The market for electronics is rapidly advancing towards miniaturization, flexibility, and elasticity, driven by the growing demand for wearable technologies, soft robotics, and human-machine interfaces. However, there remains a significant gap in materials that can simultaneously deliver high electrical conductivity, mechanical compliance, and scalability for such applications. This project addresses this challenge by **development of bi-continuous conductive polymer hydrogels (BC-CPHs), a class of advanced architectural materials with a unique combination of high electrical conductivity and exceptional mechanical strength**. These hydrogels offer transformative potential for applications ranging from flexible and stretchable electronics to soft robotics, miniaturized devices, biosensors, energy storage systems, and human-machine interfaces. By leveraging the principles of phase separation, this research aims to achieve precise control over the morphology of BC-CPHs. This novel approach enables the creation of materials with unprecedented performance in conductivity, elasticity, and structural stability, setting the stage for revolutionary advancements across various technological landscapes.

BC-CPHs are designed to merge two distinct phases—conductive and mechanical—into a single, interconnected network. This bi-continuous structure is achieved through spinodal decomposition and UV-induced photopolymerization, processes that are not yet fully understood or optimized for polymer systems. **The project will pioneer a comprehensive investigation into these mechanisms**, using a combination of experimental techniques, such as time-resolved microscopy and dynamic light scattering, and advanced computational modeling. The results will inform the design of new generation of multifunctional hydrogels with unique architecture and tailored properties, unlocking their full potential for various fields.

One of the most exciting applications of BC-CPHs lies in flexible and stretchable electronic devices. These materials provide a unique combination of softness, stretchability, and conductivity, making them ideal for interfaces that demand seamless integration with dynamic surfaces. For instance, they can be utilized in sensors, actuators, and energy storage systems where adaptability and high performance are critical. The scalability of this approach, combined with its compatibility with 3D printing and other advanced fabrication techniques, ensures economic feasibility and paves the way for broader adoption of these advanced materials across industries.

The project also **seeks to revolutionize our understanding of phase separation in complex polymer systems**. While bicontinuous structures have been explored in other contexts, their application to conductive hydrogels remains in its infancy. By integrating experimental data with multiscale computational models, this research will provide critical insights into how composition, curing conditions, and external stimuli influence the morphology and functionality of BC-CPHs. These findings will have far-reaching implications, contributing to the broader fields of materials science, soft robotics, and advanced manufacturing.

BC-CPHs are not merely a combination of mechanical and conductive phases; they represent a transformative platform capable of integrating multiple interpenetrating phases with distinct properties. For instance, thermal regulation or even magnetic functionalities can be incorporated alongside mechanical and electrical phases, unlocking entirely new possibilities for multifunctional materials. This versatility makes BC-CPHs particularly attractive for soft robotics, wearable technologies, human-machine interfaces, and next-generation energy systems, where diverse and synergistic functionalities are critical. By addressing fundamental scientific questions and targeting practical applications, this project positions BC-CPHs as a cornerstone of flexible, multifunctional, and sustainable electronics, heralding a new era of innovation across industries.