



# Optimized hard carbon derived from starch for rechargeable seawater batteries



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## ABSTRACT

The recently introduced seawater battery concept is an eco-friendly energy storage system that offers appealing electrochemical performance. Its radically innovative design, compared to conventional lithium-ion batteries, makes use of seawater as an almost infinite sodium reservoir for the positive electrode and, thereby, avoids the use of expensive, scarce, and toxic elements like nickel and cobalt. So far, the problems identified mostly originate from the available negative electrode active materials. In this study, a starch-derived hard carbon was used to optimize the system. Due to its improved disordered structure compared with commercial hard carbon, the starch hard carbon exhibits an increased reversible capacity, current-rate capability, and cycling ability. The material, in fact, depicts a high maximum power density of  $700 \text{ W kg}^{-1}$  (based on hard carbon weight) upon discharge at  $900 \text{ mA g}^{-1}$ , while still being active at  $2700 \text{ mA g}^{-1}$ . These results represent an important step toward practical application of the sodium-based seawater battery technology.

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## 1. Introduction

Energy storage systems (ESSs) have become increasingly important for the utilization of renewable energies such as solar, wind and tidal energy, since they enable shifting the consumption of previously generated electricity to a later time. Among ESSs, lithium-based rechargeable batteries are considered the most promising because of their high energy density, high energy efficiency, and long cycle and calendar lives [1,2]. However, the scarcity of lithium and cobalt resources, which are the main components in lithium-ion batteries, significantly limits future ESS applications [3,4]. In addition, the costs of lithium and cobalt resources are rising rapidly with their widespread application. Therefore, new

rechargeable systems are sought; the sodium-based rechargeable battery is one such candidate, among others, attracting increasing attention [5] because of the comparable electrochemical insertion mechanism of sodium and lithium ions, which make sodium-based batteries a drop-in technology to potentially replace or complement their lithium analogs. Moreover, sodium is among the most abundant elements in the earth's crust, and its resources are abundant, widespread, and easily accessible in large scale at low cost [6–11].

Although the use of sodium-ion batteries is an appealing strategy to replace lithium-ion batteries, the energy density is limited by its intrinsically higher standard potential ( $\text{Na}/\text{Na}^+$ ) compared to  $\text{Li}/\text{Li}^+$  [7,10]. In addition, the insertion ability of  $\text{Na}^+$  into the electrode's structure is often decreased due to its higher ionic radius compared to  $\text{Li}^+$ , resulting in higher polarization, decreased average discharge potential, and reduced cycle-life. Thus, the design of electrodes with suppressed polarization is of great importance for the achievement of sufficiently good electrochemical properties in sodium-ion batteries.

Numerous negative electrode materials for sodium-ion batteries, such as carbonaceous materials, metal oxides, and alloying

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