

# BIOCOMPATIBLE AND BIODEGRADABLE BATTERIES

## FOR WEARABLE & IMPLANTABLE DEVICES

### CURRENT ISSUE

As wearable and implantable medical devices continue to advance at an unprecedented rate, new capabilities for healthcare monitoring and treatment continue to emerge. However, the current lithium-ion battery technology used by these devices presents several fundamental challenges that currently hinder further development and integration on or within the body.



For batteries to remain a viable power source for medical devices, they must become safer, smaller, and more flexible while maintaining or enhancing current energy density levels. To achieve these requirements, design engineers need to explore and adopt innovative solutions that are currently under development, such as:



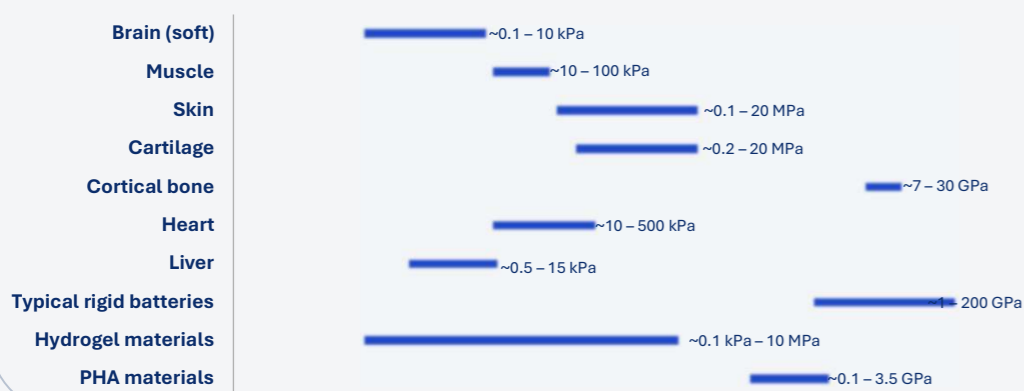
### PROJECT GOAL / TARGET OBJECTIVES / METHODOLOGY

**Project Goal:** This research project aims to design safe, flexible and mechanically compatible batteries for future wearable and implantable biomedical devices.

- Aims**
- 1: COMSOL Multiphysics will be employed to simulate and assess the conductivity of biocompatible ions like sodium and calcium in materials such as hydrogels, and compare them with traditional ions like lithium to determine optimal performance.
  - 2: Assess 2D and 3D conceptual battery designs with regards to their adaptability, anatomical compatibility, and biodegradability to determine their suitability for implantable biomedical applications.



### RIGIDITY COMPARISON: HUMAN BODY VS HYDROGEL & PHA & TRADITIONAL BATTERIES

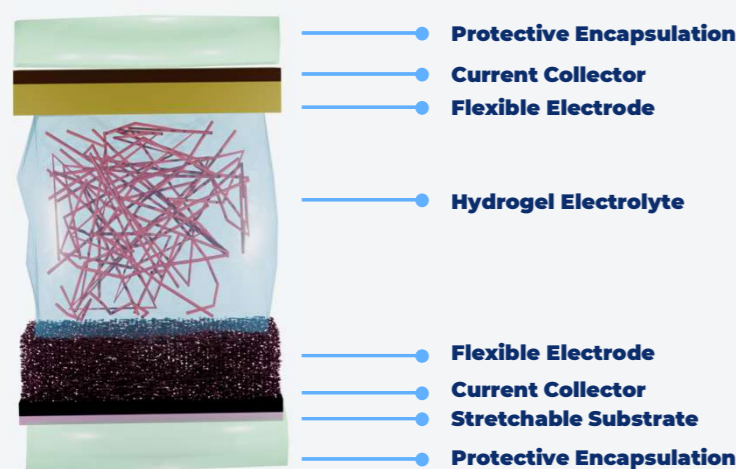


- Human tissues have a diverse array of rigidities, from soft brain tissue to rigid bone.
- The rigidity of conventional batteries is comparable to that of rigid bone, thereby restricting internal implantation sites
- Mechanical mismatch can induce adverse effects, ranging from inflammation to other immune responses
- For future biocompatible batteries to operate effectively, they need to conform to the body's surface topography and match the tissue's rigidity in the targeted area

### APPLICATION OF ALTERNATIVE MATERIALS

Hydrogels and polyhydroxyalkanoates (PHAs) are emerging as promising alternative structural materials for flexible biomedical batteries. As their unique mechanical and compositional properties enable their use in applications such as electrolyte separators to full-cell encapsulation, supporting safer and more adaptable battery architectures. When appropriately integrated, these materials can accommodate the bending, twisting, and stretching associated with natural body movements without compromising cell integrity or electrochemical performance.

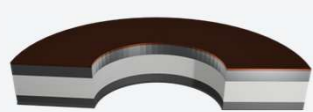
#### HYDROGEL BATTERY



#### POLYHYDROALKANOATE (PHA) BATTERY



#### BENDING CAPABILITY



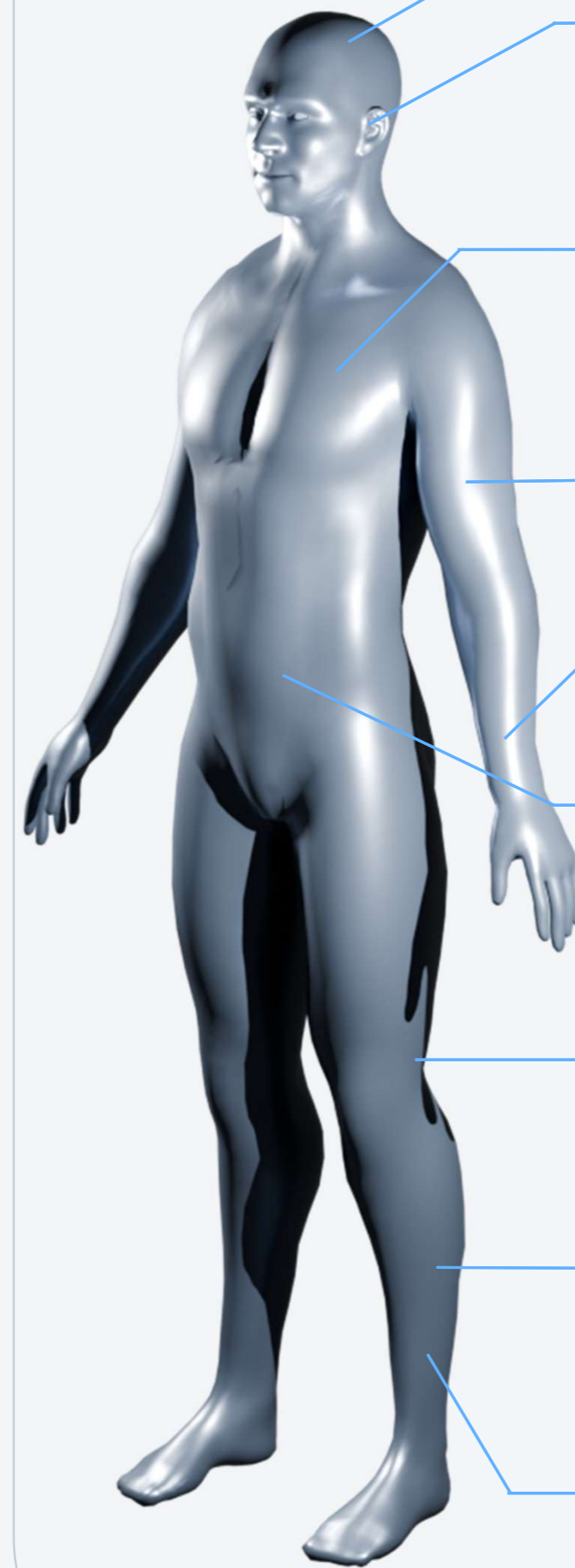
#### TWISTING CAPABILITY



#### STRETCHING CAPABILITY



### WEARABLE & IMPLANTABLE DEVICES



**BRAIN IMPLANTS**  
Record or stimulate neural activity at specific regions

**EAR-WORN DEVICE**  
Devices worn on or inside the ear that improve hearing or provide precise health tracking and physiological monitoring using biometric sensors

**CARDIAC PACEMAKER**  
Device placed under the skin near the collarbone to monitor your pulse and deliver precise electrical signals to maintain a normal, steady heartbeat.

**WEARABLE PATCHES**  
Flexible, medical or wellness devices applied directly to the skin.

**SMART BAND**  
Lightweight wearables focused on health, fitness, and daily notifications

**IMPLANTABLE PUMP**  
Device usually placed in the abdomen to continuously deliver precise doses of medication directly to a specific target area, such as the bloodstream, spinal fluid, or a tumour

**TISSUE ENGINEERING**  
Technological devices that are used in parallel with biomaterials to repair, replace, or regenerate damaged tissues and organs

**BIOSENSOR IMPLANT**  
A device placed beneath the skin, in blood vessels, or directly inside organs to continuously monitor physiological and biochemical data in real-time

**MUSCLE STIMULATOR**  
Uses low-voltage electrical impulses to trigger involuntary muscle contractions, mimicking natural brain signals used for physical therapy, muscle recovery

### COMPARISON OF BATTERY TYPES

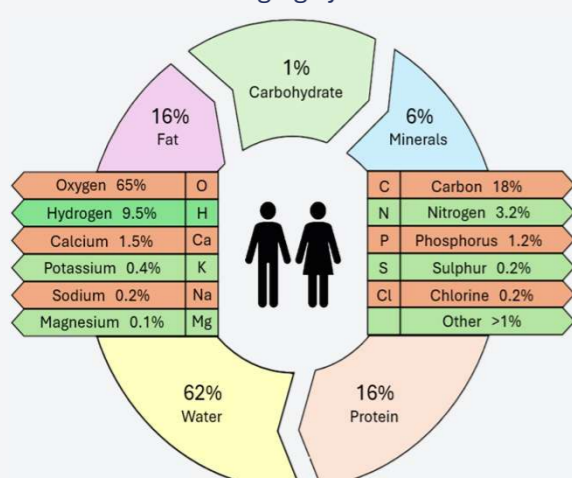
FEATURE	TYPICAL BATTERIES	HYDROGEL BATTERIES	PHA BATTERIES
Flexibility	X	✓✓✓	✓✓
Biocompatibility	X	✓✓✓	✓✓✓
Biodegradability	X	✓✓	✓✓✓
Power Density	✓✓✓	✓✓	✓✓
Energy Density	✓✓✓	✓✓	✓
Mechanical Match to Body	X	✓✓✓	✓✓
Environmental Impact	X	✓	✓✓✓

Legend: ✓✓✓ Excellent, ✓✓ Good, ✓ Fair, X Poor

### USEABLE ELEMENTS

To achieve genuine biocompatibility and mitigate the risk of adverse immune responses, battery chemistries should ideally incorporate elements that occur naturally within the human body. This approach, in turn, provides several significant benefits:

- Elements are well-tolerated by human tissues.
- The body can process and regulate these elements through existing biological pathways when no longer required.
- Using abundant, non-toxic elements minimises environmental hazards during production, use, and disposal.
- Chemistry could harness naturally occurring ions in body fluids, opening the door to innovative self-recharging systems

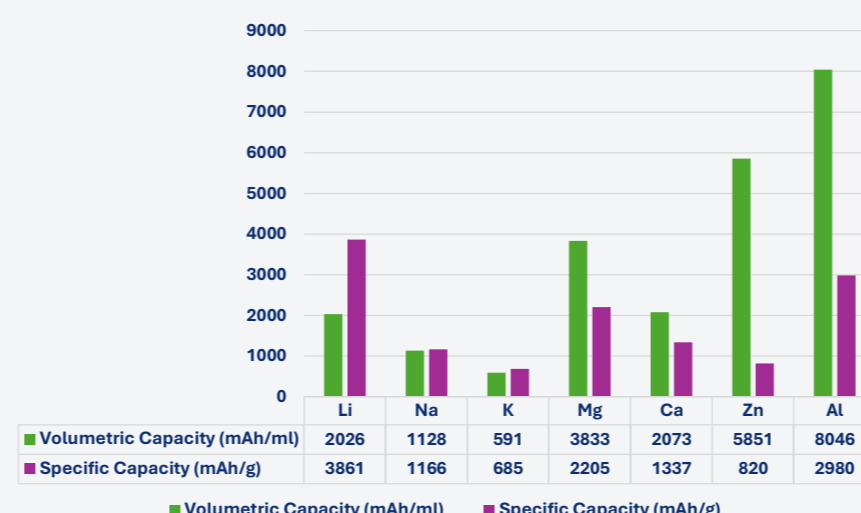


### ALTERNATIVE CHEMISTRY

#### ACTIVE ION SELECTION

The active ion in a battery is responsible for transporting charge through the electrolyte and also facilitates electron flow in the external circuit. Achieving the necessary biocompatibility in batteries requires that the active ion also be derived from elements inherently present in the human body. Considering the body's elemental composition, traditional monovalent ions can be used, but this also opens up the potential to utilise divalent ions, which may offer benefits such as:

- Greater theoretical energy density owing to the multivalent nature of the ions
- Lower tendencies toward dendrite growth compared to Li, Na, K
- Earth-abundant and cost-effective



### CHALLENGES WITH MULTI-ION CHEMISTRY

Despite the strong biocompatibility and potential advantages offered by dual-ion chemistries, several challenges must still be addressed before their practical implementation can be realised.

#### Challenges

##### Electrolyte Problems

- Poor ionic mobility
- Electrolyte instability
- Solvation / desolvation energy barrier
- Passivation layer formation
- Lack of compatible salts

##### Anode / Terminal Chemistry Problems

- Difficulty in metal plating and stripping
- Slow multivalent intercalation
- Structural collapse of crystal frameworks
- Limited suitable host materials

REFERENCES

- [1] H. D. J. Haines and M. H. Nazir, "Advancing battery technology for wearable and implantable devices: the current challenges and future directions - A short review," *Fuel*, Batter., vol. 8, p. 100148, Feb. 2020, doi: 10.1016/j.fuel.2020.100148.
- [2] "USW to develop biodegradable batteries for medical implants," 2020, <https://www.medicaldevice-network.com/news/usw-batteries-medical-implants/> (accessed May 25, 2020).
- [3] University of South Wales, "USW researchers develop biodegradable, body-safe batteries to power the future of medical implants - University of South Wales," Jul. 03, 2020, <https://www.southwales.ac.uk/news/2020/july/usw-researchers-develop-biodegradable-body-safe-batteries-to-power-the-future-of-medical-implants/> (accessed May 25, 2020).
- [4] "Wales university researchers develop biodegradable batteries to power the future of medical implants," 2020, <https://walesonline.com/news/wales-university-researchers-develop-biodegradable-batteries-to-power-the-future-of-medical-implants/> (accessed May 25, 2020).
- [5] Y. Dai, A. V. Berbenni, P. Mustarelli, D. Ravelli, C. Samori, and F. Quattaroni, "A biomass-derived polyhydroxyalkanoate biopolymer as safe and environmental-friendly skeleton in highly efficient gel electrolytes for lithium batteries," *Electrochim. Acta*, vol. 247, pp. 63–70, Sep. 2017, doi: 10.1016/j.electacta.2017.07.005.
- [6] S. Y. Yang et al., "Powering Implantable and Ingestible Electronics," *Adv. Funct. Mater.*, vol. 31, no. 44, pp. 1–49, 2021, doi: 10.1002/adfm.202009289.
- [7] Y. Wu et al., "Cathode materials for calcium-ion batteries: Current status and prospects," *Carbon Neutralization*, vol. 2, no. 5, pp. 561–573, 2023, doi: 10.1002/cn2.85.