This project investigates and develops new generation hybrid soft magnetic composites (SMCs) for energy-efficient electromagnetic applications, such as electrical motors, transformers, inductors, and sensors at high frequencies. The main objective of this project is to investigate the magnetic properties, crystal structure, morphology, and size/shape effect of the newly developed hybrid SMC materials obtained from exceptionally good soft magnetic powders with the general formula $Fe_{100-x-y-z}Ni_xCu_y(Si,P,B)_z$, x=0,…,4; y=0,…,2;z=12,…,18, ZnO insulation coating and soft-soft (Fe_3O_4@$ZnNiFe_2O_4$) or soft-hard/hard-soft (Fe_3O_4@$CoFe_2O_4$, $CoFe_2O_4$@$ZnNiFe_2O_4$, $ZnNiFe_2O_4$@$CoFe_2O_4$) core-shell spinel phase ferrite nanoparticles as magnetic insulator activator.

The research planned for implementation will allow verification of the following research hypotheses:
1. A properly selected amount of Cu addition in the NANOMET-like alloy allows for obtaining amorphous and brittle melt-spun ribbons for ball-mill powdering.
2. The plasma spheroidization process on non-spherical amorphous ball-milled ribbon powders allows obtaining amorphous/partly amorphous and fully-spherical powders.
3. By modification of the two-step synthesis method parameters, the different modulation, size, shape and magnetic properties of core-shell ferrite nanoparticles can be obtained.
4. The cold sintering compaction method allows the preparation of the hybrid SMC materials without deteriorating the magnetic properties.
5. The presence of proper core-shell nanoparticles and ZnO insulating coating enhances the magnetic properties of the hybrid SMC material, e.g. increases the permeability and decreases the energy losses.

In order to achieve the research goals and verification of the research hypotheses, the planned studies have been divided into six main work packages containing: preparation of master alloys and melt-spun ribbons; powders preparation and their plasma spheroidization; synthesis of multipurpose insulating coatings; composite core preparation; structural and magnetic properties studies. Ideal SMCs should consist of metallic ferromagnetic powders with high saturation entirely separated by a thin insulating layer with large electrical resistivity. This unique structure endows the SMCs with significant magnetic properties such as high permeability, large saturation magnetization, high electrical resistance, and low eddy current loss, even at high frequencies. Nowadays, a limited number of metallic ferromagnetic powders with fully or partly spherical shapes and possessing good soft magnetic properties can be used for SMCs. To overcome this limitation in this project, a novel technological approach will be introduced to obtain partly- and fully-spherical ferromagnetic powders of NANOMET-like alloy (NANOMET - $Fe_{83.3}Si_4B_8P_4Cu_{0.7}$). These alloys exhibit excellent soft magnetic properties, high induction saturation (Bs), and low coercive force (Hc). The proposed novel approach starts by obtaining a NANOMET-like alloy in the form of an amorphous and brittle ribbon via the melt-spinning technique; therefore, the Cu content will be properly adjusted to increase the ribbon's brittleness. Then, the ball-milled ribbon powder will be spheroidized via the plasma spheroidization process. Independently, the core-shell ferrite nanoparticles will be obtained using a novel two-step method for application as a magnetic insulation activator. Finally, the cold sintering compaction in the presence of ZnO insulating binder of NANOMET-like powders and core-shell nanoparticles will allow obtaining novel hybrid SMC materials. This project is highly interdisciplinary, combining three disciplines: process engineering, materials engineering, and physics.

As a result of the work carried out, some novelty aspects that belong to material and process engineering are expected to be obtained, which will contribute to obtaining new-generation materials. Firstly, the chemical composition of NANOMET-like alloys will be determined to achieve amorphous and brittle melt-spun ribbons. Then, the plasma spheroidization technology will be developed to obtain partly- and fully-spherical powders from non-spherical NANOMET-like ball-milled ones. Next, the novel two-step core-shell nanoparticle synthesis method will be developed. Based on both developed methods, the novel hybrid SMC materials containing NANOMET-like powders, ZnO insulation and ferrite core-shell nanoparticles will be obtained. The new knowledge related to the tuning effect of core-shell nanoparticles on complex permeability and energy loss components will help us understand the functionality of these materials. The acquired information on the correlation of crystal structure and magnetic properties of all components, including the magnetic influence of core-shell nanoparticles on insulating coating and loss components, will allow to propose new materials for high-performance and ecological power electronics.