

Carbon-air battery as a next-generation energy storage system

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Carbon/Air Secondary Battery as an Alternative to Hydrogen Fuel Storage Systems

Hydrogen-based energy storage systems can produce clean electricity using H₂ gas

But they suffer from large size and low power and energy density

A carbon/air secondary battery (CASB) as an alternative electric energy source

Charging by CO₂ electrolysis

CO₂ tank

CO₂

$$O^{2-} \rightarrow 1/2O_2 + 2e^-$$

$$O^{2-} \uparrow$$

$$CO_2 + 2e^- \rightarrow CO + O^{2-}$$

$$2CO \rightleftharpoons C + CO_2$$

→

O₂

←

Power

Advantages

- ✓ Superior power density of 80 mW cm⁻²
- ✓ Charge-discharge efficiency of 38% over 10 charge-discharge cycles

Discharging by power generation of C fuel cells

CO₂ tank

←

CO₂

$$1/2O_2 + 2e^- \rightarrow O^{2-}$$

$$O^{2-} \downarrow$$

$$CO + O^{2-} \rightarrow CO_2 + 2e^-$$

$$2CO \rightleftharpoons C + CO_2$$

→

Exhaust gas

→

Power

Fuel electrode

CASB systems are a better alternative to conventional H₂ storage systems for generating and storing electric energy

Carbon/air secondary battery system and demonstration of its charge-discharge

Kameda, Manzhos, Ihara (2021) | *Journal of Power Sources* | 10.1016/j.jpowsour.2021.230681



Credit: Tokyo Tech

One of the barriers to generating electricity from wind and solar energy is their intermittent nature. A promising alternative to accommodate the fluctuations in power output during unfavorable environmental conditions are hydrogen storage systems, which use hydrogen produced from water splitting to generate clean electricity. However, these systems suffer from poor efficiency and often need to be large in size to compensate for it. This, in turn, makes for complex thermal management and a lowered energy and power density.

In a study published in *Journal of Power Sources*, researchers from Tokyo Tech have now proposed an alternative electric energy storage system that utilizes carbon (C) as an energy source instead of hydrogen. The new system, called a "carbon/air secondary battery (CASB)," consists of a solid-oxide fuel and electrolysis cell (SOFC/ECs) where carbon generated via electrolysis of carbon dioxide (CO₂), is oxidized with air to produce energy. The SOFC/ECs can be supplied with compressed liquefied CO₂ to make up the energy storage system.

"Similar to a battery, the CASB is charged using the energy generated by the [renewable sources](#) to reduce CO₂ to C. During the subsequent discharge phase, the C is oxidized to generate energy," explains Prof. Manabu Ihara from Tokyo Tech.

As the carbon is stored in a confined space in the SOFCs/ECs, the energy density of the CASB is limited by the amount of carbon it can hold. Despite this limitation, the researchers found that the CASB had a higher volumetric energy density compared to hydrogen storage systems.

Another indicator of battery performance is the charge-discharge

efficiency. To evaluate this metric, the researchers performed a charge-discharge experiment. They observed that the transformations between C and CO₂ were due to "Boudouard reactions" characterized by a redox reaction of a mixture of carbon monoxide (CO), CO₂ and C.

Specifically, during the charging phase, C was deposited on the electrode via the electrochemical reduction of CO₂ and the reduction of CO via the Boudouard decomposition. During the discharge phase, the C was oxidized to CO and CO₂ via the Boudouard gasification reaction and electrochemical oxidation respectively. The researchers found that the C utilization for energy generation of the CASB depended on the equilibrium between the 3 different carbon species (C, CO₂, CO), also known as the "Boudouard equilibrium."

The CASB system was able to use most of the carbon deposited on the electrode for energy generation, demonstrating a high Coulombic efficiency of 84 percent, indicating that most of the stored energy can be obtained during the discharge phase. Furthermore, it showed a superior [power density](#) of 80 mW/cm² and a charge-discharge efficiency of 38 percent that was sustained over 10 charge-discharge cycles. This suggested that no degradation of the fuel electrode occurred.

"Compared to [hydrogen storage systems](#), the CASB system is expected to have a smaller system size and higher system efficiency," says Prof. Ihara. Their new system could lay the foundation for compact and efficient [carbon](#) energy storage systems that could work alongside renewable [energy](#) sources for a fossil-fuel-free future.

More information: Keisuke Kameda et al, Carbon/air secondary battery system and demonstration of its charge-discharge, *Journal of Power Sources* (2021). [DOI: 10.1016/j.jpowsour.2021.230681](https://doi.org/10.1016/j.jpowsour.2021.230681)

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