In recent decades, we have observed an extraordinary pace of civilization development and the associated constant increase in energy consumption. That is the cause of increasing pollution and degradation of the natural environment. For this reason, the search for alternative energy sources is ongoing. One such source is electrochemical devices, including fuel cells. Fuel cells are safe for the environment because they convert the energy of chemical reactions into electricity without producing pollutants. The only reaction products in a fuel cell are electricity and water. A crucial part of the fuel cell is a membrane made of an ion-conducting material (electrolyte). Currently, Nafion is the most commonly used polymer electrolyte for building membranes in fuel cells. Unfortunately, it has significant drawbacks: it is expensive and complicated to produce, environmentally unfriendly, and only conductive in its hydrated form. The presence of water in Nafion enables the transport of ions. That is a crucial limitation because the operating temperature of such a matrix is limited to below 100 °C. Such a low operating temperature of a fuel cell causes technological problems such as poor electrode performance, low heat transfer, catalytic converter deterioration, and the possibility of leakage. Increasing the operating temperature of the fuel cell would overcome these difficulties. Therefore, research is ongoing on new ecological materials that could replace Nafion.

The project aims to obtain and characterize the physicochemical properties of new composites based on nanocellulose by adding protic ionic liquids. The alternative biomaterials obtained will be solid polymer electrolytes designed with properties such as ionic conductivity above 100 °C, and stability – chemical, mechanical, and thermal – across a wide temperature range. They will also be easy to produce and environmentally friendly.

The most common natural polymer, cellulose, will be used to obtain nanocomposites. Cellulose is the building material of plants, is ecological, and is widely available. We will use cellulose nanocrystals (CNCs) and cellulose nanofibers (CNFs) to prepare new biocomposites. Nanocellulose is a nanoscale material, which means that at least one dimension of a single grain is from 1 to 100 nm. Cellulose nanocrystals and nanofibers are objects with nanometric diameters, and the lengths of the nanofibers can reach up to several micrometers. These are immensely durable, light, thermally, and chemically stable materials.

Nanocellulose matrices will swell in imidazole-based protic ionic liquids. Protic ionic liquids (PILs) are a subclass of ionic liquids. These are ionic liquids in which a positively charged atom is bonded chemically to at least one hydrogen atom. They have high thermal stability, high ionic conductivity, and relatively low viscosity. The use of imidazole-based PILs for the preparation of nanocellulose/PIL composites is motivated by their higher thermal stability compared to other ionic liquids and the immiscibility of imidazole PILs with water. This latter property will prevent the PIL from being washed out of the membrane by water, a product of the oxygen reduction reaction at the cathode in the fuel cell.

Comprehensive studies of their chemical, structural, mechanical, thermal, and electrical properties, as well as molecular dynamics, will be carried out to characterize the physicochemical properties of the obtained composites. In addition, we will study the thermal and electrical properties and molecular dynamics of protic ionic liquids. We will attempt to correlate the electrical properties of PILs and their composites with molecular dynamics and find a model capable of describing the ionic conductivity phenomena observed in the investigated compounds.

The subject of the project fits into the new direction of research on solid-state electrolytes, including the use of PIL and biopolymers. This project focuses on the emerging area of research related to solid-state electrolytes, specifically exploring the use of protic ionic liquids (PIL) and biopolymers. The execution of this project will enhance scientific knowledge and improve our understanding of conduction mechanisms in protic ionic liquids and new composite materials. The obtained electrolyte, with potential use in fuel cell technology, can make these devices more ecological and extend their operating time.