Biomedical Applications of solid-state lithium batteries

A White Paper

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1. Introduction / Background

Batteries power even the most basic of appliances in this day and age. While there are many different types of batteries that exist, the focus of this paper will be the solid-state lithium battery. And as there are several different types of appliances that such batteries could be used in, the focus of this paper will be further narrowed down to the biomedical applications of these batteries.

The field of biomedicine is a field with a large amount of potential. In recent years, there have been no shortage of advancements in this field, which makes it a ripe market to enter for product advancements to dramatically change lives. From cochlear implants, which have been around for a while, to technology that helps blind people partially regain their vision, to wearable devices that monitor vital signs and biometric feedback, this field is booming, and it will stay that way for the foreseeable future. So long as the human body is not perfect and needs assisted function, there will always be lots of innovation and activity in this arena

2. Problem Statement

Long-lived and rapid charging batteries are critical to biomedical and health applications. Traditional Lithium-ion metal batteries are too expensive, too bulky and take too long to charge. This technology has been unstable, and the chemical construction of it has caused the battery to short or sometimes catch fire. Solid-state lithium battery innovation presents an opportunity to address stability issues as well as structure the battery to even self-repair. This innovation has major implications for the longevity and utility value of health devices to improve lives.

3. Considerations

In creating batteries for biomedical uses, there are a few key constraints to keep in mind. The first is the packaging, to ensure that the toxic materials, if jostled, do not harm the wearer of the device. This is made more safe by the use of solid-state batteries instead of the liquid-state ones, so it is not as pressing.

Another key consideration is the size of the battery. It will have to be carried by the wearer, so it can't be too large or heavy. But, it will also have to be powerful enough to supply the device it's providing energy to. The battery will also have to be extremely flexible, as some of them are housed within the human body. These internal batteries will have to fit easily and comfortably within the body.

Furthermore, the battery must be compatible with the human body. Though most of the biomedical device(s) may be located outside of the body, there are still certain technologies that require the power source to be housed within the body. Because of this, it is imperative that all the materials of the battery be not only nontoxic, but also actively biocompatible.

All these considerations must be taken into account along with little to no sacrifice of the battery's energy density.

4. Applications and Resources

Applications	Resources	Battery constraints
General uses: Implantable Medical Devices Wearable applications	• Development of Implantable Medical Devices: From an Engineering Perspective • Fiber-Type Solar Cells, Nanogenerators, Batteries, and Supercapacitors for Wearable Applications • An extremely safe and wearable solid-state zinc ion battery based on a hierarchical structured polymer electrolyte	Since the wearables and implantable devices will be relatively small devices that will need a lot of power, the energy density of the battery will have to be very high for these devices. For the implantables, the batteries will need to be either rechargeable, or they will need to have a very long battery life, because it is inconvenient to keep removing the battery and replacing it when it is within your body. These will also need to be very flexible, because when it comes to wearables, there are multiple different places in which the battery can go.
Cardiac-related: Pacemakers Defibrillators Implantables Metrics	• Leadless Cardiac Pacemakers: Back to the Future • Permanent Leadless Cardiac Pacemaker Therapy • "Real life" longevity of implantable cardioverter-defibrillator devices • Battery longevity from cardiac resynchronization	The batteries that will be used in pacemakers and implantables will need to be rechargeable or have a very long battery life, because it is inconvenient to keep removing the battery and replacing it when it is within your body. For the defibrillators and metrics, this is less important, as those devices are external. The battery for the implantables will have to be packaged very

	therapy defibrillators: differences between manufacturers and discrepancies with published product performance reports • Effect of battery longevity on costs and health outcomes associated with cardiac implantable electronic devices: a Markov model-based Monte Carlo simulation • Conformal piezoelectric energy harvesting and storage from motions of the heart, lung, and diaphragm	well so that in case of damage, the toxic materials in the battery don't get exposed to the body.
Vision-related: Artificial vision Retinal and subretinal implants	• Electronic retinal implants and artificial vision: journey and present • Subretinal electronic chips allow blind patients to read letters and combine them to words	For retinal and subretinal implants, the battery must be extremely small, in order to not block the vision. It must also have a very high energy density so it's able to efficiently power the devices. The battery will also have to be light, and a rechargeable type would be best. The batteries will also have to be packaged very well so that in case of damage, the toxic materials in the battery don't get exposed to the body.
Auditory-related: Cochlear implants	• Cochlear Implants • Cochlear implants:	These batteries will be rechargeable types, though

	Current designs and future possibilities	it's not integral for them to be this way. They'll also have to be light, so it's not difficult to wear the cochlear implant. In the case of internal cochlear implants, the battery will have to be packaged well so that if something breaks, the toxic materials don't go into the wearer's ear canal and harm them.
Brain-related: Seizure treatments Neuropsychiatric rehabilitation	• Clinical utility of implantable neurostimulation devices as adjunctive treatment of uncontrolled seizures • An implantable device for neuropsychiatric rehabilitation by chronic deep brain stimulation in freely moving rats	For these applications, the battery will have to have to be packaged extremely well, since if the toxic materials are exposed to the body, there will be disastrous consequences. The battery will have to be flexible and light, and it'll have to be rechargeable since getting a surgery when it runs out of power is extremely inconvenient.
Bladder-related: Implantable bladder sensors and devices	• Implantable Bladder Sensors: A Methodological Review • A 3D Printed Implantable Device for Voiding the Bladder Using Shape Memory Alloy (SMA) Actuators	For this application, the battery will have to have to be packaged extremely well, since if the toxic materials are exposed to the body, there will be disastrous consequences. The battery will have to be flexible and light, and it'll have to be rechargeable since getting a surgery when it runs out of power is extremely inconvenient.

Drug-related: Sensors and controlled drug delivery	• Accuracy and Longevity of an Implantable Continuous Glucose Sensor in the PRECISE Study: A 180-Day, Prospective, Multicenter, Pivotal Trial • Implantable microchip: the futuristic controlled drug delivery system	The batteries for these microchips and sensors have to be small and they need to be packaged extremely well since the devices will be within the body and if there is damage to the device, then the toxic materials of the battery should not contaminate the body. Since these are microchips and sensors, the battery will need to be very small and light, and it'll also have to have a very high energy density.
Dental-related: Implantable orthodontic system	• Flexible and biocompatible high-performance solid-state micro-battery for implantable orthodontic system	Since this device will be within the mouth, it is extremely important that the battery be very well packaged and small. Having a rechargeable battery would be best, though one that could only last a single cycle would be fine also because the battery would be housed within the mouth, and would therefore be accessible.

5. Conclusion

While we have discussed several application areas in which solid-state lithium batteries will be extremely useful and life-enhancing, it is important to remember that science can sometimes progress at a slower pace than expected. This will make the market slow to reach maximum potential due to the differences between the pace of innovation and eventual market adoption. However, we live in a time full of opportunity, one where sudden scientific discoveries and creations abound. The market is also in constant pursuit of technologies and solutions that will enhance health outcomes and the quality of life. As the innovation and market motions converge, it is inevitable that the market for biocompatible solid-state lithium ion batteries will be booming within the next few years.