Electrochemical Capacitors emPOWERING the 21st Century

by Jeffrey W. Long

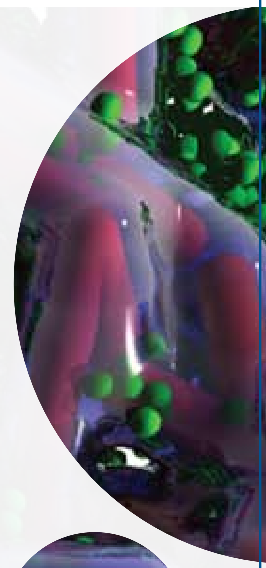
The term "electrochemical capacitor" describes a diverse class of energy-storage devices that incorporate a variety of active materials (high-surface-area carbons, electroactive polymers, and transition metal oxides and nitrides), electrolytes (conventional aqueous and nonaqueous electrolytes, advanced polymer electrolytes, and ionic liquids), and device configurations (symmetric and asymmetric).[1] Such diversity and design flexibility are important advantages that make clear why electrochemical capacitors (ECs) cover such a broad region on the power *vs.* energy density plane, and bridge the critical performance gap between the high power densities offered by conventional capacitors and the high energy densities of batteries.

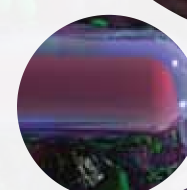
From both a practical and a fundamental perspective, ECs are closely related to batteries, and in fact the distinction between these two classes of energy-storage devices has been blurred with the recent advancements in "high-rate" batteries, and with the discovery that many battery materials exhibit capacitor-like electrochemical responses (*i.e.*, "pseudocapacitance") when prepared in nanoscale and disordered forms.[2] As a general rule, however, electrochemical capacitors can be differentiated from high-rate batteries by their operational characteristics: (i) charge–discharge response times that are on the order of seconds; (ii) sloping and symmetric charge–discharge profiles; and (iii) exceptional cycle life (typically many tens to hundreds of thousands of cycles).

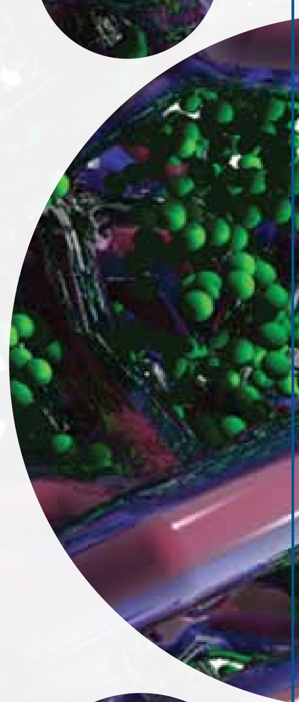
For the past several years, batteries, and in particular Li-ion batteries, have dominated the landscape of electrochemical energy-storage devices, in terms of both research and development, and commercialization activity. With the emergence of new technologies and applications with challenging power requirements, there is renewed interest in ECs, either as stand-alone energy-storage devices for high-power needs or for hybrid EC–battery systems that simultaneously address both power and energy requirements. Perhaps the most visible technologies that will be impacted by ECs are hybrid-electric power systems, where significant increases in energy efficiency can be achieved through the recovery of energy normally wasted during braking of repetitive motion, thanks to the rapid charge–discharge response of ECs. Such waste energy harvesting will become increasingly important and popular in industrial equipment like cranes, fork-lifts, and elevators, as well as in many types of vehicles including automobiles, trucks, and buses. All have great potential for improved energy efficiency.

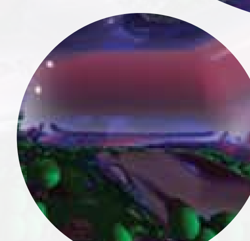
Although the level of performance of current-generation ECs is sufficient for certain applications, the full potential of ECs has yet to be realized. The further evolution of EC technology will benefit from continuing efforts at both the basic and applied level, but particularly with advances in nanoscience that result in new high-performance electrode materials and a more detailed understanding of important fundamental processes at the electrode/electrolyte interface.[3]

In the present issue of *Interface*, we appraise the status of ECs, from scientific aspects to real-world applications, and look toward a bright future for EC technology. Following "The Chalkboard" article describing the fundamentals of EC operation, Naoi and Simon lead off our feature articles with a brief overview on the various materials and device configurations that are currently investigated for ECs. Simon and Burke discuss how new nanostructured forms of carbon are impacting the performance of the most mature form of ECs, namely, electric double-layer ECs, while Naoi and Morita review how advanced polymers are exploited as both active electrode materials and electrolytes in ECs. Bélanger, Brousse, and Long describe how a well-known battery material, MnO_2, is now being investigated for new uses in asymmetric ECs. Finally Miller and Burke describe how ECs are being used in the real world, and discuss the future outlook for EC development and commercialization. ■









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2. W. Dong, D. R. Rolison, and B. Dunn, *Electrochem. Solid-State Lett.*, **3**, 457 (2000).
3. See the U.S. Department of Energy's 2007 report, "Basic Research Needs for Electrical Energy Storage," available at http://www.sc.doe.gov/bes/reports/files/EES_rpt.pdf.

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