U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

INDUSTRIAL TECHNOLOGIES PROGRAM

Self-Assembled, Nanostructured Carbon for Energy Storage and Water Treatment

The Development of Carbon Nanomaterials for Ultracapacitors and Capacitive Deionization

This project is developing and implementing reliable, scalable, and cost-effective processes for manufacturing self-assembled nanostructured carbon material. Different forms of this material can be applied to support new solutions to pressing problems in energy storage and water treatment.

In the area of energy storage, the development of carbon nanomaterials for improved ultracapacitors will enhance the commercial viability of renewable energy technologies such as wind and solar power. Ultracapacitors are experiencing rapid annual growth rates because they offer extremely high power densities suitable for energy storage in renewable energy applications. Self-assembled carbon nanomaterials and nanomanufacturing processes can help expand the market for ultracapacitors by lowering manufacturing costs while increasing ultracapacitor energy densities and resolving performance issues, such as module reliability.

In the area of water treatment, the development and implementation of carbon nanomaterials will have applications in improved capacitive deionization (CDI) systems for water treatment processes. There is a growing need for new water treatment and desalinization methods that are safe, effective, and affordable. The use of self-assembled carbon nanomaterials in CDI systems will improve system performance and affordability, allowing these CDI systems to replace more conventional and energy-intensive reverse osmosis desalinization systems.

Benefits for Our Industry and Our Nation

Ultracapacitor development is expected to have broad and significant energy, carbon, and monetary impacts:

1. Partial mitigation of energy losses from the momentary interruption of the electrical power grid
2. Improvement of power regulation and load shifting for the wind and solar renewable energy industries
3. Further enabling of fuel cell and hybrid vehicles

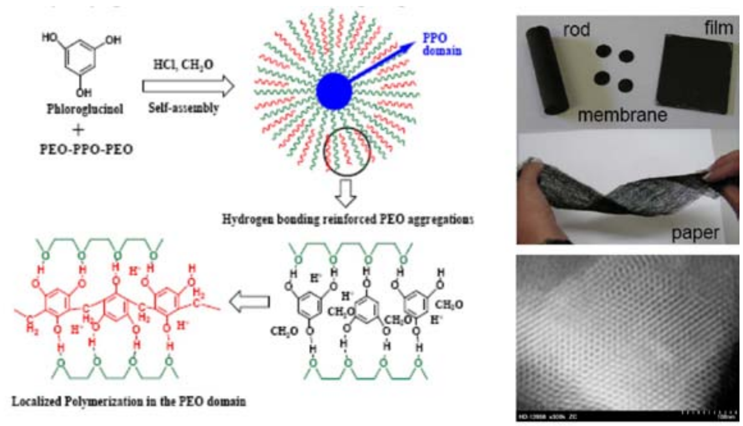

Figure 1. Left: Scheme of the self-assembly of a phloroglucinol/formaldehyde copolymer in the hydrophilic domains of PEO-PPO-PEO triblock copolymers. Top right: Mesoporous carbons in different forms: rod, film, membrane, fiber, and paper. Bottom right: Transmission electron microscopy (TEM) image of mesoporous carbon nanostructure.

Illustrations and photos courtesy of Oak Ridge National Laboratory.

In water treatment, the development and deployment of CDI systems based on nanostructured carbon has the potential to greatly reduce desalination energy costs as compared to membranes used in reverse osmosis (conventional desalination processes).

Applications in Our Nation's Industry

The broad list of potential applications for ultracapacitor technology includes transportation (hybrid automobiles and rail systems), the electrical grid (stability, power quality, and transmission and distribution energy), renewable energy (solar and wind), consumer electronics, and industrial processes. There is a very large potential market for CDI separation technologies in water treatment systems, including seawater desalination and treatment of oil- and gas-produced water, industrial water, and brackish water.

Project Description

The goal of this project is to translate a unique approach for the synthesis of self-assembled nanostructured carbon into industrially viable technologies for two important, large-scale applications: electrochemical double-layer capacitors (also referred to as ultracapacitors) for electrical energy storage, and capacitive deionization (CDI) systems for water treatment and desalination. The project is also developing reliable manufacturing processes to produce nanostructured carbon materials.

Barriers

- Production of nanostructured carbon materials for electrical energy storage that meets volumetric and gravimetric specific capacitance benchmarks
- Production of nanostructured carbon materials for CDI that meets industrial benchmarks for CDI in water treatment
- Cost-effective industrial-scale production of nanostructured carbon materials

Pathways

This project is working to overcome scale-up issues to develop reliable manufacturing processes to produce nanostructured carbon materials. Approaches are being developed to produce materials in two forms—an unconsolidated form suitable for displacement of activated carbon in current capacitor production, and a sheet form suitable for CDI applications. The work is centered on overcoming issues that hinder the translation of the nanomaterial production process from a laboratory scale to commercial production. These issues include the optimization of process variables to achieve desired product properties, the identification and mitigation of factors that lead to product variability, the development of a process for recycling costly chemicals used as templates for structuring the carbon, and the adaptation of the process to employ inexpensive, renewable feedstocks. The performance of the materials will be demonstrated in prototype devices.

Milestones

This project started in September 2008.

- Optimize of material properties such as energy density, ion capacity, regenerability, and lifetime to improve performance (Completed)
- Improve process efficiency and economics via use of less costly, renewable precursors and recycling block copolymer nanopore structuring agents (Completed)
- Scale-up nanomanufacturing production through the development and demonstration of scalable manufacturing techniques for the reliable production of micron-scale powders for ultracapacitors and sheets for CDI (Completed)
- Test prototype nanostructured carbon materials against commercial products. Specifically, two options are being pursued for prototype testing: 1) a sheet form that is constructed from carbonized mesoporous carbon and a polymeric binder that can be utilized in concert with titanium current collectors; and 2) titanium-carbon composite materials. In addition, testing of electrode production is also in progress.

Commercialization

Industrial partners Honeywell Specialty Materials and Campbell Applied Physics (CAP) together possess the resources and technical strength to provide low-risk conduits for successful product commercialization. Honeywell is a supplier of electrical energy storage materials, including electrodes and electrolytes for ultracapacitors, while CAP is actively developing and deploying advanced technology water purification systems. Specifically, the products to be commercialized are based on U.S. patent application 2006057051, “Highly ordered porous carbon materials having well defined nanostructures and method of synthesis,” with potential commercialization in 3–5 years.

Project Partners

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