

More than 80% of the current energy economy relies on fossil fuels. Hydrogen, with its specific energy density three times higher than that of common fossil fuels is considered a sustainable and clean fuel of the near future. But why we have not yet replaced fossil fuels with H₂? From a chemist point of view this issue boils down to one crucial problem: **we are still not able to efficiently produce H₂ from water and then extract maximum electricity from this fuel by oxidizing it with atmospheric O₂. This is due to the lack of cheap and efficient catalysts for H–H and O=O bonds formation and cleavage.** The vision of *hydrogen economy* relies on efficient production of H₂ from water and its efficient utilization in fuel cells. Both, electricity-to-H₂ and H₂-to-electricity conversions are still very inefficient. Today, most of H₂ production comes from natural gas, while electrolysis of H₂O accounts for only 2% of commercial H₂. In *hydrogen economy* H₂ acts as the energy carrier (energy is stored in H–H bonds), and the energy utilization is independent of thermal cycles. Obtaining energy from a fuel by its direct combustion in air is limited by the Carnot cycle (only ~30% of energy can be extracted from the fuel). In theory, fuel cells offer efficiency close to 100%, but in reality efficiency of H₂/air fuel cells is ~40%. The core of H₂-based economy is down to a simple, reversible process: $\text{H}_2\text{O} \rightleftharpoons \frac{1}{2}\text{O}_2 + \text{H}_2$ exhibiting standard potential of 1.23 V. It comprises four separate reactions: H₂ evolution reaction, O₂ evolution reaction, H₂ oxidation reaction, and O₂ reduction reaction. O₂ reduction and evolution reactions rates are two orders of magnitude slower than that of the corresponding H₂ oxidation and evolution rates and account for most of energy losses. Consequently, water-splitting needs an extremely high input voltage >1.6 V (instead of 1.23), while fuel cells can only output a very low cell voltage <0.9 V. Redox reactions in which both electrons and protons are transferred (electroprotic reactions) are responsible for fuel-forming and fuel consuming processes in chemistry and biology. Electroprotic processes in nature are facilitated by metalloenzymes which possess 3d transition metal ions in their active centers. Nitrogenases or oxidases utilize multiple electron- and proton-transfer steps to activate stable molecules of N₂ or O₂. By copying the nature, researchers investigate artificial 3d metal complexes as catalysts in energy conversion reactions. Glucose formation by CO₂ reduction in photosynthesis and the reverse – its oxidation by O₂ in respiration – are both multistage H⁺/e⁻ transfer processes catalyzed by transition metals. The energy stored in the C–H bonds in glucose can be released by indirect reactions with O₂ at physically separated processes. Energy conversion in biology or in fuel cells occurs at physically separated electroprotic half reactions. Respiration in aerobic organisms or H₂ oxidation in fuel cell utilizes O₂ as the terminal electron acceptor and catalyst is required for efficient progress of such reactions. The goal of this project is to develop **single-atom catalysts (SACs)** based on Fe(II) ions coordinated by four pyridinic nitrogens (a square-planar Fe(II)–N₄ site) infused into porous carbons. Due to the mononuclear nature of the active sites, SACs bridge the gap between homogeneous and heterogeneous catalysis with 100% utilization of the metallic phase. Fe(II)–N₄–C single-atom catalysts mimic metal complexes in metalloenzymes based on *porphyrinic* rings (e.g. *heme*) but they are much more active, stable and resistant to poisoning due to the surrounding conductive graphene-like sheets and because the chelating nitrogens are in pyridinic configuration while in porphyrins they are in pyrrolic configuration. To obtain carbon-based Fe(II)–N₄ catalysts high temperature treatment is required, and hence control of their final structure is extremely difficult. However, due to the exceptional thermochemical stability of Fe(II)–N₄ sites they can be selectively created. For this reason a multi-stage synthesis where each step of the Fe(II)–N₄ site formation is realized at specific conditions should be the best approach to maximize their content within carbon material. Fe(II)–N₄–C can catalyze various electroprotic processes including CO₂ and N₂ electroreduction and hence they are considered versatile and universal. O₂ electroreduction will be the main reaction under scrutiny due to its importance in H₂ fuel cells. Nowadays, Pt catalyst represents 45% of the fuel-cell stack cost. Direct H₂ fuel cell electric vehicles (with cruise ranges of ~650 km and refueling time of 4 min.) are selling at increasing rates in the United States (over 6500 in 2019), but the current Pt target loading (**10g Pt per vehicle**) still presents an impediment for the large-scale fuel cell cars manufacturing. Fe(II)–N₄–C catalysts are estimated to be ~200 times cheaper than Pt-based catalysts and they constitute great alternative to noble metal-based electrocatalysts not only for fuel cell cars but also for CO₂ and N₂ electroreduction. From a broader perspective, since ca. 85% of all chemicals are produced in catalyst-assisted processes, single-atom catalysis holds great potential for fast development.