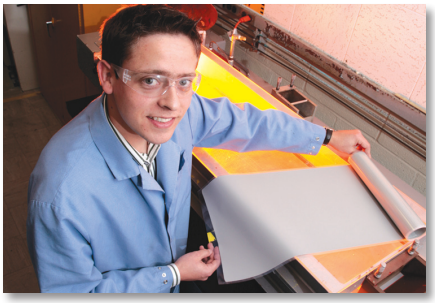
Advanced Manufacturing for

# A New Generation of Batteries

Innovative processing and next generation manufacturing to help satisfy America's demand for batteries for greener vehicles and renewable energy.

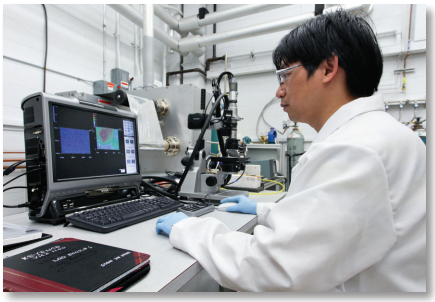
OAK RIDGE NATIONAL LABORATORY
MANAGED BY UT-BATTELLE FOR THE DEPARTMENT OF ENERGY

# Materials Processing and Next Generation Manufacturing for Advanced Batteries

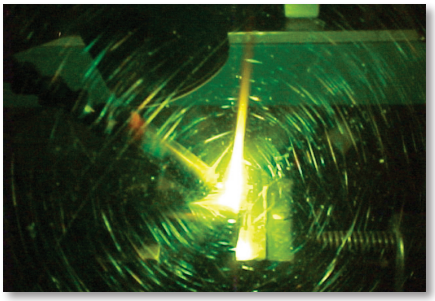


Coatings

Drying



Computational Manufacturing



Joining

High performance batteries are a leapfrog technology for the electrification of transportation and storage of renewable energy. However, battery manufacturing is too expensive and too slow. Battery manufacturing's production yield from raw materials to finished systems remains at a very low levels. Quality control procedures for manufacturing are very limited compared to other industries. Improvements in energy densities and product life through advanced manufacturing can increase the energy saving potential in the processing. Finally, a cost effective and streamlined processing for next generation manufacturing can further reduce the energy consumption in the process.

ORNL's materials processing and next generation manufacturing programs funded through the DOE Industrial and Vehicle Technologies programs and other federal and private sponsors, will enable new manufacturing procedures and radically changed concepts to improve battery cost structures and allow for reliable technology with long life. Cost effective and efficient battery manufacturing enables U.S. industry to domestically produce batteries for electrification of transportation (including light duty and heavy duty vehicles, rail, aviation), grid applications, and other applications to reduce the U.S. dependence on foreign oil and reduce our carbon footprint.

## Coating Technologies and Processes

The development of low-cost high-yield coating technologies is one of the most important elements for reducing manufacturing costs and increasing the reliability of batteries. ORNL's research on wet and dry coating technologies could reduce the time and energy needed for typical formation procedures after the battery is assembled. ORNL scientists and engineers are also looking into scaled melting and advanced powder fabrication and laser processing techniques to fuse powders into nanocomposite coatings that are many times more efficient than conventional processing methods. Coating technologies range from high performance vacuum processing to highly efficient and controllable slot-die, tape casting, spray coating, rapid prototyping, and direct manufacturing techniques.

Coating thicknesses produced at ORNL range from nanometers to many hundreds of micrometers with pilot scale line speeds of up to tens of feet per minute. Configurations are in single, multi- and simultaneously deposited multi-coatings.

## Drying and Heating Technologies

ORNL's expertise in radiant technologies together with conventional furnace technologies enables a side by side comparison and advanced development for next generation drying and curing procedures. Drying may include evaporation of solvents, sintering, curing of polymers, and bonding of coatings and on diffusion layers of individual materials. Several systems with a variety of integrated layers exist at ORNL for thorough studies and development consisting of typical battery drying temperatures between 100-150°C to sintering and heating treatments of up to 3,000°C.

## Computational Manufacturing

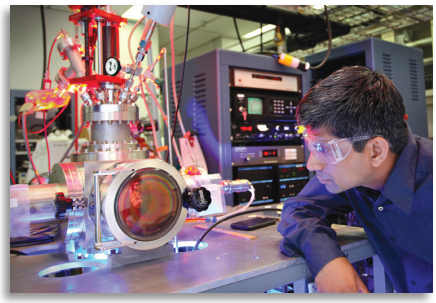
Advanced computational modeling provides an unprecedented capability to study and optimize the overall performance and safety of the batteries created by next generation manufacturing. This is accomplished by enabling rapid prototyping and screening of battery materials and configurations, as well as providing accurate lifetime predictions and best possible manufacturing parameters for deposition, drying, curing, assembly, packaging, etc.

## Joining

Low thermal impact joining is of very high importance for advanced batteries because such devices are filled with thermally sensitive materials prior to sealing. Ultrasonic joining, a candidate for such applications, is just one of many advanced joining techniques ORNL is currently researching.


### Materials Synthesis

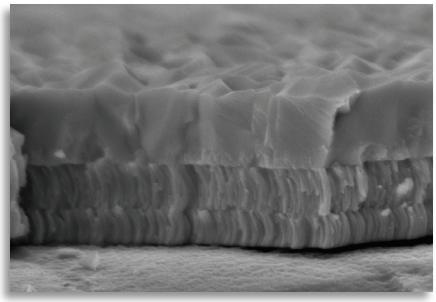
Much recent research on lithium secondary batteries has focused on the use of composite materials to improve both performance and safety. Scientists at ORNL are exploring the use of carbon, graphite, and carbon fiber composites to improve the thermal and electrical conductivity of battery materials. Materials synthesis includes the study of complex, new, or improved material systems and the structure-property relationships that develop from starting materials, processing, and resulting properties. Through studying material synthesis, ORNL researchers hope to identify industrially viable technologies for the large-scale application of electrochemical capacitors.



Materials Synthesis

### Characterization

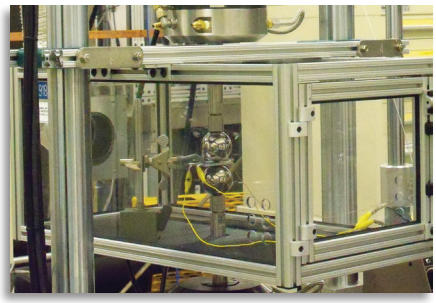
New and advanced characterization tools are being developed and utilized at ORNL. These characterization tools allow a better understanding of the manufacturing and processing steps and effects of processing parameters on materials and components. In-situ radiant drying studies, sintering processes, thermal treatment characterization are among ORNL's capabilities. In addition, ORNL is developing in-situ liquid electron microscopy to study charge and discharge phenomena in batteries in a scanning electron microscope and *in-situ* fatigue studies utilizing acoustic emissions together with diffraction and spectroscopy methods in special setups.



Characterization

### Thermal Runaway Characterization

Thermal runaway in batteries is a safety concern that can lead to degradation of performance and catastrophic failure. ORNL is developing infrared imaging to better understand temperature distribution inside secondary lithium batteries to prevent internal short circuiting and thermal runaway.



Thermal Runaway

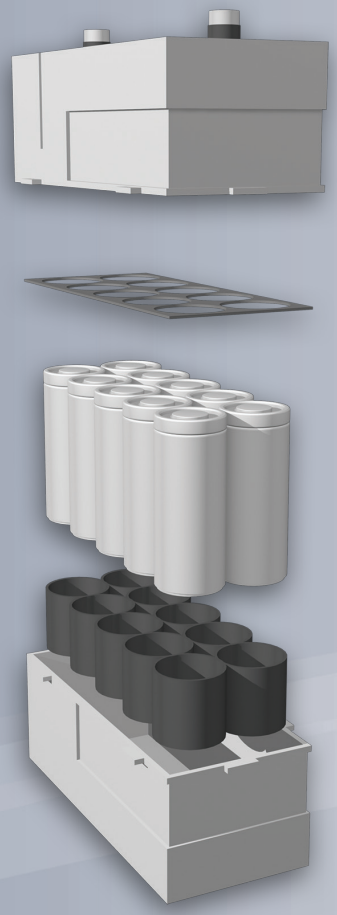
## ORNL User Facilities

ORNL also provides a number of user centers as a doorway for developers and industry to advanced national laboratory facilities. Some of those facilities are:

- **High Temperature Materials Laboratory** conducts world-class analysis and testing of materials structure and properties.
- **Center for Nanophase Material Sciences** houses tools and expertise for the synthesis of high performance materials and nanostructures.
- **National Center for Computational Sciences** provides the world's most powerful computing resources for researching how the physical world works and using that knowledge to address pressing national and international concerns.
- **National Transportation Research Center** focuses on fuels, engines and emissions, power electronics and electric machines, heavy vehicle safety research, transportation analysis, and high-risk/high-value packaging.
- **Shared Research Equipment User Facility** includes electron beam microcharacterization tools that are used in battery research.
- **Spallation Neutron Source** is an accelerator-based neutron source that provides the world's most intense pulsed neutron beams for scientific research.

# Accelerating Commercialization by Collaboration through a Next Generation Industrial Manufacturing Center

ORNL is looking to the future with plans for advanced facilities and investments in novel energy storage manufacturing research initiatives. It is actively pursuing the construction of an advanced battery fabrication technology development center to accelerate development, screening, and validation of future-generation battery materials, processing technologies, and cell designs. The envisioned facility will occupy several thousand square feet of space and consist of new state-of-the-art equipment as well as existing equipment relocated and consolidated from other laboratories across the site. It will house a flexible coating and fabrication line and a reconfigurable suite of modules comprising innovative processes beyond today's state-of-the-art. The modules will include novel deposition systems; drying and consolidation systems; winding, folding, and stacking systems; and joining technology systems. The facility will have sufficient automation to assess and demonstrate the potential of scaling developments to commercial volumes.



The facility will be designed for open-access use by researchers from industry, universities, and other national laboratories and will also be used to train battery technicians, engineers, and researchers as part of a workforce development focus to support substantial job growth in the domestic battery industry. ORNL's extensive characterization capabilities can also be applied at the facility to assist in failure mode and effects analysis, component and process validation, in-line quality sensing and process control, and enhanced evaluation at each processing stage.

# ORNL Office of Energy Materials

The ORNL Office of Energy Materials manages the DOE Industrial Technologies and Office of Fossil Energy programs and the materials efforts for the laboratory's DARPA and NASA sponsors. The Office brings the lab's world-class science capabilities to life by partnering with industry to provide real world solutions to the nation's most important energy challenges.

The U.S. manufacturing sector consumes 32% of the nation's energy and worldwide industry represents 38% of the total global opportunity for reducing carbon through energy efficiency. The mission of the Office of Energy Materials is to improve national energy security, climate, environment, and economic competitiveness by transforming the way U.S. industry uses energy. ORNL is a global leader in materials science and technology, energy-efficient processing, nanomanufacturing, controls and sensors, and best practices for industrial energy efficiency.

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U.S. DEPARTMENT OF ENERGY

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