Li-ion batteries are currently the most dynamically growing devices for electrical energy storage for portable electronics, electric and hybrid vehicles, as well as for large scale energy storage. Since resources of lithium and transition metals, particularly cobalt, are limited, cobalt-free Na-ion batteries have been recognized as one of the potential candidates for next-generation rechargeable batteries, because of their comparable energy density, significantly reduced costs and practically unlimited resources of sodium. Sodium is the fourth most common element on earth. Furthermore, known compounds are exhibiting reversible reaction with sodium with a similar mechanism of operation to that of Li-ion batteries and competitive level of 3 – 4 V vs. Na^+/Na and with electrochemical capacity between 100 – 150 Ah kg^{-1} enabling practical application in electrochemical energy storage. Although Na-ion batteries are a highly promising technology for energy storage, they are not available in the market yet. Efforts in materials research and innovation are necessary to prepare industrial manufacturing of Na-ion batteries, and simultaneously, to improve the competitiveness of the European industry.

In the AGH UST we develop a low cost, green chemistry, low temperature synthesis method yielding nanometric cathode material $Na_2Fe_2(SO_4)_3$ with 3D skeleton structure exhibiting promising electrochemical properties. There are only a few, literature reports on synthesis of this material suggesting that it is not possible to obtain it without a significant amount of impurities (17 wt.%). The AGH group proposed a synthesis method, which leads to a much lower impurity level (3 wt.%). Our cathode material exhibits the highest Fe^{3+}/Fe^{2+} redox potential found so far, equal to 3.7 V vs. Na^+/Na. Such high redox potential combined with high capacity for sodium intercalation leads to particularly large theoretical energy density of 456 Wh kg^{-1}. These features enable the design of Na-ion batteries competitive with an Li-ion analogue, which until recently seemed unfeasible. In order to achieve this goal, the intrinsic drawback of this material, i.e. a low electrical conductivity that limits the current density generated by the cell, has to be overcome.

It is assumed that the substitution of Fe by another 3d metal can modify the localized nature of electronic states responsible for the very low electrical conductivity of $Na_2Fe_2(SO_4)_3$. The disclosure of relationships between crystal and electronic structure, valence states, transport properties, and reactivity in relation to sodium will provide an invaluable tool for the development of high efficiency of the sodium intercalation process and consequently a high battery performance.

Due to the decisive role of cathode material in high voltage Na-ion batteries we will focus on comprehensive interdisciplinary research involving chemistry, physics and solid state electrochemistry as well as computer modeling. We intend to optimize synthesis method, chemical composition and morphology of nanometric $Na_2M_2(SO_4)_3$ (M=Fe, Mn, Ni…)-based cathode material in order to control the electrochemical processes and the cathode potential and its changes during sodium deintercalation/intercalation, as well as to ensure high performance and the required reliability of batteries.

Based on the expertise of the Polish partner (PI J. Molenda) in electronic structure engineering and the Germany partner (PI E. Zschech) in the field of 3D microstructure characterization of materials for the first time we will perform joint efforts towards development of advanced hierarchically structured cathode materials for Na-ion batteries. A profound microstructure study of the composite cathode material in order to improve the macroscopic electrical conductivity (a serious drawback of this material) will be undertaken. These studies will be targeted to design and engineering of advanced materials with tailored 3D microstructure. We plan to apply multi-scale microscopy techniques including newly developed, unique transmission X-ray microscope for a wide range of photon energies (deepXscan DXS 1) combined with a chamber for electrochemical processes will allow non-destructive high-resolution imaging of kinetic processes (operando) to characterize the 3D morphology of the obtained hierarchically structured electrodes with optimized microstructure. Taking into account the potential of both partners, there is a realistic chance to develop a high voltage (3.7 V) sustainable cobalt-free cathode material for Na-ion batteries within this project.