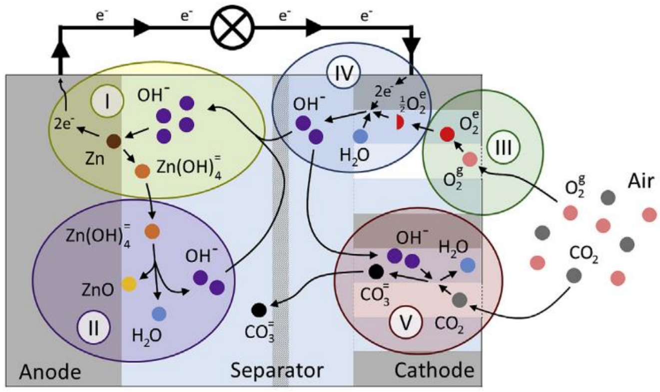
Rechargeable Zinc-Air Batteries

Batteries are an indispensable and growing part of our everyday lives. From our smartphones and computers to electric vehicles and renewable energy, modern society runs on battery power. As our needs continue to evolve, new battery technologies are required to supplement our reliance on Li-ion batteries (LIBs). Rechargeable zinc-air batteries (ZABs) stand out as one such technology.

Zinc-Air Batteries: Safe, Cheap, and High-Energy

ZABs can safely store large amounts of energy using cheap and abundant materials. The principle is simple: a zinc metal anode is combined with an air cathode that reduces oxygen directly from the air to reversibly form solid zinc-oxide. The result is an affordable battery with a theoretical energy density many times greater than current LIBs. Furthermore, ZABs are very safe to operate. While an internal short-circuit would cause a LIB to burst into flames or explode, the same event in a ZAB would cause no safety hazards apart from the shutdown of the cell.



Schematic of alkaline ZAB operation from J. Power Sources, 360 (2017) 136-149.

Until recently, ZABs have mostly been limited to single-use applications. When the battery is exposed to air, CO_2 absorbs into the alkaline electrolyte and contributes to parasitic degradation reactions. This limits the lifetime of the battery to just a few months. Additionally, zinc metal changes shape as the cell is electrically recharged, which also limits battery lifetime. New advances in electrolyte technology and cell design are beginning to overcome these challenges, and rechargeable ZABs are starting to carve out a foothold in the stationary energy storage market.

From Electric Vehicles to Renewable Energy Storage

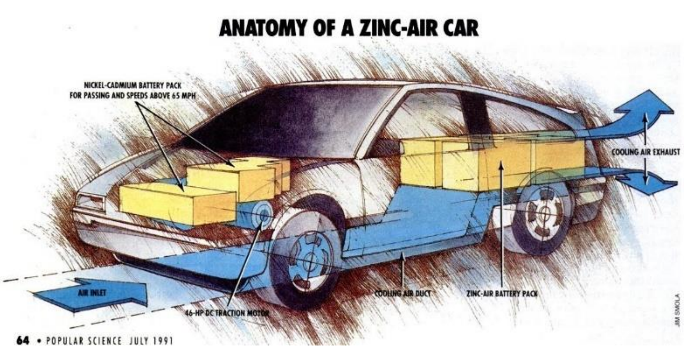
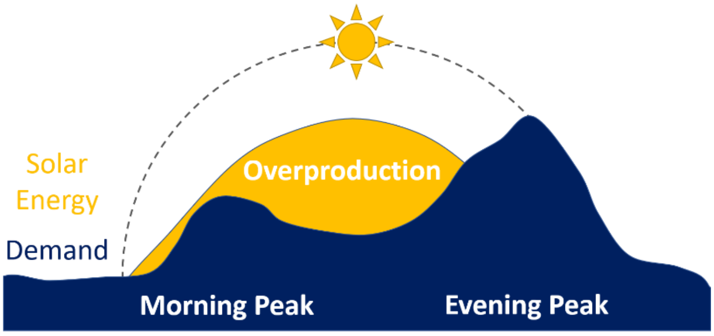


Illustration of a zinc-air car profiled by the magazine *Popular Science* in July 1991.

ZABs were among the first batteries to be developed for electric vehicles (EVs). Successful pilot projects with cars and city busses were conducted throughout the 1990s. These EV batteries utilized a "mechanically rechargeable" system, in which the discharged zinc paste was physically removed and replaced with new material. But when simpler electrically rechargeable LIBs became the dominant mobile battery, the applications of ZABs shifted towards stationary applications.

Today, rechargeable ZABs are making a comeback for grid-scale energy storage. A significant portion of the electric grid mix is coming from renewable energy sources like wind and solar PV. This presents some challenges for grid-operators, because energy is often produced in the middle of the day when it is not needed. One solution to this challenge is the installation of large, cheap batteries to store energy produced during the day for use later during peak demand in the evening. ZABs are ideal for this application.



ZABs can store extra energy produced during the day for use during times of peak demand.

Start-up companies in Europe and the United States are establishing a foothold for ZABs in the stationary storage market. The exceptional safety and low cost of ZAB systems make them attractive for both homeowners and power plant operators.

A Battery for Europe

European companies have manufactured of single-use ZABs for decades, accumulating a wealth of experience and technical know-how in the process. Additionally, Sweden is one of the world's leading zinc suppliers, producing about 260 thousand metric tons per year. In contrast, Li-ion batteries are dependent on rare materials like cobalt, which is both expensive and concentrated in remote parts of Africa. Europe's combination of technological expertise and reliable material supply help make ZABs attractive alternatives to LIBs. If successfully launched on the large-scale, the entire ZAB value chain from raw materials to recycling could be based in Europe.

Promise, Challenges, and Outlook

The successful development of rechargeable ZABs promises cheap, safe, high-energy storage for industrial and residential applications. This will provide a critical boost in efforts to reduce greenhouse gas emissions and transition to an economically and environmentally sustainable energy infrastructure. But first there are some challenges that must be addressed.

The calendar and cycling lifetime of ZABs must be improved. New ideas to prevent electrolyte degradation from CO_2 absorption and to limit the changing shape of the zinc electrode are needed to make these systems competitive with the current generation of LIBs. Research into these topics is ongoing and steady advances in electrolyte technology and electrode design give good reason to be optimistic.

Advances in new bi-functional catalyst materials could also slingshot ZABs into the next generation. Today, most air catalysts are known to be stable and active towards either oxygen reduction (discharging) or oxygen evolution (charging) but not both. This limits the efficiency and power capability of the battery. Advances in high-throughput model-based screening of materials are providing researchers with new paths to explore in the search for active and stable catalyst materials.

ZABs – and other metal-air systems – are an important part of next-generation energy storage systems.

Promise
- Cheap, safe, and high-energy storage for stationary applications.
- Established manufacturing expertise and material supply within Europe.

Challenges
- Short lifetime due to electrolyte degradation and zinc electrode shape change.
- Low power capability and efficiency due to catalyst limitations.
- System engineering required to maintain proper electrolyte levels over long periods.

Outlook
- Development of new carbonation-resistant electrolyte materials.
- Design of advanced zinc electrodes to resist shape change.
- High-throughput screening, selection, and testing of new catalyst materials.