ABSTRACT FOR THE GENERAL PUBLIC

To effectively fight climate change, we must not only reduce CO_2 emissions, but also find new ways to reuse this greenhouse gas. One of the promising methods is CO_2 methanation**,** a process that turns carbon dioxide and hydrogen into methane, a clean and storable fuel. However, to make it viable, we need efficient and environmentally friendly catalysts to accelerate the reaction.

According to the above, the project aims to design a new generation of nickel-based catalysts using natural minerals (bentonite, kaolin) and agricultural waste (plant ash, rice husks). These materials are inexpensive, widely available, and often discarded, making them ideal for sustainable applications. By converting them into high-performance catalysts, we support a circular economy.

The proposed research project will be carried out through seven carefully planned stages and brings together partners from the Instituto de Tecnología Química (ITQ) Universitat Politècnica de València, and Sorbonne University in Paris. Each partner contributes unique expertise: ITQ is renowned for its work on mesoporous materials, and Sorbonne brings advanced knowledge in CO_2 methanation chemistry. The works will start with processing various natural materials to identify the most promising modification procedures. The project then moves to synthesizing materials with well-known properties and characteristic porous structures to serve as benchmarks, a task done in collaboration with ITQ during research visits. Next, the team will create mesoporous supports directly from natural resources and compare their performance to synthetic counterparts. Another part of the research investigates how adding small amounts of elements such as alkali metals, alkaline earth metals, and lanthanides (rare earth elements) can improve the efficiency and durability of the catalysts. We will study their individual and combined effects on methane production, CO_2 conversion, and catalyst stability. Finally, the project will test and compare four techniques for applying active substances onto the supports, to find out which methods work best with natural materials. All of the materials will be analyzed to understand their properties. Finally, the catalysts will be tested at both AGH and Sorbonne University to evaluate their performance in methane production. The team will look at how efficient, selective, and durable the materials are, even under challenging conditions. The final stage will integrate all findings into a comprehensive picture, showing which synthesis methods work best and why.

The motivation behind this research project stems from the numerous challenges facing the clean energy sector. Nickel-based catalysts are commonly used in CO_2 methanation processes, but their effectiveness decreases over time. This decline is mainly due to their sensitivity to reaction temperatures, carbon deposition as a side reaction product, and the presence of impurities in the gas mixture. Studies have shown that adding rare-earth elements or alkali/alkaline earth metals can improve the durability and efficiency of these catalysts. However, there is still a lack of clear data on how these elements interact in more complex, multi-component systems. Another important reason for undertaking this research is the high environmental cost of conventional catalytic materials, which are often energy-intensive to produce and generate waste. To address this, the project proposes replacing them with more sustainable raw materials. This approach not only reduces the amount of by-products, but also gives new value to underutilized natural resources.

This project is expected to deliver several important scientific and environmental outcomes that can help advance clean energy technologies and support global efforts to reduce greenhouse gas emission: (1) new knowledge on sustainable catalysts – a deeper understanding of how different natural supports can be activated and optimized to rival or even outperform conventional synthetic materials; (2) clearer understanding of promoting elements – we expect to clarify the roles of alkali/alkaline-earth and lanthanide metals (individually and in combination) in enhancing CO_2 methanation; (3) evaluation of modern catalysts preparation methods – through the systematic comparison we will determine which techniques work best with natural supports; (4) prototype catalysts for future green technologies – although the project is focused on fundamental research rather than commercial applications, it will deliver a set of well-characterized catalyst samples serving as prototypes for future use in renewable energy systems (power-to-gas technologies, carbon recycling plants); (5) practical contribution to circular economy goals – transformation of agricultural/mineral waste into valuable materials highlights how *waste* can become a key in sustainable solutions for climate change; (6) strengthened international collaboration and knowledge transfer – collaborative work with ITQ and Sorbonne Université ensures high-quality research, access to specialized expertise, and long term international partnerships extending beyond this project. Taken together, these results will provide the scientific community with new knowledge to design greener catalysts, which help us to mitigate excessive CO_2 emission.