As a clean fuel that can be produced from diverse resources, hydrogen holds great promise. Splitting water has long been seen as a viable method of generating hydrogen, and with novel materials and technologies developed by a research team from Nanjing University in China’s Jiangsu province, turning pure water into a clean fuel is no longer a dream.

Perfecting solar-hydrogen conversion

Since the discovery by two Japanese researchers in 1972, that a titanium dioxide (TiO₂) electrode, when exposed to ultraviolet light, can split water into hydrogen and oxygen (the Honda-Fujishima effect), photocatalysis has intrigued scientists. It uses less energy, and is more economical than using electricity to split water. Yet, until the end of the 1990s, most photocatalytic technologies relied only on ultraviolet light, which accounts for just 4% of sunlight that reaches Earth, resulting in low solar-to-hydrogen conversion efficiencies.

For Zhigang Zou, director of the Ecomaterials and Renewable Energy Research Center (ERERC) of Nanjing University, and a member of the Chinese Academy of Sciences, harnessing visible light, which accounts for 43% of solar energy, to produce hydrogen is an effective approach to improve conversion efficiency. Since returning to China from Japan in 2003, Zou has been leading the ERERC team to explore photocatalytic technologies. To maximize responsiveness to visible light, they proposed new designs to control energy band structures, and established a material-screening process, leading to novel photocatalytic materials. Key to their success are novel nanostratifying strategies for photocatalysts and photoelectrodes. In investigating how nanostructures influence the charge transport and separation, they found ways to accelerate separation of photo-induced electron-hole pairs, and revealed how the band and interface engineering can reduce the electron-hole recombination. Their nanostructure design led to an increase in the solar-to-hydrogen conversion efficiency from 0.7% to more than 8%, a world record. They also showed that a nanoscale coating can prevent photocorrosion of semiconductors with optimal band gaps, suggesting ways to enhance the durability of photoelectrodes.

Drawing on these results, Zou’s team developed a novel technology to produce hydrogen by splitting seawater using visible sunlight, which attracted global attention and won the second prize of the State Natural Science Award in 2014. ERERC has investigated the mechanism of electron and proton transfer in electrode reactions, chemical bond breakage and formation, and surface adsorption, leading to dramatic improvement in catalyst activity and stability. Their specially designed membrane electrode mass production line, with annual production capacity of 6,000 m², products are widely exported to the United States. A major use of fuel cells is to power electric vehicles. With hydrogen power and fuel cells emerging as fields of strategic importance, ERERC supports development of these industries by setting up national standards, industry guidelines, and development plans. Their fuel-cell testing service platform filled a national need. The team is also looking to the outer space. A domestic pioneer in photocatalytic reduction of CO₂, Zou’s team is working with the China Aerospace Science and Technology Corporation for extraterrestrial application of their artificial photosynthesis technologies. Simulating the natural photosynthesis process of green plants, they seek to achieve controlled conversion of CO₂ into oxygen and carbon-containing fuels, enabling in-situ resource recovery from waste in confined spaces. The technology has potential to support life in space, relieving the reliance on supplies provided by space stations or manned spacecraft.

Fuel cell advances

To turn the hydrogen into electricity, Zou’s team is also dedicated to developing fuel cell technologies. “Ultimately, we want to enable low-cost, high-efficiency and environmentally friendly production and utilization of hydrogen power,” said Zou. Seeing that nano-electrocatalysts could be key elements for the performance and cost of fuel cells, Zou’s ERERC team has investigated the mechanism of electron and proton transfer in electrode reactions, chemical bond breakage and formation, and surface adsorption, leading to powerful, durable membrane electrodes. With their specially designed photoelectrodes, the team has established a membrane electrode mass production line, with annual production capacity of 6,000 m². Products are widely exported to the United States. A major use of fuel cells is to power electric vehicles. With hydrogen power and fuel cells emerging as fields of strategic importance, ERERC supports development of these industries by setting up national standards, industry guidelines, and development plans. Their fuel-cell testing service platform filled a national need. The team is also looking to the outer space. A domestic pioneer in photocatalytic reduction of CO₂, Zou’s team is working with the China Aerospace Science and Technology Corporation for extraterrestrial application of their artificial photosynthesis technologies. Simulating the natural photosynthesis process of green plants, they seek to achieve controlled conversion of CO₂ into oxygen and carbon-containing fuels, enabling in-situ resource recovery from waste in confined spaces. The technology has potential to support life in space, relieving the reliance on supplies provided by space stations or manned spacecraft.

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Achievements at Kunshan Innovation Institute:

• Four R&D platforms, on hydrogen energy utilization, next-generation solar cells, environmental engineering, and smart optoelectronics.
• A national-level testing centre certified by China National Accreditation Service for Conformity Assessment (CNAS), with facilities for services including sample preparation to theoretical simulation.
• Launched four enterprises, bringing products to market.
• Undertook 72 technology projects funded by enterprises, including funding of ¥15 million per year.
• Filed 274 patent applications and won another 102, including 34 invention patents.