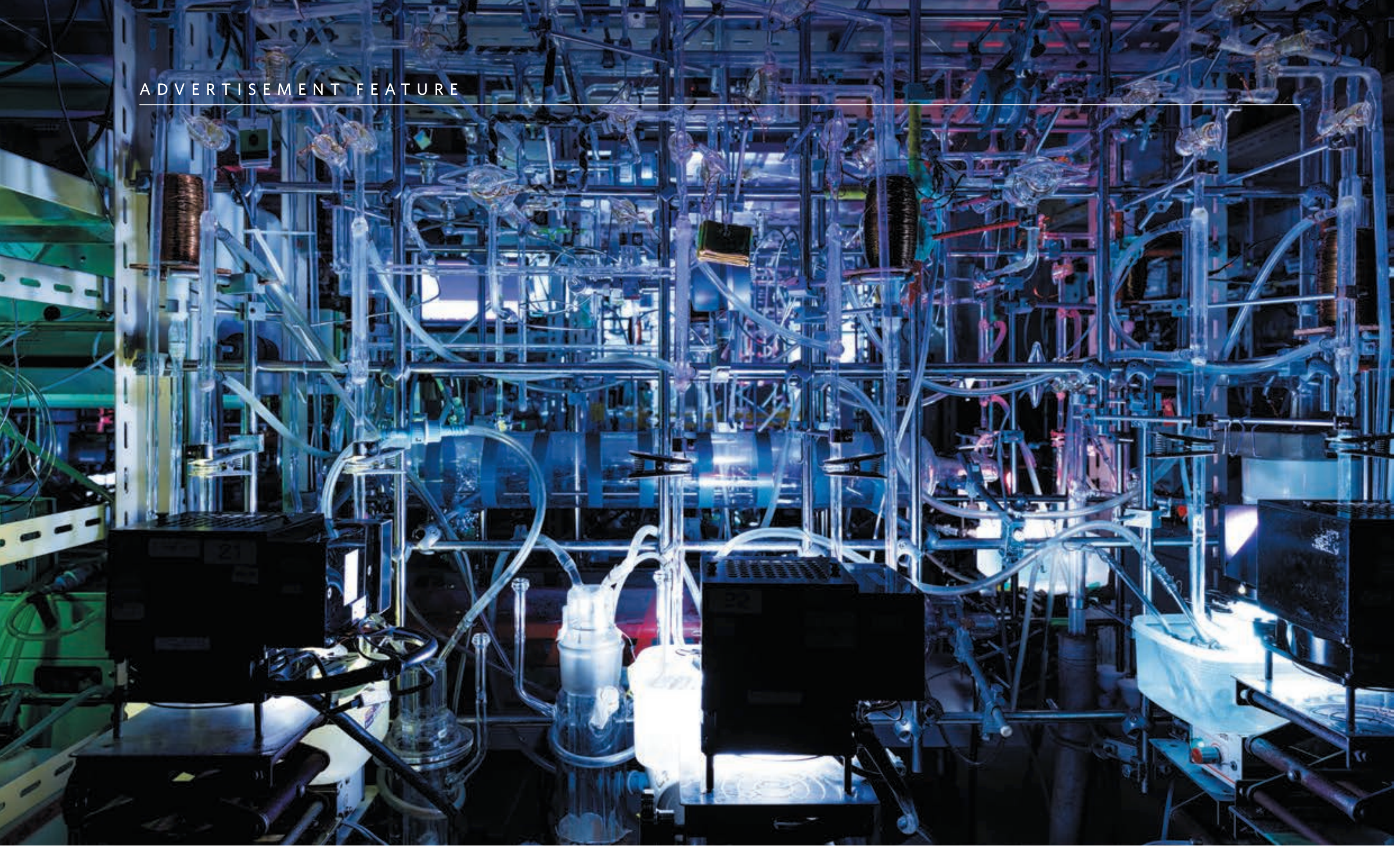

MIRRORING THE POWER OF PLANTS TO USE CARBON DIOXIDE

Nanoscale technologies at the Tokyo University of Science are creating new uses for carbon dioxide and helping to develop more-sustainable batteries based on the ubiquitous element sodium.

If the world is to stand a fighting chance of sticking to the ambitious goals for limiting atmospheric levels of greenhouse gases set out in 2016's Paris Agreement, it won't be enough to just reduce carbon emissions. It will be essential to embrace carbon-negative technologies that suck up carbon dioxide.

Some carbon-negative technologies approach carbon dioxide as a resource to be harnessed, rather than a waste gas to be locked up. That's the radical vision driving researchers at the Carbon Value Research Center (CVRC), a newly established research hub at the Tokyo University of Science (TUS) in Japan. As its name implies, the centre is seeking ways to add value to carbon dioxide by developing technologies that convert the gas into valuable substances.

▲ **A system used by Akihiko Kudo's team to analyse photocatalytic systems for artificial photosynthesis.**

MIMICKING PLANTS

After all, that's how plants deal with carbon dioxide; by harnessing sunlight, they convert carbon dioxide from the atmosphere into organic compounds that enrich their ecosystems. Scientists are trying to imitate nature by developing systems that can perform artificial photosynthesis, broadly defined as chemical reactions that use sunlight to produce fuels such as hydrogen, and useful chemicals such as alcohols and olefins from carbon dioxide, water and nitrogen.

Akihiko Kudo, director of the new centre and a professor in the TUS Department of Applied Chemistry, is excited by the potential of artificial photosynthesis. "With the potential to solve resource, energy, and environmental problems on a global scale, the realization of artificial photosynthesis will greatly impact society," Kudo says.

In plants, the natural pigment chlorophyll lies at the heart of the photosynthetic system and converts sunlight into chemical energy. Photocatalysts perform an equivalent role in artificial-photosynthesis systems, and are critical to their performance. It is this aspect that Kudo and his team are researching. "Finding an efficient photocatalyst is crucial for making artificial photosynthesis a commercially viable technology," he says.

Kudo's lab has been synthesizing various nanostructured inorganic compounds and investigating their photocatalytic activity. In particular, they have been developing photocatalysts that can better exploit the full solar spectrum as they can absorb light at longer wavelengths that extend into the near infrared, as well as shorter, visible-light wavelengths.

SPLITTING WATER USING SUNLIGHT

One particularly exciting form of artificial photosynthesis is using solar power to split water and thereby produce hydrogen. So called 'green' hydrogen is the ultimate environmentally friendly fuel: produced from abundant water and sunlight, its only waste product is water.

Yuichi Negishi, a professor at the Department of Applied Chemistry and the CVRC, is playing a crucial part in developing new photocatalysts and electrocatalysts for artificial photosynthesis and water splitting. He specializes in metal and alloy nanoclusters, which are typically just one nanometre across and consist of several dozen atoms. Not only do they exhibit very different properties from bulk metals, but their properties can also be radically altered by tweaking the number of atoms in them. By coating materials with nanoclusters it is possible to impart materials with new functions.

Negishi is using metal nanoclusters to both enhance water-splitting photocatalysts and improve the functionality of hydrogen fuel cells. "The core driving the reactions in these devices is metal nanoparticles," says Negishi. "We believe that by introducing our high-performance metal nanocluster technology, we can further enhance the functionality of these materials. This high functionality will, in turn, lead to superior device properties."

As an example of nanoclusters' ability to improve existing materials, Negishi's team has achieved a nearly 20-fold increase in hydrogen generation by developing a membrane coated with nanoclusters that prevents the reverse reaction in a water-splitting photocatalyst — essentially hydrogen and oxygen combining to form water — thereby greatly enhancing its efficiency. They have also recently demonstrated a method to coat a surface with gold nanoclusters without them clumping and have used it to realize a water-splitting photocatalyst with high activity and stability.

▲ **1. Yuichi Negishi (left), Akihiko Kudo (middle) and Shinichi Komaba (right) are seeking to develop carbon-negative technologies.**

2. One of the earliest dry-cell batteries in the world, developed by Sakizou Yai in 1887.

3. Batteries based on sodium and potassium are promising alternatives to lithium-ion batteries.

BATTERIES WITH BOOSTED SUSTAINABILITY

Batteries are another key technology for sustainable development, as renewable energy from sources such as wind and solar can be intermittent and has to be stored and transported to where it is needed. TUS has a history of battery research stretching back to 1887 when inventor Sakizou Yai produced one of the earliest dry-cell batteries in the world. Shinichi Komaba, a professor at both the CVRC and the Department of Applied Chemistry, is carrying on that tradition through his research into the electrochemistry of electrochemical devices, including metal-ion batteries.

Lithium-ion batteries currently power everything from electric vehicles to smart phones. But lithium is a limited resource and it will become increasingly scarce in the future. In contrast, sodium, which is the element immediately below lithium in the periodic table, is chemically similar, but is enormously abundant in the world's oceans. Therefore, sodium-ion batteries would be much cheaper and more sustainable than lithium-ion ones, and could also have higher energy capacities.

When Komaba began working on sodium-ion batteries at TUS in 2005, he was warned there was no future in the technology. "Many people advised me not to work in the field as they thought it was going nowhere," he recalls. But he persisted, and is now considered a world leader in a thriving field. After decades of lithium dominating battery research, a sodium renaissance is under way, with the number of papers published in the field increasing more than 500% between 2013 and 2018.

Komaba's research has revealed several key advantages of sodium-ion batteries over lithium-ion ones, including the higher mobility of sodium ions, the rich chemistry of sodium insertion materials, and the lower viscosities of electrolytes. Recently, his team has also discovered an energy-efficient way to fabricate hard-carbon electrodes that boast huge sodium storage capacities. "This raises the possibility of realizing sodium-ion batteries with energy densities that rival those of lithium-ion batteries," says Komaba. "This overturns the accepted wisdom regarding sodium-ion batteries."

Technologies such as artificial photosynthesis, water splitting and sodium-ion batteries are all examples of nanotechnologies that have the potential to overcome global problems, especially the need to slow the trend of rising carbon dioxide levels in the atmosphere. Researchers at CVRC are leading the way in developing technologies that harness the nanoscale to address pressing global issues.■

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