

In the face of growing energy demand and the challenges posed by the ongoing climate crisis, it is essential to develop novel, clean, and renewable energy sources. Hydrogen, particularly so-called green hydrogen produced through water electrolysis powered by renewable energy sources, is considered one of the most promising fuels of the future. It is an energy carrier with high energy density that emits no greenhouse gases during use and can also be produced locally and efficiently stored, supporting the development of decentralized energy systems. The use of green hydrogen is gaining increasing recognition in sectors such as transportation, the chemical industry, and energy, offering a real opportunity to reduce carbon dioxide emissions and reduce dependence on fossil fuels. Nevertheless, despite its many advantages, the widespread implementation of this technology still faces challenges, particularly the high production costs associated with the use of expensive and rare noble metals as catalysts in the water electrolysis process. Therefore, the development of new, alternative catalytic materials with high activity and stability, based on abundant elements, is one of the key research directions in hydrogen technologies.

The aim of the proposed project is to develop advanced hybrid catalytic materials based on transition metal nitrides and carbon matrices doped with non-metallic heteroatoms. Although materials based on metal nitrides have been gaining increasing attention in the scientific literature, few studies have addressed their combination with doped carbon, despite the fact that such hybrid materials show great potential for green hydrogen production. The integration of these two material types aims to enhance the activity and stability of the catalysts while reducing their production costs. The proposed solution offers an attractive alternative to conventional catalysts based on noble metals, which, despite their high electrochemical activity, are associated with high manufacturing costs. The project will include the synthesis and comprehensive characterization of the physicochemical properties of innovative catalytic materials composed of transition metal nitrides and carbon matrices doped with phosphorus and sulfur. The scope of the research will cover both the optimization of synthesis parameters and an in-depth analysis of the crystal structure, surface morphology, and composition of the obtained catalysts. The materials will be tested for their electrochemical activity in two key reactions of the water electrolysis process: the hydrogen evolution reaction (HER) and the oxygen evolution reaction (OER). The project involves an application-oriented approach, in particular the relationships between chemical composition, surface structure and catalytic activity and stability of the catalysts obtained will be investigated. This analysis will enable the identification of structural and chemical features that are critical for achieving high performance and stability in the developed electrocatalysts.

The ultimate outcome of the project will be to establish a solid foundation for further development of green hydrogen production technologies on a larger scale. This project aligns with current trends in the development of sustainable energy technologies and may play a significant role in the energy transition toward climate neutrality and independence from fossil fuels. The results of the project will expand knowledge in the field of designing stable, efficient, and cost-effective catalysts based on earth-abundant elements, which may accelerate the development of green hydrogen technologies. The proposed solutions may find applications in transportation, the chemical industry, and energy storage. The project supports the goals of energy transition and climate neutrality, contributing to the advancement of the hydrogen economy and innovative low-emission technologies.