# Battery Boon: The Rechargeable Lithium-Air Battery

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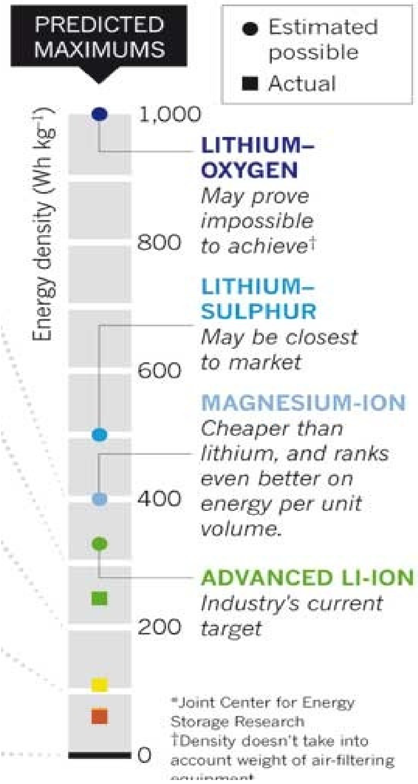
*The current climate for battery innovation is one of frenzied growth. Even though the most advanced lithium-ion batteries are improving every year, there is no shortage of ideas for their replacement—the next big rechargeable battery. Many lithium-ion battery alternatives fight for recognition but none quite compare to the lithium-air battery. Delicately balancing size, weight, and functionality, the lithium-air battery uses oxygen from the surrounding air as the cathode material making it, theoretically, one of the lightest and most efficient batteries possible. If engineers can overcome the hurdles holding lithium-air batteries back, this technology could transform the way we power our portable world.*

## Introduction

Whether it powers the mobile phone in your pocket, the laptop in your backpack, or maybe even an electric vehicle in your garage, all of us rely on rechargeable batteries in some way. Nobody wants to lug around a bulky, heavy laptop or drive an electric car that runs out of power quickly. Today's portable society demands that the batteries powering our devices are small, lightweight, and long-lasting. Building the ultimate rechargeable battery that perfectly balances energy demand with weight and size is a distant engineering goal; however, engineers make significant progress in packing more energy into lighter, smaller batteries every year.

Rather than using the large, heavy metal, lead, as Gaston Planté did when creating the first rechargeable battery in 1859, the batteries powering our portable devices today primarily employ the lightest and smallest metal in the world, lithium [1]. Each year, most modern lithium batteries can store more energy than the year before; however, this trend is not expected to last. Researchers estimate the energy per kilogram, or specific energy, of lithium-ion batteries can only be improved by an additional 30% from today's value before improvement stagnates [2]. A few potential battery alternatives such as magnesium-ion and lithium-sulfur batteries are realistic alternatives that can surpass this energy density plateau; however, as seen in Fig. 1, neither of these alternatives comes close to matching the energy density potential of a lithium-oxygen, or lithium-air battery.

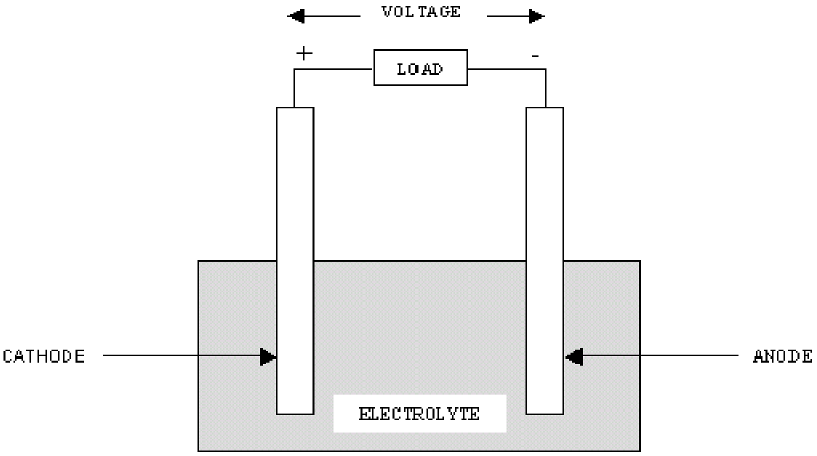


*Modified from Source: C.-X. Zu & H. Li Energy Environ. Sci. 4, 2614–2624 (2011)/Avicenne*

Figure: 1 Lithium-Oxygen holds the highest possible energy density, though some believe they have insurmountable technological barriers.

## Battery Fundamentals

The operating principle of a lithium-air rechargeable battery is functionally identical to that of a basic battery, also known as a voltaic cell. As seen in Fig. 2, a voltaic cell is made of three essential pieces: two terminals called the anode and the cathode and a chemical medium called the electrolyte, which fills the gap between the anode and cathode [3].



Source: http://depts.washington.edu/matseed/batteries/MSE/components.html

Figure 2: Fundamental components of a voltaic cell

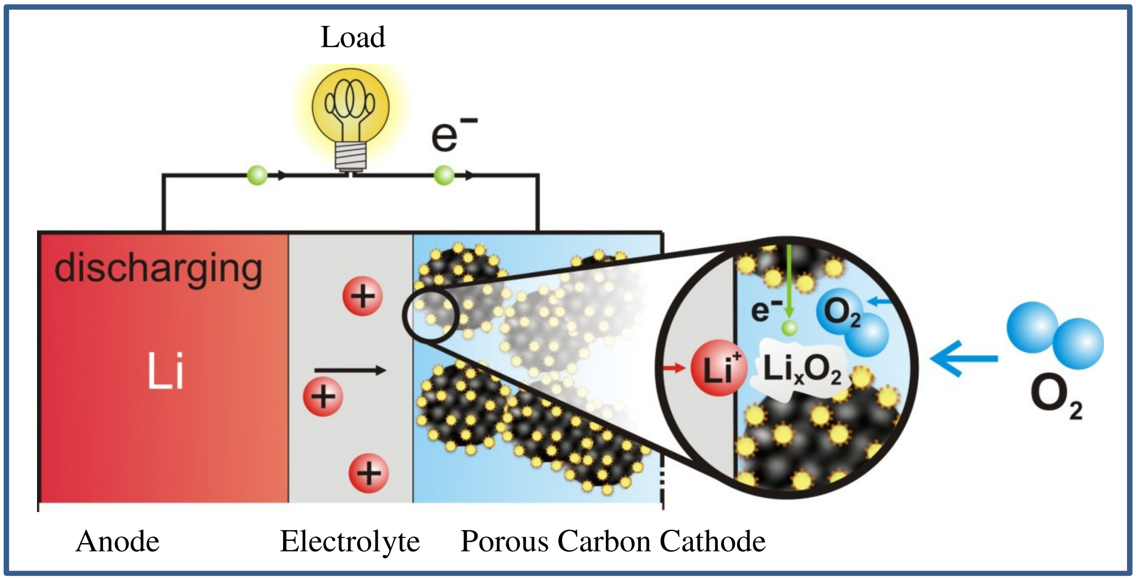
During the discharge phase, the phase when the battery releases stored energy, a wire connects the anode and the cathode to a power using device or, “load”, causing chemical reactions to occur at the anode and cathode simultaneously [3]. The anode undergoes an oxidation reaction, a reaction where a material layer deposited on the anode splits into electrons and positively charged ions. Meanwhile, a material on the cathode called the oxidizer material undergoes a reduction reaction, a reaction where electrons, travelling through the wire from the anode to the cathode, bind with positively charged ions in the electrolyte solution and with the oxidizer material to form a new material layer on the cathode surface. The flow of electrons through the wire determines the battery’s output—the amount of energy it can supply to the load [3]. The battery will continue to supply energy until the anode material has been completely oxidized, at which point the battery will cease to function.

During the charge phase, the phase where the energy stored in a battery is replenished, the load is replaced with a power source like a phone or laptop charger. Chargers like these funnel energy into the battery to reverse the direction the electrons flow through the wire [4]. Electrons flowing in the opposite direction than those of a discharging battery—from cathode to anode rather than anode to cathode—indicate that the reactions occurring at the anode and cathode have switched; now, the oxidation products, electrons and ions, are formed at the cathode and the reduction product, the original material layer, is reformed at the anode. The battery is fully charged when additional charging replenishes no more of the original material layer at the anode.

Maybe add an animation here showing the movement of electrons and ions in a cell discharging and charging?

## Lithium-Air Batteries

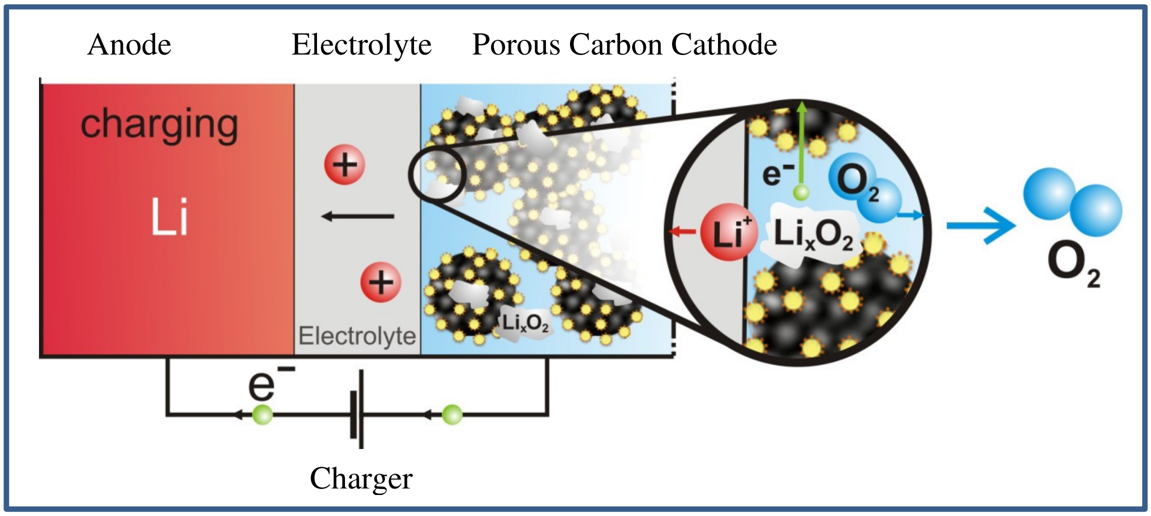
If we extend fundamental battery principles to a lithium-air battery, we can see each of these parts in action [5]. During the discharge phase shown in Fig. 3, a solid lithium layer at the anode is oxidized to release positive lithium ions into the surrounding electrolyte. The ions migrate through the electrolyte solution toward the porous carbon cathode where oxygen, filtered from the surrounding air, bonds with the lithium ions to form lithium oxides, $LiO_2$ and $Li_2O_2$ [5] & [6].



Modified from Source: http://web.mit.edu/eel/lowT.html

Figure 3: A discharging lithium-air battery

Recharging a lithium-air battery, seen in Fig. 4, splits the lithium oxide molecules at the cathode into oxygen and positively charged lithium ions. The oxygen is returned to the surrounding air and the lithium ions return to the anode where they re-form the starting material, solid lithium [6].



Modified from Source: http://web.mit.edu/eel/lowT.html

Figure 4: A Charging lithium-air battery

Lithium-air batteries far surpass their lithium-ion counterparts in energy storage by reacting with atmospheric oxygen. Lithium-ion batteries require a built-in oxidizer material at the cathode to complete the reduction reaction. Storing this oxidizer material adds weight and volume to the battery without significantly improving the battery's energy capacity. Rather than store an oxidizer material, Lithium-air batteries recycle an external oxidizer material, oxygen, by continuously filtering surrounding air through a porous carbon cathode. Without the need for a built-in oxidizer material, lithium-air batteries can store more lithium anode material and can thus store significantly more energy than a lithium-ion battery of the same weight and volume. According to researchers Nobuyuki Imanishi and Osamu Yamamoto, converting from modern lithium-ion batteries to theoretical lithium-air batteries could improve today's battery specific energy tenfold[7]!

## Consequences

Considering the massive energy density improvement lithium-air batteries could bring relative to current battery technology, the creation of a full-scale, functional rechargeable lithium-air battery could have sweeping effects in multiple industries. The electric vehicle industry in particular stands to gain much from a perfected lithium-air battery. Industry leader Tesla Motors is able power their Model S sedan for up to 265 miles of driving using current battery technology [8]. Experts predict that by using lithium-air batteries instead, Tesla's reported maximum mileage value could almost be doubled, reaching values comparable to the mileage achieved by petroleum fueled vehicles [2].

Automotive companies are not the only ones with their eyes on lithium-air batteries. The solar industry in particular will benefit greatly from higher capacity batteries. One of the major barriers preventing the mass use of solar panels in energy production is the current lack of efficient methods to store the excess generated energy [9]. If this energy could be stored, it could be saved for nighttime hours or for cloudy days when solar panels lose some of their effectiveness. Because lithium-air batteries are predicted to be lighter, smaller, and to contain considerably more energy capacity than current lithium-ion batteries, the renewable energy sector would be able to greatly raise prohibitive energy storage limits for solar and wind harvesting technologies. Lithium-air batteries' smaller, more capacious design could allow engineers to link several of them to a single solar panel or wind turbine without taking up additional space [10]. Batteries that improve solar panels and wind turbine effectiveness during efficiency poor conditions would certainly make solar and wind power a more practical energy alternative.

## Challenges

Unfortunately, the path to developing lithium-air batteries capable of propelling these industries into the next generation of energy usage is not trivial. It is unquestionable that lithium-air batteries are promising devices that could drastically increase the amount of storable energy in batteries; however, a number of significant technological barriers must be overcome before lithium-air batteries see widespread commercial use. Lithium metal is highly reactive with even small amounts of water, forming lithium hydroxide and highly explosive hydrogen gas [11]. The possibility of this hydrogen gas exploding is a clear safety hazard that engineers cannot ignore. Water vapor in the air must therefore be filtered out before entering the cathode and water cannot be present in the electrolyte solution unless the lithium is protected from it. Additionally, the lithium oxides that form at the cathode during the discharge phase tend to clog the pores of the carbon cathode, preventing the battery from fully discharging [12]. Unwanted solids called dendrites can also form on the anode surface in some lithium-air batteries which, over time, cause the battery to short circuit [13].

## Practicality

Considering the difficulty and scope of the challenges currently preventing lithium-air batteries from widespread use, some researchers have given up the pursuit altogether in favor of other air based batteries like sodium-air or aluminum-air batteries that have fewer hurdles to overcome before becoming a reality [1]. Sodium-air batteries are improvements over lithium-ion batteries and can currently recharge more reliably than lithium-air equivalents; however, sodium-air batteries are a little heavier and can store much less energy than their lithium-air counterparts [1]. Conversely, aluminum-air batteries actually store more energy than lithium-air batteries but are expensive, much heavier, and are not currently rechargeable [14] & [15]. While some researchers do not believe that the solutions to lithium-air challenges will be practical, there are plenty of researchers excited about the technology and confident that the problems can be solved.

## Conclusion

While sodium-air and aluminum-air batteries are both attractive fields of air battery research, neither addresses the needs of our portable society quite as well as the lithium-air battery could. Compact, lightweight, rechargeable, and energy dense, lithium-air batteries balance function with convenience and could be poised to take their place in the phone in your pocket, the car in your garage, the laptop in your backpack, and in the many other portable technologies that shape our world.

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