Status and Outlook for Fusion Energy in the Emerging Energy System

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Driven by the need to expand access to electrical energy while reducing CO_2 emissions, investment in the deployment of wind and solar generation of electrical energy is growing rapidly as their unit costs decline. Diurnal storage, usually in the form of utility-scale Li-ion battery systems, is also beginning to be integrated with these generation technologies to improve system reliability. However, multiple studies show that incorporation of significant amounts of dispatchable carbon-free generation from a mix of nuclear fission-based generation, engineered geothermal, hydropower, and/or fossil-fuel generation with carbon capture and sequestration in a renewables-heavy power grid offers the least cost pathway to a high-reliability carbon-free electricity system. Motivated by the need for additional carbon-free dispatchable generation as well as by recent advances in publicly funded controlled fusion research, a significant amount of private capital has begun to flow into the development of nuclear fusion as a fundamentally new carbon-free generation technology. This talk will review these developments and provide a summary of the status, outlook, and remaining challenges of fusion as a practical, affordable and safe energy technology.

Sunlight to X: Converting solar energy into chemicals, fuels and products

William Tumas, National Renewable Energy Laboratory, Golden, CO

There are remarkable advances for efficiently and cost-effectively interconverting solar and chemical energy (i.e. power to X and solar to X) to create products, fuels, and materials. This lecture will discuss the opportunities and challenges at the nexus of renewable energy, chemistry, physics and materials science. Advances in materials discovery, photovoltaics, solar fuels, hydrogen generation and utilization, electrochemical conversions, and carbon dioxide utilization will be presented along with key questions and remaining challenges. An overview of NREL's program in electrons to molecules initiative will be provided along with a summary of the Mission Innovation Sunlight to X innovation community. Cost, performance, reliability, supply chain, scalability, and sustainability challenges for electrochemical and photoelectrochemical conversions include the electrolyzer/device, power supply/power electronics, balance of system, energy source/renewable electricity, and feedstocks. The value proposition for innovation, translational R&D, and process integration will also be discussed.

Grand Challenges in the Physics of Wind Energy

Julie Kay Lundquist, Johns Hopkins University

As the world moves away from fossil fuels and towards more renewably-generated electricity, interdisciplinary challenges become more prominent. In the wind energy arena, the intersection of atmospheric science, engineering, and physics offer several interesting areas of research. In this talk, I will survey some of the "Grand Challenges" of wind energy research. These challenges include fundamental approaches for turbulence modelling, development of novel simulation approaches, assessment of the impacts of wind turbine wakes, and quantification of winds and loads in extreme conditions like tropical cyclones.

Probing Mechanisms in Energy Storage and Conversion Materials via Synchrotron X-ray Imaging and Multimodal Characterizations

Karen Chen-Wiegart
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The presentation will focus on the critical importance of gaining a mechanistic insight into the morphological, chemical, and structural changes of energy materials to propel future technological advancements. We will discuss the essential contributions of multimodal, imaging and *operando* synchrotron X-ray techniques to advance our understanding of these intricate materials systems. Specific examples to be explored include advanced beyond Li-ion battery, materials designed for harsh conditions such as those encountered with molten salts and thermal cycling, as well as nanoporous and nanostructured materials created by dealloying.

Accelerating Scientific Discovery in Catalysis with Interpretable Deep Learning

Hongliang Xin, Department of Chemical Engineering, Virginia Tech

In the rapidly evolving landscape of catalysis science, the discovery of novel catalytic materials stands as a pivotal challenge with vast implications for energy sustainability, decarbonization of industrial processes, and environmental remediation. Attributed to its unique capability of recognizing hidden patterns in high-dimensional data, machine learning offers exciting new directions in catalysis science. While deep learning technologies have witnessed remarkable strides over the past decades, particularly in healthcare, finance, and entertainment, exploiting its potential in scientific research poses distinct challenges. These challenges often stem from the complexity of scientific data, the need for interpretability, and the rigorous standards of reproducibility and validation inherent to scientific methods. In this talk, we present an interpretable deep learning framework for accelerating catalytic materials design, with electrochemical carbon, nitrogen, and oxygen transformations on highly complex nanostructures as specific examples. Our discussion will delve into the challenges and prospects of interfacing artificial intelligence (AI) with self-driving labs as a materials innovation platform, and more importantly, for advancing our domain knowledge beyond conventional wisdom. We envision future directions in developing human-centered, semi-autonomous AI agents, facilitating the maturation of the data science paradigm for scientific discovery in catalysis.

Batteries for Long Duration Electrical Storage: Options and Obstacles

Carlo Segre, Illinois Institute of Technology & Influit Energy, LLC

As the power generation landscape turns increasingly to renewable energy sources, the need for effective long-duration energy storage (LDES) solutions becomes critical. This talk examines the technical, economic, and systemic challenges facing the widespread deployment of LDES technologies. We explore how current battery technologies, while effective for short-duration storage, face significant limitations for multi-day or seasonal storage applications, including degradation issues, energy density constraints, and high capital costs.

The discussion will cover LDES alternatives from Li-ion to flow battery solutions, analyzing their respective technological readiness levels, cost and scaling potential. Special attention will be paid to a new form of nanofluid flow battery being developed by our team which has the potential to overcome many of the barriers currently present for large scale deployment of LDES systems.