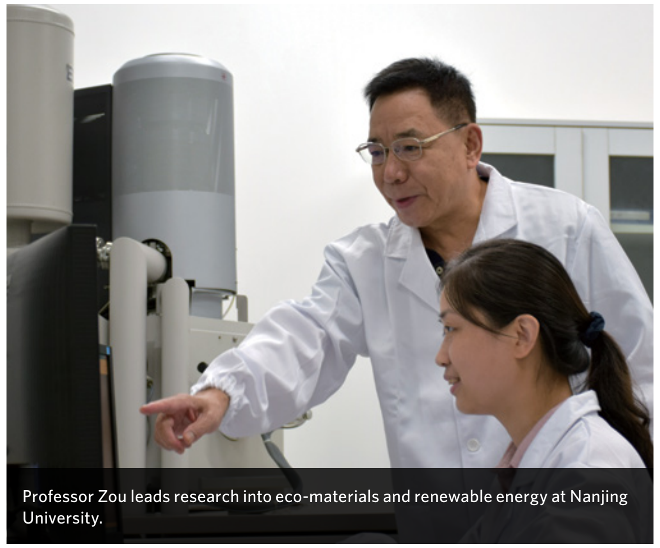
A watertight plan to fuel the future

A series of RESEARCH BREAKTHROUGHS AND TECHNOLOGICAL TRANSFERS by a research team in Nanjing, China, promotes the development of sustainable energy.



Professor Zou leads research into eco-materials and renewable energy at Nanjing University.

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 (TiO_2) 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 nanostructuring 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 0.1% 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 is recognized as a pioneer of green energy in China.

The team has also worked on other technologies to produce hydrogen and turn it into electricity, including using wind and light, to electrolyze water. They were the first to propose a new generation of thin-film solar cells for hydrogen production. Their carbon electrode-based perovskite solar cell was the largest of its kind, boasting an energy conversion rate of 9.39%, which was certified internationally.

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 environmental-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 dramatic improvement in catalyst activity and stability.

They have developed controllable techniques for fabricating high-performance nano-electrocatalysts, which can be used in mass production, boosting China's annual output of catalysts, which previously relied on foreign imports.

For the design of fuel cell systems, supporting the membrane electrode assembly is the key because it facilitates electrochemical conversion of the fuel to electricity. To guarantee high performance and durability for membrane electrodes, while minimizing the use of expensive platinum, Zou's team developed new techniques for catalyst slurry preparation, and precise coating to effectively control the catalyst microstructure, leading to powerful, durable membrane electrodes. With their specially designed equipment, the team has established a membrane electrode mass production line, with annual production capacity of 6,000 m^2. Products are widely used by domestic enterprises, as well as exported to the United States.

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A large-area perovskite solar cell developed at the Kunshan Innovation Institute of Nanjing University obtains TÜV certification.

A membrane electrode assembly for hydrogen fuel cells is under review.

A fuel cell stack undergoes comprehensive testing.

This large-area perovskite solar cell has completed one-year testing under natural light.

A major use of fuel cells is to power electric vehicles. To meet market needs, Zou's team has developed fuel-cell reactors and power source equipment that can be mass produced, including a hydrogen fuel cell with a life expectancy of more than 5,000 hours. Working with a network of local enterprises, the team has assisted the development of micro electric cars.

Smart city incubation

To accelerate technological transfer and commercialization of green energy technologies, Nanjing University co-established the Kunshan Innovation Institute with the local government in 2011.

Led by ERERC, the institute has incubated a company dedicated to R&D on clean and renewable energy. In addition to fuel cell technologies, the company has also commercialized intelligent lighting systems for energy conservation and smart city development.

With hydrogen power and fuel cell industries 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 CO_2, 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 of green plants, they seek to achieve controlled conversion of CO_2 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.

"We'll take steps to develop photosynthetic materials for extraterrestrial use, and to test the technology," said Zou. "It is expected to support manned deep-space exploration." ■

Achievements at Kunshan Innovation Institute:

- **Four** R&D platforms, on hydrogen energy utilization, next-generation solar cells, resource utilization and environmental engineering, and smart optoelectronics
- A national-level testing centre certified by China Metrology Accreditation (CMA) and China National Accreditation Service for Conformity Assessment (CNAS), with facilities for services including sample preparation to theoretical simulation
- Started **four** enterprises, bringing products to market
- Undertook **72** technology projects funded by enterprises, with a total funding of **91.9** million yuan
- Filed **174** patent applications and was awarded **102**, including **34** invention patents

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