

With the growing demand for clean energy, hydrogen has emerged as one of the key candidates for future fuel sources. Hydrogen can be produced via water electrolysis; however, its efficiency depends on the electrocatalysts used. Currently, the most effective materials for this purpose are noble metal-based catalysts (e.g., platinum, iridium), which are costly and scarce. A promising alternative is the use of **single-atom catalysts (SACs)**, which offer high reaction efficiency while significantly reducing metal consumption.

This project aims to **develop an innovative methodology to enhance the stability and efficiency of SACs by integrating metal-organic frameworks (MOFs), conductive nanomaterials (single-walled carbon nanotubes – SWCNTs and borophene), and plastic deformation technology – high-pressure torsion (HPT)**. MOFs, as the starting material, will undergo controlled carbonization to form continuous carbon frameworks with high electrical conductivity and catalytic activity. E.g. nickel and cobalt single-atom sites will be precisely introduced to create stable active centers. The integration of SWCNTs and borophene will improve charge transport and mechanical properties, while HPT will allow additional structural control by introducing defects and increasing the active surface area.

This project will provide **new insights into the impact of MOF structure, nanomaterial integration, and HPT processing on SAC performance**. The developed methodology may contribute to the advancement of **durable, efficient, and cost-effective catalysts** for hydrogen production, representing a significant step toward future energy technologies. The research findings could be applied in modern clean energy production systems and in optimizing materials for fuel cells and supercapacitors.