1. PHD PROJECT DESCRIPTION (4000 characters max., including the aims and work plan)

Project title: Non-electrochemical extraction of hydrogen from water

1.1. Project goals

- ✓ The project aims to develop a method of obtaining hydrogen from different type of algae.
- ✓ To upgrade the knowledge and skills in the area of "green" energy harvesting devices design.
- ✓ An attempt to obtain prototypes of various electrochemical devices
- ✓ To upgrade social competences such as team working and cooperation spirit.

1.2. Outline

Hydrogen is the fuel of the future, but perhaps not that far away. Today, the ecologically cleanest source of this substance is water and its decomposition in the photosynthesis process, carried out by algae working in appropriate conditions.
However, there is a serious obstacle standing in the way of constructing efficient and truly green bioreactors. It turns out that hydrogenases, enzymes directly responsible for hydrogen production, are destroyed in the presence of oxygen. Could they be made resistant to the influence of the atmosphere? So far, this has not been possible because the mechanism of their degradation by oxygen was not well understood.
The most ecological source of hydrogen could be bioreactors with green algae. The proposed method uses widely available reagents (commercial graphite/graphene powder, water, surfactants, raw materials different types of algae) and is environmentally friendly. This project aims to develop, investigate, and characterize novel, stable, and cost-efficient electrodes for electrochemical applications mainly for green hydrogen. The knowledge and experience in materials chemistry and electrochemistry, as well as access to highly specialized equipment (TEM, Raman spectrometer, Potentiostat/Galvanostat, spectrofluorimeter, UV-Vis), is required for the successful realization of the planned studies.

1.3. Work plan

The following research stages will be included in the research to obtain the doctoral degree:

1) To explore the relation between the chemical structure of carbon materials and obtaining hydrogen
2) Alternative synthesis pathway to obtain new materials.
3) Carbonization in a different range of temperature 500-1200°C of investigated carbon material / template / binder mixtures obtained by soft and hard templating.
4) Physico-chemical characterization of obtained carbon matrixes by instrumental methods:

nitrogen adsorption (porous structure and surface area), elemental analysis (chemical composition), XPS spectroscopy (chemical structure of the surface), X-ray (crystal structure), Raman spectroscopy (identification of graphene agglomeration degree), SEM/HRTEM microscopy (identification of spatial structure).

5) Research on selected applications of obtained materials for green hydrogen, bioreactors and electrochemical equipment.

1.4. Literature *(max. 10 listed, as a suggestion for a PhD candidate)*

1) **P. Kamedulski**, W. Zielinski, P. Nowak, **J.P. Lukaszewicz**, A. Ilnicka, 3D hierarchical porous hybrid nanostructure of carbon nanotubes and N-doped activated carbon, Scientific Reports 10 (1), 1-11, **2020**.

2) **P. Kamedulski,** M. Skorupska, P. Binkowski, W. Arendarska, A. Ilnicka, **J.P. Łukaszewicz**, High surface area mesoporous graphene for electrochemical applications, Scientific Reports, 2021, 11, 22054.

3) **P. Kamedulski, J.P. Lukaszewicz**, L. Witczak, P. Szroeder, P. Ziolkowski, The Importance of Structural Factors for the Electrochemical Performance of Graphene/Carbon Nanotube/Melamine Powders towards the Catalytic Activity of Oxygen Reduction Reaction, Materials 14 (9), 2448, **2021**.

4) X. Luo, Y. Chen, Y. Mo, A review of charge storage in porous carbon-based supercapacitors, New Carbon Materials 36 (1), 49-68, **2021**.

5) **Kamedulski, P.**; Truszkowski, S.; **Lukaszewicz, J.P.;** Highly Effective Methods of Obtaining N-Doped Graphene by Gamma Irradiation, Materials, 2020, 13 (21), 4975.

6) Ilnicka, A.; Skorupska, M.; Szkoda, M., Zarach, Z., **Łukaszewicz, J.P.** N-doped carbon materials as electrodes for highly stable supercapacitors, Materials Research Letters 2023, 11 (3), 213-221

7) A. Ilnicka, M. Skorupska, M. Szkoda, Z. Zarach, **P. Kamedulski**, W. Zieliński, **J.P. Łukaszewicz**, Combined effect of nitrogen-doped functional groups and porosity of porous carbons on electrochemical performance of supercapacitor, Scientific Reports, 2021, 11, 18387.

8) A. Ilnicka, M. Skorupska, M. Tyc, K. Kowalska, **P. Kamedulski**, W. Zieliński, **J.P. Łukaszewicz**, Green-algae and gelatin-derived nitrogen-rich carbon as an outstanding competitor to Pt-loaded carbon catalysts, Scientific Reports, 2021, 11(1), 1-13.

1.5. Required initial knowledge and skills of the PhD candidate

1) Basic knowledge on photovoltaic devices and their design
2) Orientation in contemporary and future trends in the area of "green" energy harvesting methods
3) Analytical thinking
4) Eager to learn
5) Ability to work in the laboratory (plan and perform synthesis, spectral measurements, electrochemical tests)
6) Understanding of materials synthesis and chemistry
7) Thinking oriented on innovation and application
8) Knowledge of carbon material science
9) Knowledge about basic methods to characterize obtained compounds
10) Eager to work hard

1.6. Expected development of the PhD candidate's knowledge and skills

1) Project management: the ability to plan and organize the project as well as delegating and negotiating tasks among project members.
2) Perseverance: the driver and determination to continue and finish a PhD student project.
3) Supervising and coaching: the ability to transfer knowledge and inspire others.
4) Communication skills in English at conferences and in writing publications.
5) Writing grant proposals.
6) Research data collection, analysis and conversion to research papers.