

How to Unify Catalytic Processes for Energy Technologies?
Merging Oxygen Evolution and Oxygen Reduction Reactions
With Multifunctional Metal Oxide Catalysts

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Attaining efficient catalysis of both the oxygen evolution reaction (OER) and oxygen reduction reaction (ORR) plays a major role in energy conversion and storage devices, especially in fuel cells, metal-air batteries, electrolysis cells, and in solar fuel synthetic reactors.^[1-8] Design and development of active materials that are naturally abundant, eco-friendly and economically viable have still remained an unresolved problem in energy conversion and storage. Interestingly, in nature, OER occurs in photosystem II (PS II) that is present in the green plants, algae and cyanobacteria. The reaction proceeds in the PS II and is catalyzed by a Mn₄Ca cluster, the oxygen evolution center (OEC) by the four-electron and four-proton redox reaction, and has been the inspiration to resolve the predicament of sustainable energy production. Although numerous efforts have been made to utilize the naturally occurring enzymes towards electrochemical OER, the instability of such enzymes at operating conditions causes the major concern for commercialization. Over the years, extensive investigations have been carried out to find suitable OER catalysts which could work very efficiently for the reaction of water splitting (solar fuels). The best known materials for OER are based on ruthenium and iridium species. However, the scarcity of such materials limits their large scale application. On the other hand, platinum-based materials are known to be the most active for the reverse reaction of OER, i.e., for ORR in fuel cells and metal-air batteries. The main drawback of using platinum as the catalyst is the high cost and their deactivation during continuous operation. Similarly, the attempts have also been made to couple (or even merge) OER and ORR with the respective high performance catalysts to explore bifunctionality. The highly active ruthenium- or iridium-based OER catalysts are less effective for ORR and the efficient platinum-based ORR materials are moderately active for their reverse reaction, OER.

Recently, we could show that the OER and ORR processes can be merged in single multifunctional metal oxide catalysts which are easily accessible by the single-source precursor approach.

For example, we reported on cobalt manganese spinels¹ and iron cobalt oxides² which represent unprecedented multifunctional catalysts that are highly active, remarkably stable, and unify electrochemical oxygen evolution reaction (OER) at both alkaline and neutral pH, oxidant-driven, photochemical water oxidation in various pH, and electrochemical oxygen reduction reaction (ORR) in alkaline medium. These and related materials syntheses with the ultimate aim to unify catalytic processes for energy technology will be discussed in the talk.

1. P. W. Menezes, A. Indra, N. R. Sahraie, A. Bergmann, P. Strasser, and M. Driess *ChemSusChem* **2015**, 8, 164.
2. A. Indra, P. W. Menezes, N. R. Sahraie, A. Bergmann, C. Das, M. Tallarida, D. Schmeißer, P. Strasser, and M. Driess *J. Am. Chem. Soc.* **2014**, 136, 17530.