# INNOVATIVE HYDROGEN PRODUCTION FROM WATER

**Tokio Ohta**
*Yokohama National University, Japan*

**Keywords:** Innovative method, renewable energy, Gibb free energy, thermal energy, thermolysis, electrolysis, thermochemical cycle, photoelectrochemical method, mechano-catalytic method, photobiochemical method, fermentation

## Contents



## Summary

"Innovative technology" is defined as unconventional technology that promotes efficiency and/or sustainability. The water-splitting method utilizing renewable energy is emphasized. Available renewable energy resources are reviewed.

Solid polymer electrolysis, the thermochemical cycle method, photoelectrochemical method, and mechano-catalytic method are reviewed. Hydrogen production by the photobiochemical method and by fermentation are mentioned.



## 1. Definition of "Innovative Technology"

(a) Technology quite different from the conventional one; for example, the electrolyte in an electrolytic cell is, conventionally, a liquid. However, if an efficient solid polymer takes the place of the liquid, the technology is innovative. The changes should be "sustainable," "economical" (cost down), "energy saving," "ecological," "material saving," "safety," "non-pollutant," "recycle," "beneficial to human beings and environments." Hydrogen energy systems are innovative.
(b) Energy conversion technology that applies a renewable energy resource. For example, if fossil fuel is used to produce hydrogen, the hydrogen energy systems are, in principle, not "innovative," because the utilization of fossil fuel is

contradictory to the catchwords listed in (a).

## 2. Renewable Energy Resources

### 2.1. Solar Energy

Solar energy coming onto the earth is divided into the following branches.

- Direct reflection: 52 PW (30%).
- Converted to heat: 81 PW (47%).
- Vaporization (e.g., rainfall): 40 PW (23%).
- Wind, ocean wave, ocean flow, ocean convection etc.: 0.378 PW (0.37%).
- Photosynthesis: 40 TW (0.023%).
- Direct photons onto the earth's surface: approximately 1 kW $m^2$.

### 2.2. Tide Energy and Geothermal Energy

- Tide energy: 3 TW.
- Geothermal energy: 0.3 TW.

On the other hand, the total primary energy consumed in 1999 was 8.5 Gt (in oil equivalent ton). Therefore, the wattage is

$$\text{Wattage of world energy supply} = 8.5 \text{ Gt Y} = 9.056 \text{ TW} \quad (1)$$

It is not easy to provide this amount of energy by renewable energies.

The defects of renewable energies are (1) the low energy density and (2) the intermittence. A very large surface area is required to overcome these defects. Therefore, the condensed forms are preferable. The energies of moving fluid such as hydraulic power, ocean wave, and wind are examples, among which the wasted hydraulic power must be developed more, because the energy density is given by

$$\text{Energy density} \propto a\rho V^3 \quad (2)$$

where $\rho$ and $V$ denote air density and velocity respectively. The utilization of rapidly moving liquid is more profitable. If innovative technology such as mechano-catalytic water splitting is applied, hydrogen can be obtained from even the faucet of the waterworks.

## 3. Five Innovative Hydrogen Production Technologies

As the statistics in the article *Statistics on Hydrogen Production and Consumption* show, hydrogen production today is almost always based on the splitting of fossil fuel. This is not always sustainable.

First, the principles of water splitting are briefly reviewed. The total energy (the enthalpy change) necessary to split water is the sum of the Gibbs free energy and the thermal energy.

The free energy can be given by electrical energy, mechanical energy, chemical energy, and photon energy. Therefore, these energies as well as thermal energy must be provided from renewable energies in order to make the production system sustainable.

The sustainable and the innovative methods of hydrogen production are summarized below.

### 3.1 Solid Polymer Electrolysis

A water electrolyzer with high performance using solid polymer, where proton conducts charge, has been invented.

This is called SPE (solid polymer electrolyzer) and the typical material is Nafion. Water vapor with high temperature can be applied to SPE with less free energy.

SPE combined with renewable energy can be sustainable. Practical examples are the combinations with photovoltaic generation and wind power generation.

### 3.2 Ideal Water-splitting Process

Water thermolysis (pyrolysis) means the water-splitting system that utilizes thermal energy. Figure 1 shows the temperature ($T$)–entropy ($S$) diagram for an ideal thermolysis.

The water vapor in A-state (gaseous $H_2O$ at $T_1$K) changes to B-state (mixed gas of $H_2$ and $O_2$ at $T_2$K) by the thermal energy ($Q_i$) from the outside. B-state changes to C-state (separated gases of $H_2$ and $O_2$ at $T_2$K) by obtaining the external free energy ($W_i$).

Thermal energy ($Q_o$) is recovered by the cooling transition from C-state to D-state (separated gases of $H_2$ and $O_2$ at $T_1$K). Free energy returns by the process from D-state to A-state, which is realized, for example, by the fuel cell.

If the input thermal energy ($Q_i$) is equal to the output thermal energy ($Q_o$) and the input free energy ($W_i$) is equal to the output free energy ($W_o$), this cycle is reversible and Carnot efficiency is attained.

If no thermal energy is utilized, the water-splitting process is reversible, so that the efficiency is 100%.

For example, water electrolysis, water photolysis, and mechano-catalytic water splitting, may have 100% efficiency, if the Joulian heat and other energy losses are neglected.

-
-
-



**Bibliography**

Domen K., Ikeda S., Takata T., Tanaka A., Hara M., and Kondo J. N. (2000). Mechano-catalytic water-splitting into hydrogen and oxygen on some metal oxides, *Energy Systems: Adaptive Complexity* (ed. T. Ohta), pp. 159–179. Oxford: Elsevier Science. [The details of the discovery experiments are introduced of mechano-catalytic water-splitting.]

Fujishima A. and Honda K. (1972). Electrochemical photolysis of water at a semiconductor electrode. *Nature* **238**, 37. [The discovery of photoelectrochemical water-splitting using $TIO_2$ electrode.]

Funk J. E. and Reinstrom R. M. (1966). Energy requirements in the production of hydrogen from water. *I & EC Process Design and Development* **5**(3). [This is the first paper that proposed the thermochemical water splitting in the order of energy requirement.]

Mitsui A. (1979). Biological and biochemical hydrogen production. *Solar-hydrogen Energy Systems*, Chapter 8 (ed. T Ohta), 264 pp. Oxford: Pergamon Press. [Comprehensive explanation of biological and biochemical hydrogen production. The author is the pioneer in this field.]

Ohta T., ed. (1979). *Solar-hydrogen Energy Systems,* 264 pp. Oxford: Pergamon Press. [Collections of the pioneering researches on solar production of hydrogen.]

Ohta T. (1999). *Energy Technology*, *Sources*, *Systems and Frontier Conversions*, 235 pp. Oxford: Pergamon Press. [Energy systems and their elemental technologies are introduced and evaluated from the view point of efficiency and the global environment.]

Ohta T. (2000). *Energy Systems: Adaptive Complexity*, 230 pp. Oxford: Elsevier Science [The first book on energy systems as approached from the adaptive complexity.]

Sato S. (1979). Thermochemical hydrogen production. *Solar-hydrogen Energy Systems*, Chapter 5 (ed. T. Ohta), 264 pp. Oxford: Pergamon Press. [Detailed and concrete description of thermochemical cycles for water splitting.]

**Biographical Sketch**

**Tokio Ohta**, born November 3, 1925, in Japan, received his education from the Department of Physics, University of Kyoto with a Ph.D. degree in Solid State Physics; he has taught at the University of Kyoto, Portland State University of Oregon, USA, and at the University of Tokyo, and served as the Dean of Faculty of Engineering, Yokohama National University (1985–1988), and President of Yokohama National University (1988–1994). Since 1999 he has been Superintendent of the International Network University; other appointments include the Committee Staff of Science and Technology to the Prime Minister (1974–1994) and the Committee Staff of the Minister of International Trade send Industry (1794–1999). He has published some 160 papers and 60 books on solid state physics and energy systems. He has been elected Vice President of the International Association for Hydrogen Energy, and is the Founding Past President of the Hydrogen Energy Systems Society of Japan.