Development of Nanostructured Materials for Energy Storage at Oak Ridge National Laboratory

Presented at:
EPRI Nanotechnology Workshop

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OAK RIDGE NATIONAL LABORATORY
U. S. DEPARTMENT OF ENERGY

Today, ORNL is DOE's largest multipurpose science laboratory

- $1.04 billion budget
- 4,000 employees
- 3,000 research guests annually
- Nation's largest unclassified scientific computing facility

- Nation's largest science facility: the $1.4 billion Spallation Neutron Source
- Nation's largest concentration of open source materials research
- Nation's largest energy laboratory
- $300 million modernization in progress

ORNL: World's premier laboratory for materials science and energy R&D

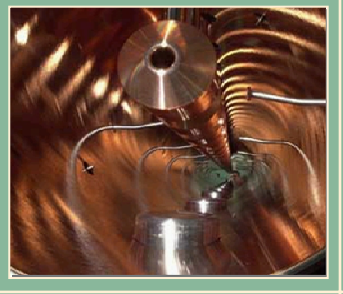
We have six primary mission roles:

- **Delivering and sustaining the world's foremost center for neutron scattering.**
- **World leadership in computational science and engineering at scale.**
- **Sustained world leadership in materials science through discovery, syntheses, and characterization of materials at the nanoscale.**
- **Leadership in microbial biology and proteomics, producing bio-based solutions to energy challenges and enabling the new field of "ecogenomics."**
- **International leadership in energy technology through science.**
- **Applying our S&T base to deliver "first-of-a-kind" security technologies and implement arms control and nonproliferation programs.**

We are developing and deploying world-class tools for nanoscale R&D

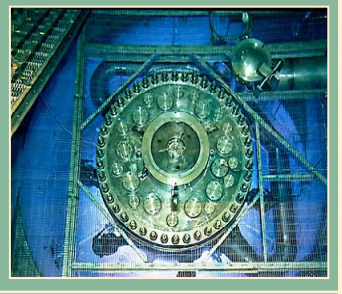
Spallation Neutron Source

- High-intensity neutrons for materials research at the nanoscale
- 1.4 MW of beam power on target
- 16 instruments



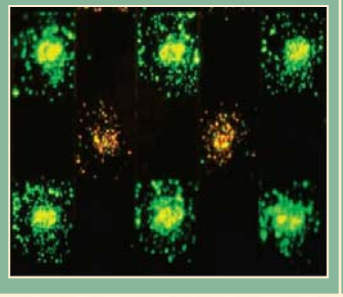
High Flux Isotope Reactor

- The nation's leading research reactor
- World-class for neutron scattering



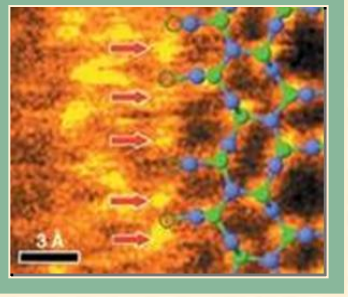
Center for Nanophase Materials Sciences

- $65M facility begins operations in October 2005
- 75 user projects already under way



Ultrahigh-resolution microscopy

- Advanced Microscopy Laboratory
- Aberration-corrected electron microscope
- World-record resolution: 0.6 Å

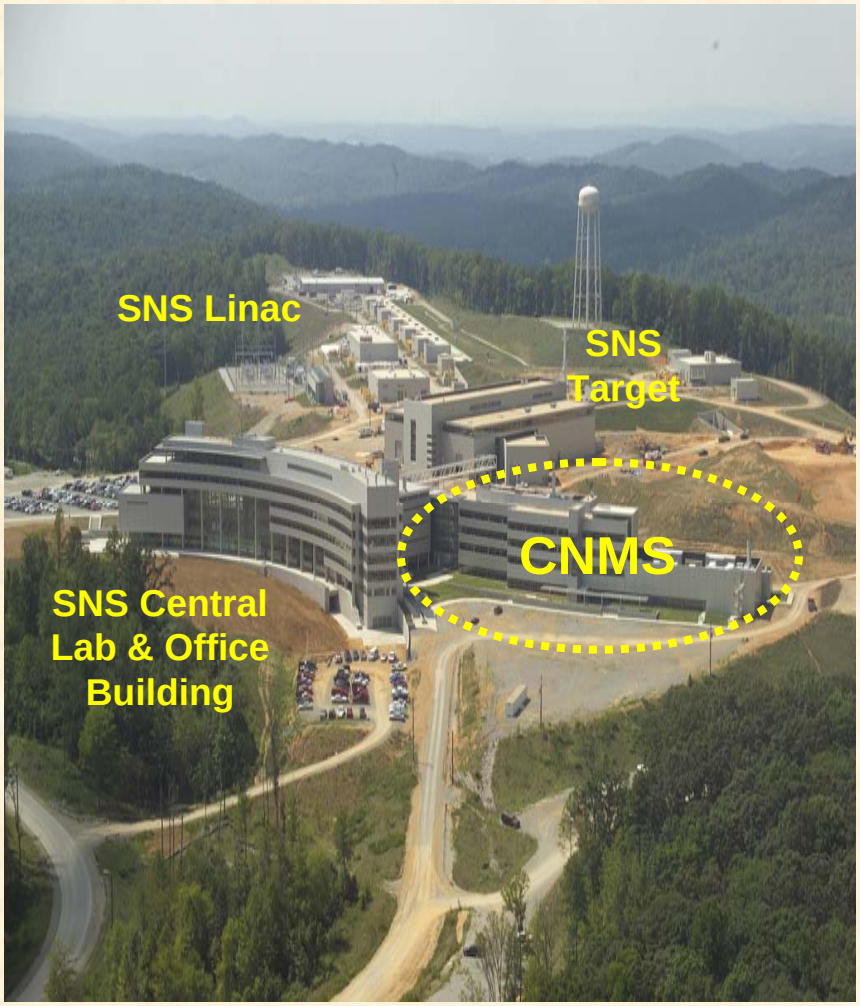


We are opening world leadership capabilities:

Spallation Neutron Source (neutron scattering) and Center for Nanophase Materials Sciences (nano science)

Center for Nanophase Materials Sciences

- **Facility**
  - Co-located with SNS and UT-ORNL Joint Institute for Neutron Scattering
  - Provides access to unique neutron scattering capabilities for nanoscience as well as infrastructure support for visitors
  - Opened in October 2005
- **Science Themes**
  - Macromolecular Complex Systems
  - Functional Nanomaterials
  - Nanoscale Magnetism & Transport
  - Catalysis & Nano-Building Blocks
  - Nanomaterials Theory Institute
  - Nanofabrication Research Laboratory
  - Nanoscale Imaging, Characterization, and Manipulation
- **User Projects**
  - "Jump Start" phase- 74 projects initiated from 134 user proposals in 2004–2005
  - 120 new user proposals received in August 2005



The CNMS User Program

Selected Characteristics of the NSRC User Access Policy

– from "General Policies and Procedures for User Access to the DOE NSRCs" (version1.1) posted on CNMS website at *CNMS >> Becoming a User >> General Policies*

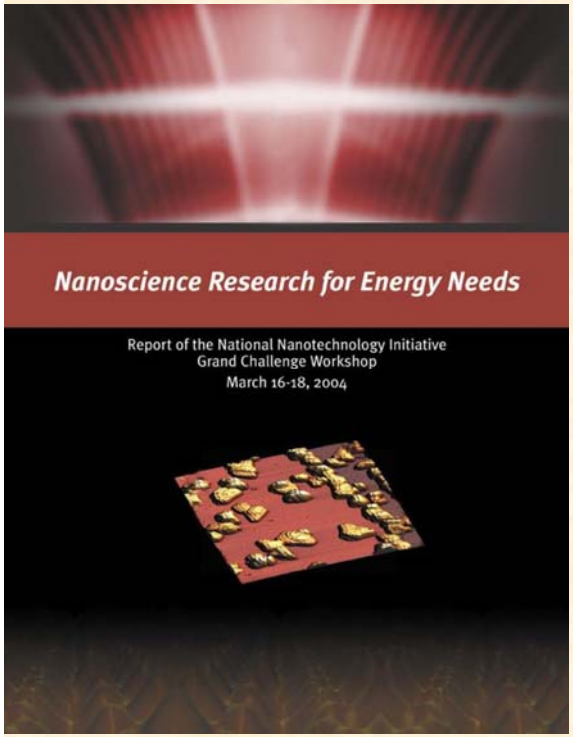
- **Open access to ALL based on scientific and technical quality of a user proposal**
  - **Well-defined access policies & procedures posted on CNMS web site**
  - **Proposal: simple, not burdensome for proposers or reviewers**
- **External, peer-reviewed evaluation required**
- **Flexibility to accommodate spectrum of user modes and needs**
  - **"General Users": Access to existing tools / support / collaboration**
  - **"Partner Users": Enhance NSRC capabilities or contribute to operation, while carrying out research**
  - **"Rapid Access": Time-sensitive, small, proof-of-principle projects**
  - **"Proprietary Users": Using unique capabilities for R&D to benefit US economy**

We address the energy challenges of the present . . . and the future

Generation	Distribution	Consumption
Fossil Fission Renewables Fusion	Transmission technology Hydrogen Distributed energy resources	Buildings Industry Transportation

Supporting DOE's strategic goals for energy security and independence

Nanotechnology is expected to produce broad benefit

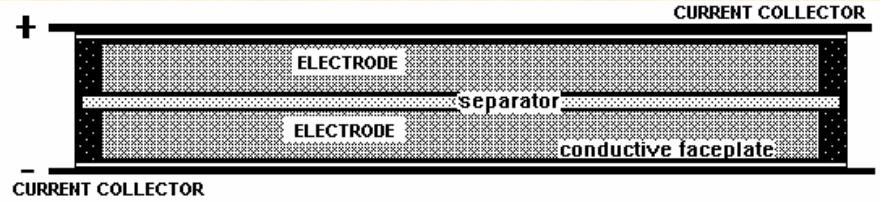


Key energy areas:

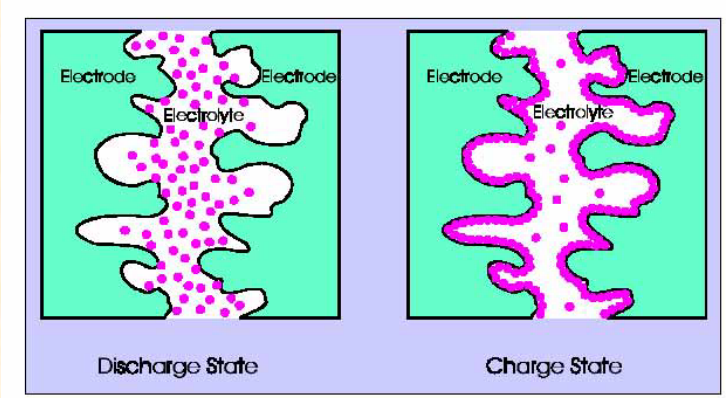
- **Highly selective catalysts for clean and energy efficient manufacturing**
- **Harvesting of solar energy with 20% efficiency and 100X lower cost**
- **Solid-state lighting at 50% less power consumption**
- **Super-strong lightweight materials to improve efficiency of transportation**
- **Reversible hydrogen storage materials**
- **Power transmission lines capable of 1 GW**
- **Low-cost fuel cells, batteries, thermoelectrics, and ultracapacitors**
- **Materials synthesis and energy harvesting based on mechanisms of biology**

Advanced materials are key for improved energy storage

- **Electrochemical capacitors**
  - **Reversible storage in electric double layer, rather than electrochemical reactions**
  - **High cycle lifetime**
  - **High power**
  - **Low-hazard materials**
  - **Typically, lower energy density**



- **Needs:**
  - **Electrode materials with**
    - **High accessible surface area**
    - **High conductivity**
  - **Compatibility of electrodes with electrolyte**



ORNL project is investigating advanced materials for electrochemical capacitors

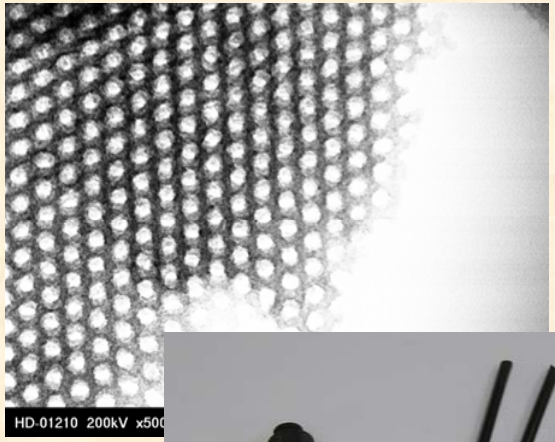
- **Objective: Develop a capability to synthesize novel carbon-based materials with advanced and tailored energy-storage performance**

- **Energy storage mechanism in electric double layer**
  - **Nanoscale dimensions**

- **Development of advanced materials requires control of properties at nanoscale**

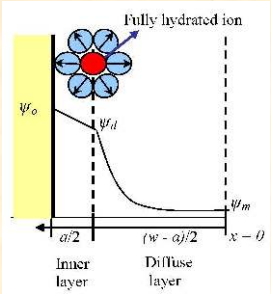
We aim to capitalize on materials generated from basic science on chemical separations

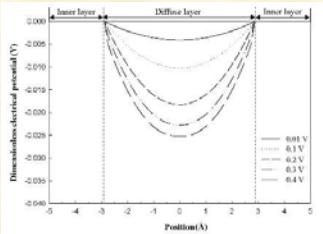
- **Initial test materials – mesoporous carbon synthesized for chromatography**
- **Preliminary tests in conjunction with EPRI PEAC**
  - **High power density**
    - **3-4X better than current commercial materials**
  - **Good energy density**
  - **Excellent frequency response!**
    - **Significant fraction of pores smaller than optimal**
- **Needs:**
  - **Better pore size distribution**
  - **Improved material form and connection to current collector**



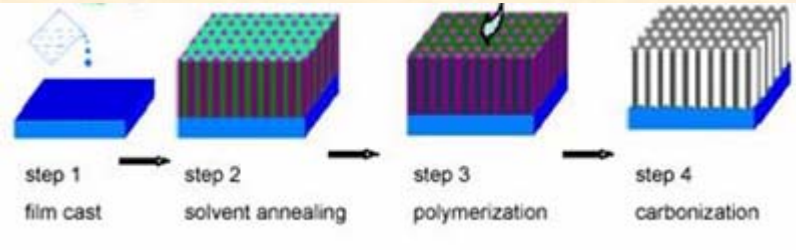
Research combines multiple elements to translate nanoscience discovery to technology

Theory and modeling

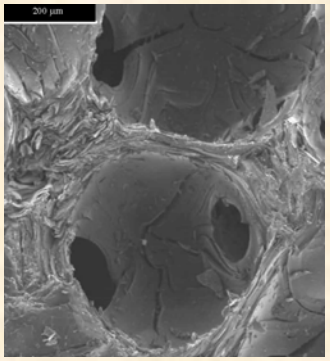




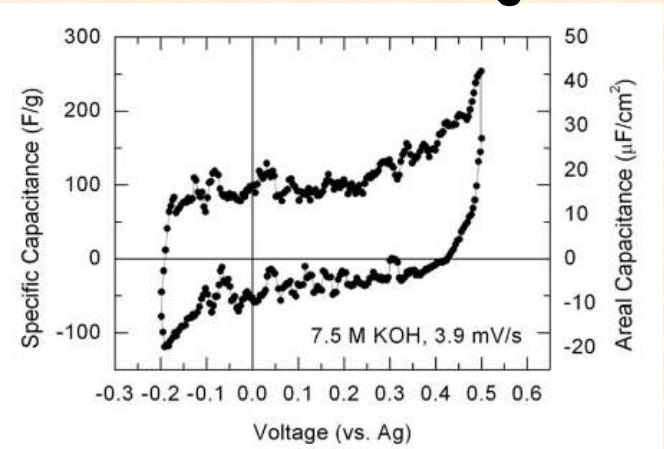
Synthesis



Characterization

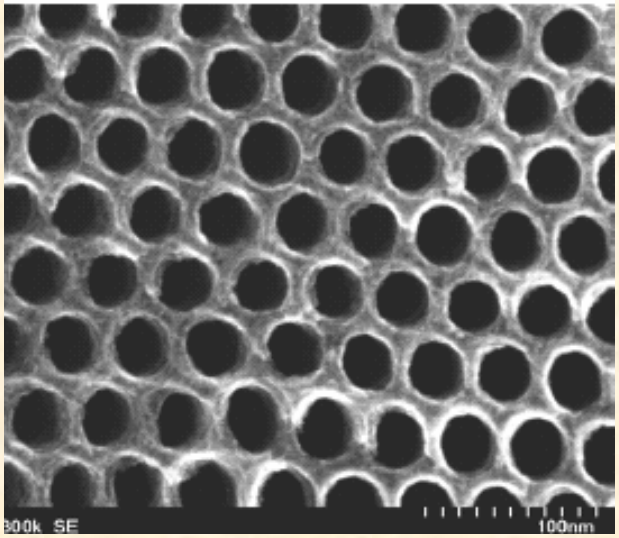


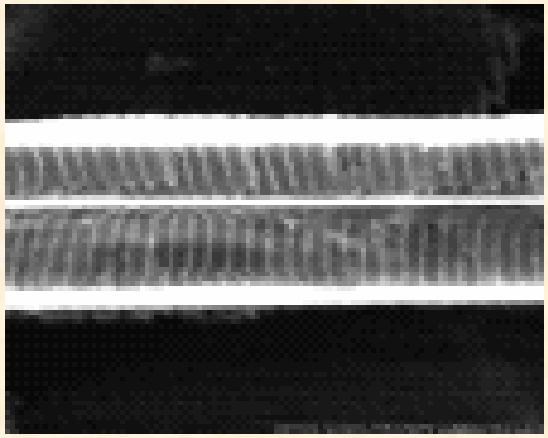
Performance Testing

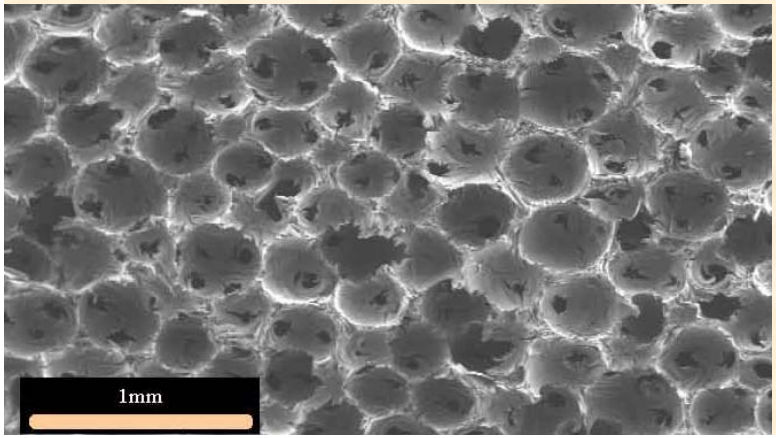


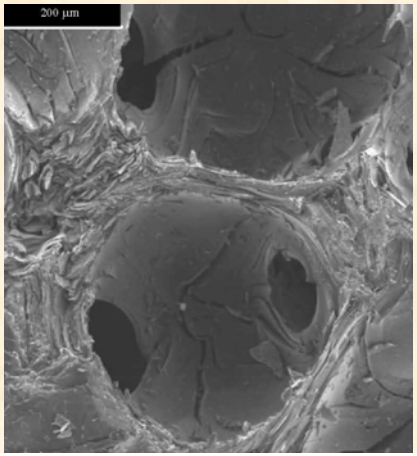
Focus is on controlled synthesis of mesoporous materials

- **Synthesize mesoporous materials with systematically varied characteristics**
  - **pore size**
  - **specific surface area**
  - **film thickness**
  - **graphitization**
- **Issues**
  - **Connection with current collector**
  - **Compatibility with electrolyte**
  - **Scalability and cost of synthesis**









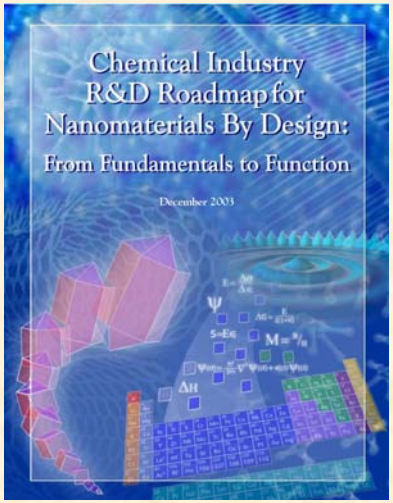
UT-BATTELLE

Collaboration will accelerate progress

- **Interaction with EPRI Solutions during exploratory research**
  - **Performance targets**
  - **Review progress relative to industry needs**

- **Partner in follow-on projects**
  - **Material optimization**
  - **Incorporation into devices**
  - **Scale-up**
  - **etc.**

Work is aligned with nanomaterials by design roadmap



TODAY: Discovery-based Science & Product Development

Discover novel nanostructures, nanoparticles, & nanomaterials through investigator-initiated exploratory research on a broad range of materials → Determine nanomaterial properties (chemical, physical, and biological) → Identify potential uses of value → Assess commercial viability → Nanomaterials enter limited markets

Driving Change in R&D

Start with existing needs, problems, or challenges in end-uses → Design, produce, and scale up nano-based materials with the exact properties needed → Large numbers of diverse products based on Nanomaterials By Design rapidly enter and succeed in multiple markets

FUTURE: Application-based Problem Solving

http://www.chemicalvision2020.org/nanotechnology.html

Chemical/semiconductor industry priority R&D needs

- **Synthesis & Self Assembly**
  - **Synthesis of Nanostructured Materials**
  - **Directed & Self Assembly**
- **Nanomaterial structure properties**
  - **Magneto-electronic & Transport Properties**
  - **Nano-surface Properties & Mechanisms**
  - **Nano-mechanical & Interface Properties**
  - **Thermal Properties of Nanostructured Materials**
- **New Metrology Capabilities**
  - **Large Volume Electronic Property Metrology Capability**
  - **In situ Nano-particle (sub 50nm) Monitor**
- **Manufacturing**
  - **Develop a fundamental engineering knowledge of the unit operations that can be used in integrated manufacturing of organic nanomaterials and inorganic nanoparticle products**
  - **Real-time characterization techniques for process monitoring and process control**
  - **Scale-up for commercial-scale unit operations**

Summary

- **Nanotechnology will have a major impact on energy technologies**
- **DOE national laboratories have leading capabilities for nanoscience discovery and development of technologies**
- **ORNL is active in R&D on materials for ultracapacitors and other energy conversion and storage technologies**
- **Transition from nanoscience to commercialized technologies will require multisciplinary work**
  - **Open to collaboration!**