The Future of Energy Storage

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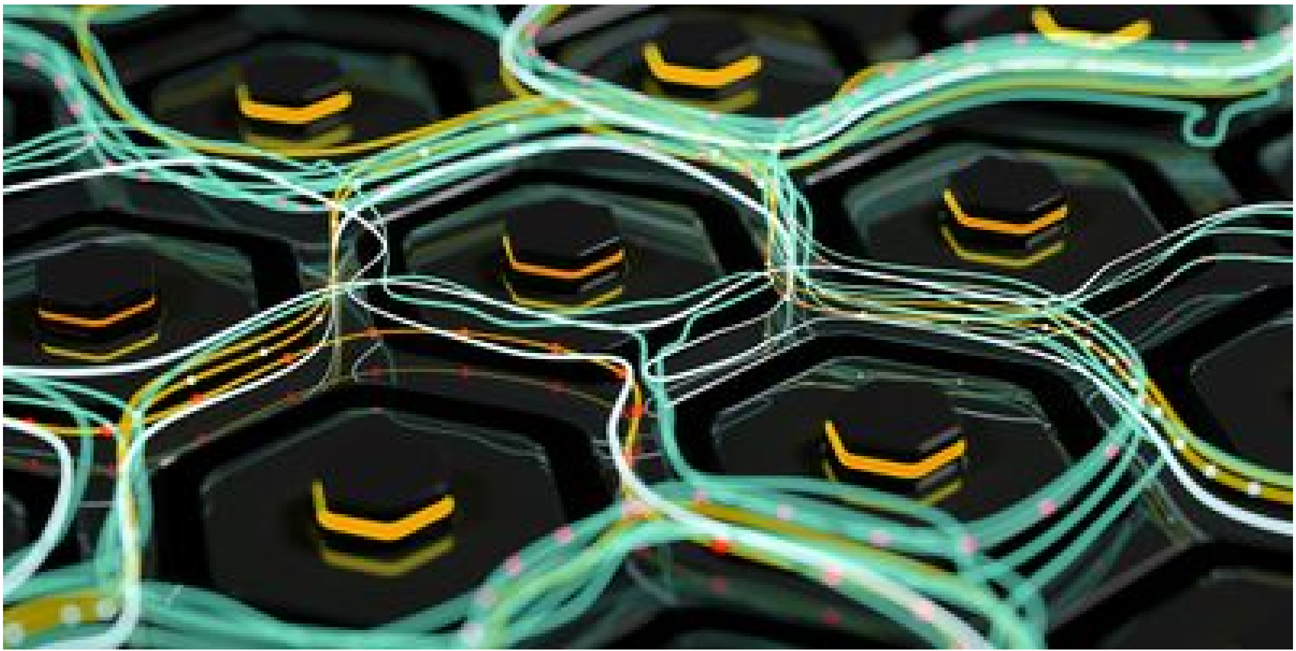

George Crabtree, director of the Joint Center for Energy Storage Research (JCESR), discusses the current state of energy storage, including the most popular energy storage options, challenges in creating new technologies, and where the energy industry is headed next.

Q: What are the most popular energy storage technologies available today?

A: By far, the world's most popular battery on the market today is the lithium-ion (Li-ion) battery. The rise of Li-ion has been phenomenal since its introduction in 1991, enabling laptops, tablets, smartphones, and other personal electronics that revolutionized the way we interact with people and information. Since the early 2010s, these same Li-ion batteries also power electric vehicles (EVs), requiring batteries 10,000 times larger. Since about 2018, Li-ion batteries have been installed in the electricity grid to smooth the variability of wind and solar farms, requiring batteries 1,000-10,000 times larger than those of EVs.

But Li-ion batteries are meeting serious challenges. They have a complicated international supply chain with three key battery materials—lithium, nickel, and cobalt. [They are] expensive and limited, keeping costs high, increasing dependence on foreign suppliers, and delaying supply chain ramp-up to meet rapidly growing demand. Li-ion batteries also have performance limitations for some applications. They cannot discharge at full power for more than four to six hours, preventing them from stabilizing grid applications using solar or wind energy against consecutive cloudy or calm days. And they cannot reach the high-energy densities required to power long-haul trucks, rail, marine shipping, and aviation, which requires two to three times the energy density of Li-ion. In our climate-constrained world, we must search beyond Li-ion batteries to meet these energy storage needs.

Q: How has the modern energy grid adapted to accommodate renewable energy and other changes?

A: The biggest change so far is the rapid deployment of wind, solar, and battery storage driven by falling prices, government incentives, and the climate emergency. Predictions are for global wind and solar capacity to surpass gas and coal by 2024. These deployments, impressive as they are, are not enough to decarbonize the grid. We have no commercial many-day battery storage needed to stabilize a primarily renewable grid for consecutive cloudy or calm days. In addition, we expect demand for grid electricity to grow sharply as EVs replace gasoline cars and as buildings electrify to replace natural gas. Offshore wind remains a largely untapped resource that could help supply the additional demand, and we need other long-duration energy storage options for the many-day, monthly, and seasonal time frames. JCESR is working on next-generation organic redox flow batteries for 10+ hour applications, and we need new chemical energy carriers such as green hydrogen, ammonia, and other hydrogen-rich, carbon-free carriers yet to be discovered.

Q: How have you seen the energy storage sector evolve? What has become possible today that wasn’t possible a decade ago?

A: The changes in a decade have been phenomenal. Ten years ago, the prices of solar, wind, and batteries were prohibitive. None were seen as practical solutions at scale. Now all three are highly competitive with traditional coal and gas alternatives for baseload power and peaker plants. On the science front, we are seeing intentional design of batteries replacing the much more common approach of trial and error. Edison was the champion of trial and error, claiming that invention is two percent inspiration and 98 percent perspiration. In his day, there were very few tools, such as nanoscale observation of energy storage phenomena or computer simulation, artificial intelligence, and machine learning. These modern scientific tools open new horizons in understanding and prediction of behavior at the atomic and molecular level, enabling the design of batteries with specific atomic composition and structure to produce needed performance. We can design batteries for high-energy density (for heavy duty transportation), for many-day discharge at full power, or for inexpensive, earth-abundant, domestic supply chains. This ability to match battery design to specific needs is a new feature on the energy storage landscape. It promises to diversify batteries beyond the conventional Li-ion paradigm, greatly enriching the possibility space and accelerating the decarbonization transition. This goal to design and build batteries "from the bottom up" is a signature strategy of JCESR.

Q: Can you explain some of the main challenges of decarbonization that meet modern-day demands?

A: Commercial Li-ion technology will decarbonize passenger cars, which produce about half the carbon emissions of the transportation sector. Decarbonizing heavy duty transportation requires technology that has not been invented yet. Candidates for its electrification include high-energy density batteries, fuel cells running on green hydrogen, and a combustible, carbon-free chemical energy carrier such as green hydrogen, ammonia, or a hydrogen derivative that remains to be discovered. The scientific community is working hard to explore all three of these opportunities. It is not yet clear where the boundaries for each of these technologies might lie, and hybrids such as battery-fuel cell or battery-green hydrogen are distinct possibilities.

Decarbonizing heavy industry including the manufacture of iron, steel, ammonia, and plastics is a special challenge: making these products requires not only large quantities of high temperature heat from burning fossil fuels, but also fossil feedstocks like methane for the production of plastics. One innovative decarbonization solution is replacing thermochemical production processes with electrochemistry, where reactions are driven by voltages and electric fields at ambient temperature, eliminating the need for high temperature process heat. Often, green hydrogen or other carbon-free chemicals can replace fossil feedstocks for electrochemical manufacturing, fully eliminating carbon from the production process.

Q: How do you envision the future of energy storage? What developments and innovations are still to come?

A: Ideally, energy storage will take many new forms, spanning next-generation batteries and chemical energy carriers, as well as thermal storage (with steam, molten salt, or other materials as the carrier) and gravity storage (where heavy materials such as rocks or cement are raised and lowered to store and release energy). We want to be able to convert energy easily among electricity, heat, mechanical motion, and chemical bonds. We might, for example, convert electricity to green hydrogen by electrolysis or hydrogen to electricity in fuel cells or combustion turbines. We could power transportation with batteries in electric passenger cars and with fuel cells and green hydrogen (or one of its derivatives) in heavy duty transportation. And we could power heavy industry with electrochemical manufacturing using carbon-free feedstocks. This kind of integrated, flexible energy system allows us to direct energy via multiple routes to a given application, increasing reliability should one or another energy source be unavailable.

Such an integrated, flexible, [and] comprehensive energy system would replace our present fragmented energy system, where oil and gasoline power transportation, coal and gas power industry, and electricity, the most flexible energy carrier, powers lighting, heating, cooling, appliances, motors, electronics, communications, and light rail. Two of these three energy carriers are fossil fuels that must be reduced or eliminated to avoid the worst consequences of climate change; the third, electricity, combined with a carbon-free energy carrier such as green hydrogen, is poised to become the backbone of the future energy system. Getting to this new energy system will be a very interesting journey.

George Crabtree, an Argonne National Laboratory senior scientist and Distinguished Fellow, is the director of the Joint Center for Energy Storage Research. He has won numerous awards for his research, including the Kamerlingh Onnes Prize and the US Department of Energy Award for Outstanding Scientific Accomplishment in Solid State Physics, which he has won four times. Crabtree has published more than 440 papers in leading scientific journals, collected more than 18,000 career citations, and has given more than 150 invited talks at national and international scientific conferences.