Currently, most of the world's energy needs come from fossil fuels. Unfortunately, the combustion of hydrocarbon fuels is responsible for greenhouse gas emissions and thus a large part of air pollution. Moreover, with growing concerns about the depletion of non-renewable resources and the consequent shortage of energy, the demand for which is constantly increasing, the world faces an urgent need to develop alternative fuels. Of the various alternatives, hydrogen fuel is promising, due to its environmental friendliness, resulting from reduced CO_2 emissions, and its unlimited availability. At the same time, it is a high-quality energy carrier that can be used with high efficiency. A promising method for obtaining hydrogen as a high-density energy carrier is electrochemical water splitting. So far, the noble metal platinum remains the most effective catalyst for hydrogen evolution reactions, while iridium oxide and ruthenium oxide are highly active for oxygen evolution reactions. Nevertheless, scarcity, as well as high cost, limit their widespread use. Therefore, the development of low-cost, highly active, and stable base metal-based catalysts is crucial.

Nitrides and their derivatives are widely considered very promising alternatives for water electrolysis due to their unique structure. However, metal nitrides are non-stable in a wide pH range. Accordingly, **the main aim of the Project's research work is the development and dissemination of innovative strategies for synthesizing stable nitride-based catalysts for effective "green hydrogen" production**. In order to achieve the goal, it was proposed to obtain advanced hybrid catalysts by combining the properties of metal nitride and nitrogen-doped graphene, which will consequently contribute to improve stability and catalytic performance. The proposed detailed aims will be based on the synthesis and characterization of nitrides including metal nitrides and their composites with nitrogen-doped graphene, and electrochemical tests. Two main reactions, the hydrogen evolution reaction (HER) and oxygen evolution reaction (OER) will be the basis of verifying practical application. The key innovation lies in the synthesis of new composite catalysts and controlling their physicochemical and electrochemical properties. A very important element of **the ongoing research will be the obtaining of novel catalysts that are highly stable and bi-functional, i.e., that exhibit activity in both the HER reaction and the OER reaction**. Furthermore, the synthesis strategy will be established taking into account the high variability of metal composition. The chemical state of atoms will be examined and characterized to make possible the choice of the most effective catalysts for the OER and HER reactions. This way, we will gain a precise determination of catalyst site types, which will be particularly important for the interpretation of electrochemical measurements. An important step will be determining the relationship between elemental composition and the materials' electrochemical activity in water splitting in contact with different electrolytes.

The proposed Project is expected, that will adopt a truly multi-scale approach to study possible catalysts – nitrides and their composites with nitrogen-doped graphene. Advancements in materials synthesis hold the key to producing novel catalysts and developing effective water splitting. Noble-metal-free catalysts can, in the future, reduce the costs of hydrogen production. For these reasons, the project aims to create a high technological, societal, and economic impact. The objectives and planned research within the framework of this proposal are interdisciplinary. It is believed that the structure-property connection in the catalysts and their composites with heteroatoms-doped graphene should be extensively analysed. The discoveries anticipated under this proposal will have a broad impact on research in a diverse range of disciplines, including materials science, chemistry, and electrochemistry. Therefore, the results gathered as part of this Project will be important for the future in the production of hydrogen, whose use in vehicles will be economically significant.