**Workshop Title:** Characterization of Electrochemical Energy Storage Systems: Advanced Spectroscopy, Microscopy and Diffraction Techniques

**Organizers:** Hong Gan (Brookhaven National Laboratory), David Bock (Brookhaven National Laboratory)

A workshop titled “Characterization of Electrochemical Energy Storage Systems: Advanced Spectroscopy, Microscopy, and Diffraction Techniques” was held during the 2018 NSLS-II and CFN Joint Users’ Meeting at Brookhaven National Laboratory, Upton, NY on May 22nd, 2018. The workshop brought together experts in advanced characterization from across the national lab network to showcase state of the art capabilities in spectroscopy, diffraction, and microscopy as they apply to electrochemical energy storage systems. The five hour and 30 minute workshop hosted seven domestic speakers.

The workshop began with a talk from Johanna Nelson Weker (SSRL, SLAC National Accelerator Laboratory), who discussed a multimodal approach combing information from high resolution X-ray microscopy and spectra-microscopy, micro- and nano-tomography, X-ray diffraction, and X-ray absorption spectroscopy to track electrochemical, morphological, and structural changes in electrode materials in real time during typical battery operation. Dr. Weker also discussed best practices for the design and construction of cells for *in situ* and *operando* experiments. The next speaker, Dong Su (Brookhaven National Laboratory), shifted topics to advanced (scanning) transmission electron microscopy techniques. His talk covered recent work on using in-situ and analytical TEM to characterize the conversion-reaction oxide material (Fe3O4) for lithium ion battery electrodes, and Pt based nanocatalysts for fuel cells, and demonstrated that a combined *in situ* and *ex situ* TEM approach can be used to determine the kinetics of battery reaction pathways as well as strain coupling at interfaces. Ashfia Huq’s (Oak Ridge National Laboratory) presentation followed, detailing the use of neutron crystallography to elucidate structures of electrode and solid electrolyte materials used in Li-ion battery materials. She also discussed the recent development of *operando* neutron powder diffraction approaches. The fourth speaker, Carlo Segre (Illinois Institute of Technology) described the use of *in situ* and *operando* X-ray absorption spectroscopy, including what elements and electrode materials are conducive for these types of measurements, the design of cells for *in situ* work, and recent results on high cycling performance materials for lithium ion batteries and aqueous based nanofluid flow batteries. Karen Chen-Weigart’s (Stony Brook University and Brookhaven National Laboratory) presentation discussed multi-modal, multi-dimensional, and *operando* synchrotron to provide 3-dimensional spatial characterization, time resolved measurements in a real environment, and elemental and chemical sensitivity. She also presented novel coherent scattering techniques that are now available to address dynamics on the order of sub-seconds and which provide new possibilities in studying materials processing for energy storage materials. The next speaker, Marca Doeff’s (Lawrence Berkeley National Laboratory) presentation described the use of soft X-ray absorption spectroscopy (XAS) and X-ray photoelectron spectroscopy (XPS) for depth profiling and interrogation of interfaces in NMC (LiNixMnyCozO2) cathodes and LLZO (variants of Li7La3Zr2O12) ceramic electrolytes. In the final talk Jianming Bai (Brookhaven National Laboratory) covered the use of in-situ synchrotron X-ray powder diffraction (SXPD) as applied in studies of synthesis processes of cathode materials for Li-ion batteries, with specific examples including LixNa1-xVOPO4F0.5 and layered cathode materials.

In summary, the workshop presentations identified best practices and guidelines for *in situ* and *operando* studies, detailed the capabilities and limitations of current methodology, and gave examples of synergistic experiments that lead to transformative advances in the field. The breadth of expertise from the workshop speakers provided the audience a comprehensive overview of advanced characterization techniques for probing energy storage systems.