we need to think about how to broaden the range to include the strongest light, visible light.

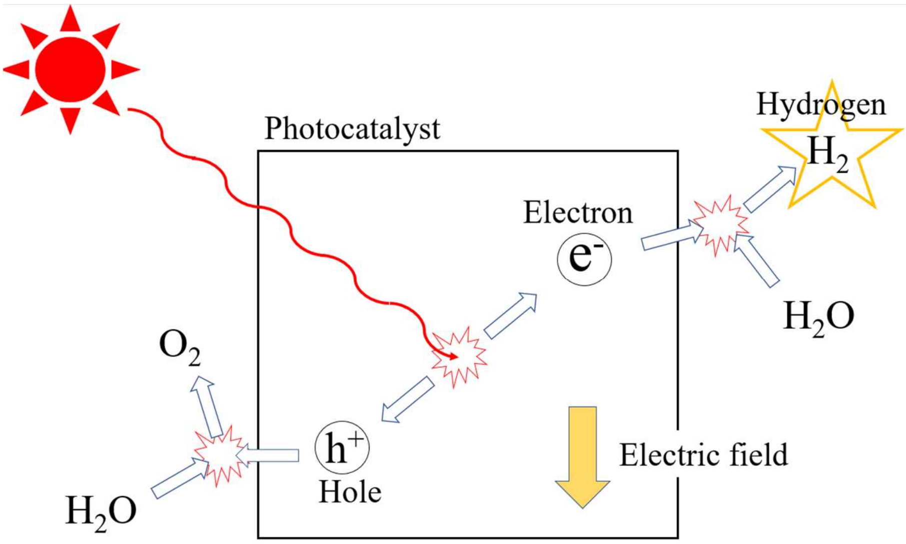
Another is how much energy of absorbed light can be used to produce hydrogen: this is known as quantum efficiency. The main reason why the quantum efficiency is not 100%, is the following. If electron meets hole in the photocatalyst, electron enters the hole of hole, since hole is just a place with no electron. At that time the energy that electron receives from sunlight is emitted as the light outside the photocatalyst and is wasted. This is called pair annihilation. Until now, most photocatalysts have a quantum efficiency of only 10%, and there are only a few cases that have a quantum efficiency of 50%.

In May 2020, the Japanese group announced in Nature that they had succeeded in making a photocatalyst with almost 100 % quantum efficiency and understood its mechanism [1]. They devised a way to make the photocatalyst so that an electric field is created inside the photocatalyst. The electric field moves particles with positive charge and ones with negative charge in opposite directions. Because holes and electrons have charge of +1 and -1, they move in opposite directions by the electric field. Then, electrons and holes do not meet and pair annihilation does not occur. As a result, the efficiency of the photocatalyst was dramatically improved compared to previous ones. Their research had greatly advanced water decomposition.

Of course, this does not mean that all problems have been solved. Their photocatalyst can absorb only ultraviolet rays. The problem of wavelength needs to be solved. However, they revealed the mechanism, and therefore we expect to produce a perfect photocatalyst in the near future. The era of the hydrogen society is not today, but it may be soon.

References

[1] T. Takata, et al., “Photocatalytic water splitting with a quantum efficiency of almost unity,” Nature,581 (2020) 411-414.


Photocatalyst
Hydrogen
H_2
Electron
e^-
H_2O
O_2
h^+
Hole
Electric field
H_2O