

# Overview of Materials R&D at Oak Ridge National Laboratory

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***GSID Workshop on Materials for Ground Platforms***  
**TARDEC**

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# Materials Research and Development Is a Core Competency at ORNL

- Broad and deep mix of skills in materials science, physics, chemistry, and engineering
- World-leading neutron sciences capabilities (SNS and HFIR)
- Powerful scientific computing complex (LCF)
- Challenging problems in science, engineering, energy, environment, national security
- New and updated facilities, equipment
- Commitment to translational research from fundamental science to application

Spallation Neutron Source



Center for Nanophase  
Materials Sciences

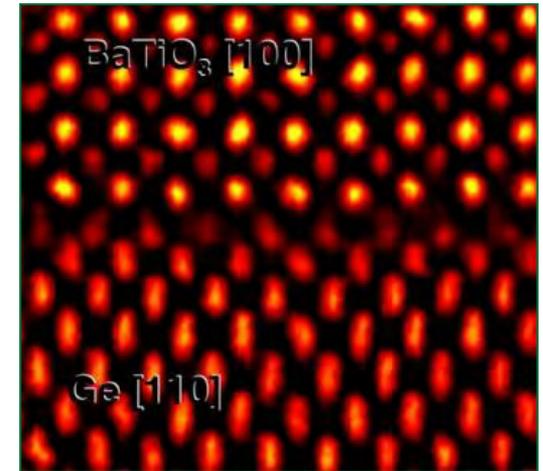


Leadership Computing Facility



# Materials Work at ORNL

- Longstanding accomplishments in
  - fundamental materials science
  - metals and alloys
  - ceramics
  - polymer matrix composites
- Present and future growth areas
  - Lightweight materials (titanium, magnesium, aluminum, carbon fibers and composites) with superior properties and performance
  - Materials for extreme environments (temperature, loading, radiation, etc.)
  - Energy storage
  - Solar energy
  - Nanoscience and Nanomanufacturing



# Materials R&D Covers Breadth of DOE's Science to Energy Pathway

## Discovery Research

## Use-inspired Basic Research

## Applied Research

## Technology Maturation & Deployment

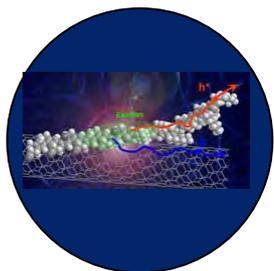
- Basic research for fundamental new understanding on materials or systems that may be only peripherally connected or even unconnected to today's problems
- Development of new tools, techniques, and facilities
- Basic research for fundamental new understanding, with the goal of addressing short-term showstoppers on real-world applications in the energy technologies
- Research with the goal of meeting *technical milestones*, with emphasis on the development, performance, cost reduction, and durability of materials and components or on efficient processes
- Proof of technology concepts
- Scale-up research
- At-scale demonstration
- Cost reduction
- Prototyping
- Manufacturing R&D
- Deployment support

**Goal: new understanding**  
**Mandate: open-ended**  
**Focus: phenomena**  
**Metric: knowledge generation**

**Goal: practical targets**  
**Mandate: restricted to target**  
**Focus: performance**  
**Metric: milestone achievement**

# Example: ORNL Industrial Technologies Program

Providing integrated solutions to accelerate innovation to industrial deployment



Scientific Research



Industry Needs



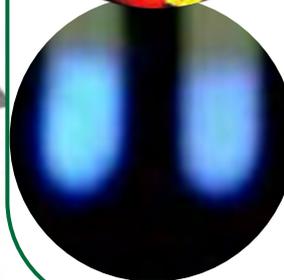
Industry and University Partnerships



Save Energy  
Now Delivery &  
Implementation



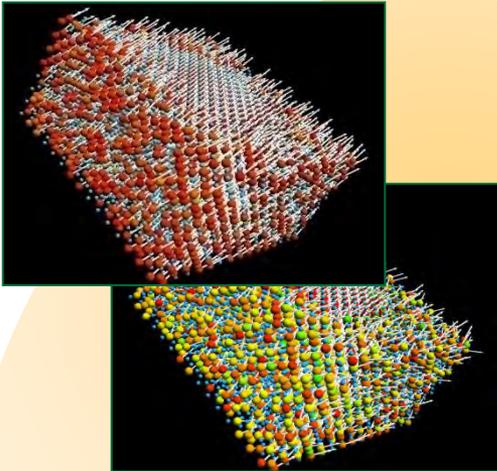
Energy Intensive  
Materials &  
Processes



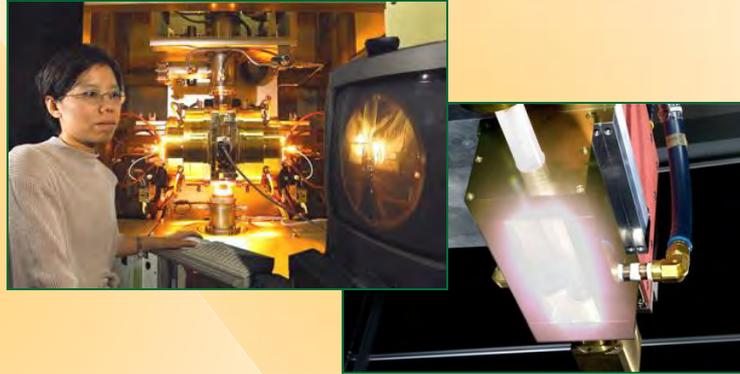
Nano-  
Manufacturing  
R&D

Integrated Approach

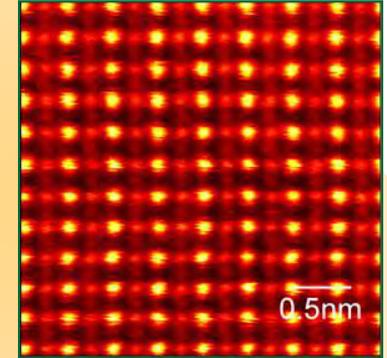
# ORNL Materials Science and Technology



Theory and Modeling



Controlled Synthesis and Processing

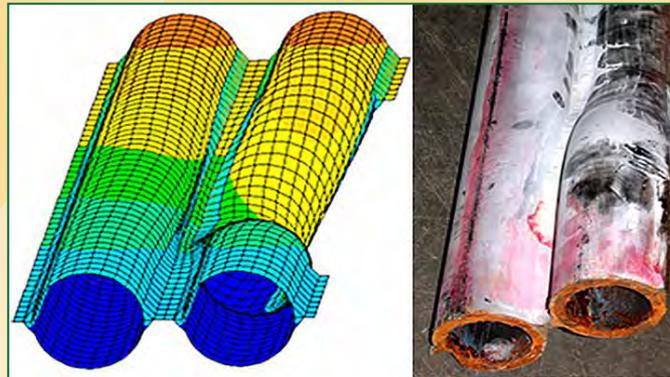


Structural Characterization

Bridge fundamental science and energy technology applications



Physical/Mechanical Characterization



Interaction with Extreme Environments



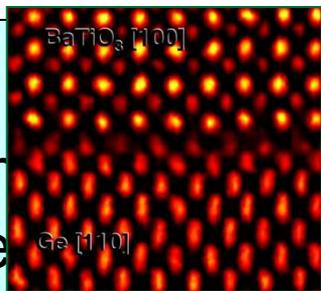
Applied Materials Physics

# Our R&D Encompasses All Aspects of MSE: Synthesis-Characterization-Properties-Performance

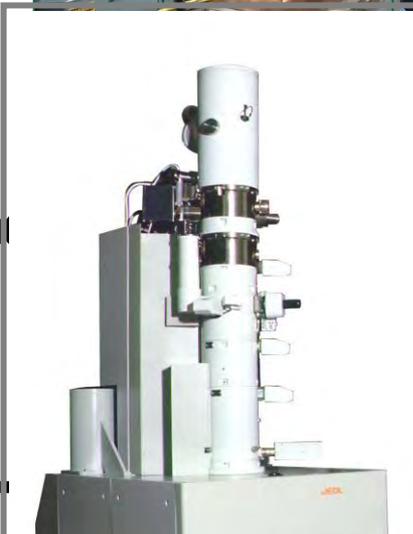
Atomic-Level Synthesis

Materials processing

Melting/casting



Extrusion



Properties

Performance

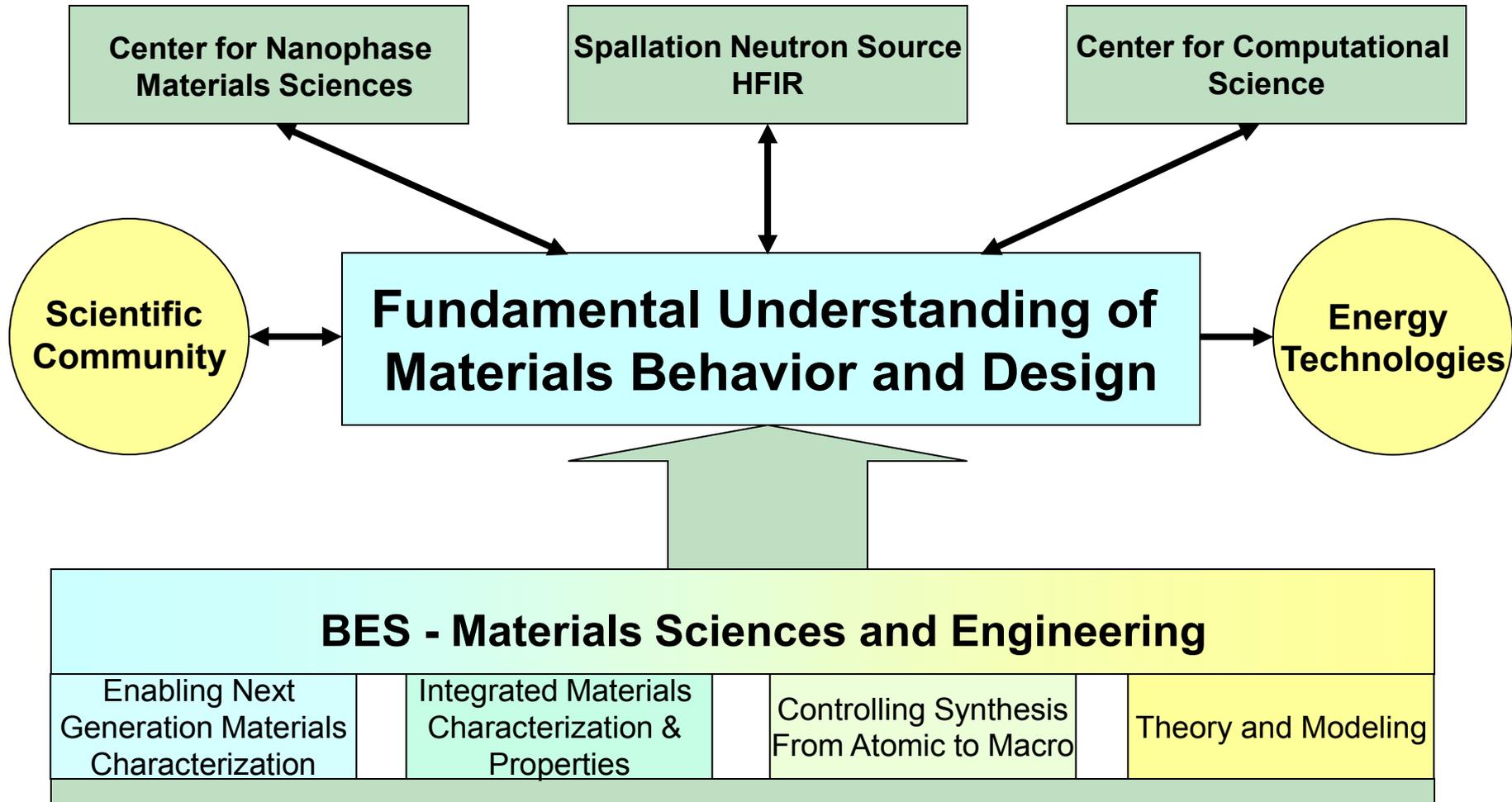
Our toys are nice, but it is the people and their know-how, and the synergies, that really make the difference

Synchrotron X-ray scattering

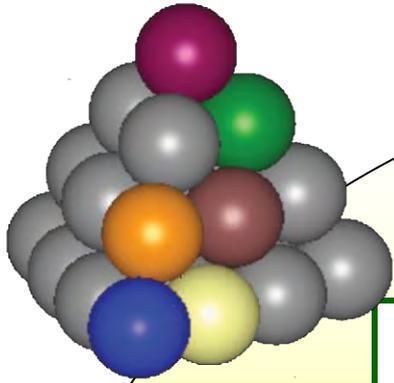
Sub-Angstrom aberration corrected STEM/TEM

Mechanical Testing

# Fundamental Materials Science

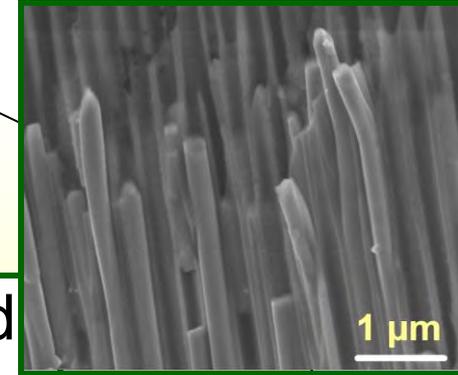


# Fundamental Materials Science Themes



## *Characterization*

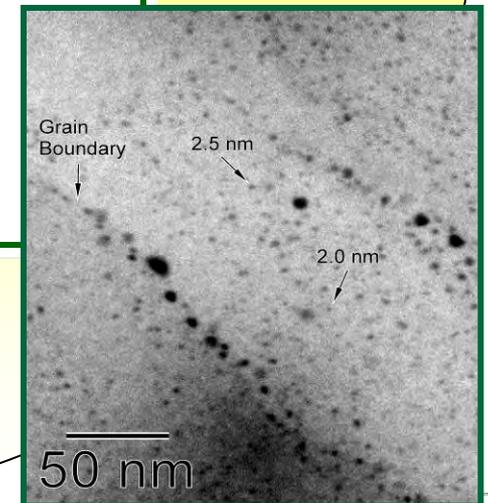
- Physics of strongly correlated and complex systems
- Reduced dimensionality
- Atomistic and molecular basis of synthesis, structure, and functionality
- Defects and physics of deformation and stability



## *Theory*

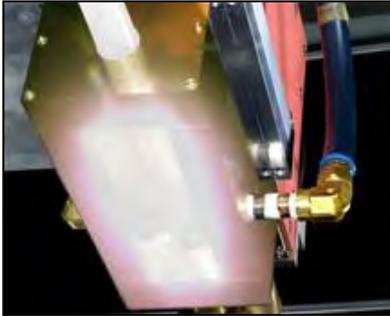
## *Synthesis*

## *Next Generation Tools*



# Advanced Materials Processing

**Goal: Enable U. S. Expansion of Energy Efficient Advanced Materials and Processing/Manufacturing by Focusing on Breakthrough Processing Technologies**



## Pulse Thermal Processing

- Low Cost Photovoltaics, High Temperature crystallization on polymers
- Increase magnetic media storage by 200x



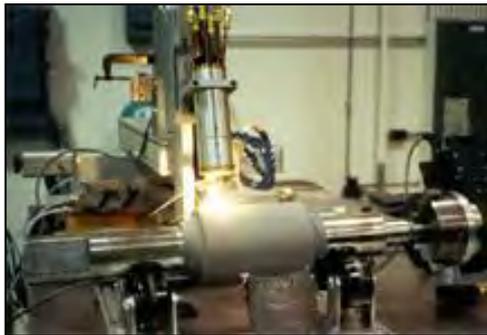
## Magnetic Field Processing

- Enhanced phase transformation kinetics
- Novel microstructures and superior properties
- Energy Savings: 14 trillion BTU/yr



## Electron Beam Processing

- Nonthermal Processing of Large Composites
- Terahertz sensors – Utilize as a free electron laser for testing THz sensors



## Laser Processing

- Laser bio coatings
- Processing of carbon nanohorns and other nanomaterials by vaporization

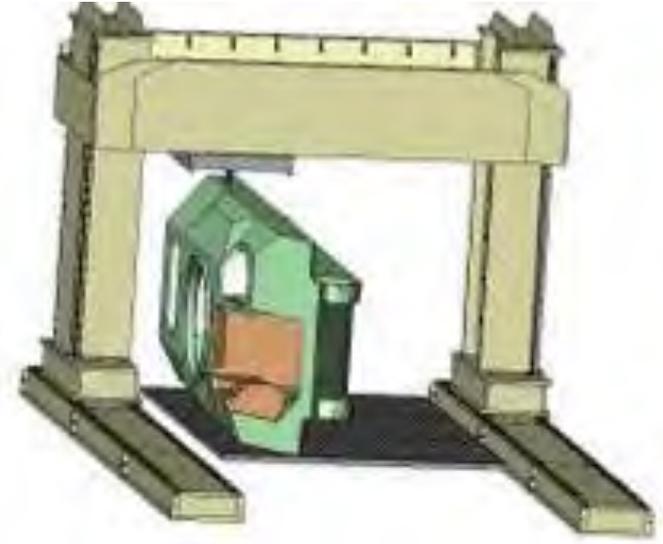


## Laser-Assisted Friction Stir Welding

- Enable Solid-State Joining of High Temperature Materials, Steel and Titanium Alloys
- Composite Joining, Casting Repair, and Surface Modification

# Field Deployable FSW

- Today: A very successful “specialty” welding process
  - Cost effective and highly energy efficient
  - Materials limited to Al and other low melting materials
  - Gantry systems limited to in-house fabrication of simple geometry and thin-sectioned structures
- Industry Needs and Market Opportunities
  - Steel structures
  - Complex and thick sectioned structures
  - On-site construction capability



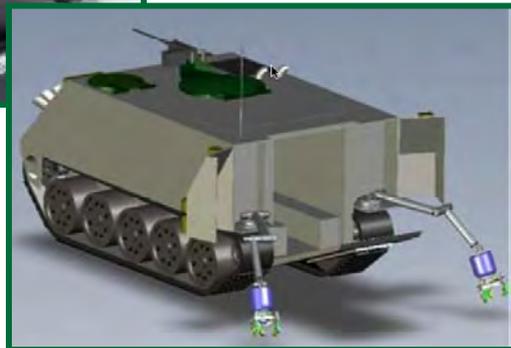
# Field Deployable FSW



ORNL Advanced Robotic R&D



ORNL FSW R&D



- *Capability for joining of high-performance materials (low-cost Ti, armored steels, etc) beyond Al alloys*
- *Field deployable repair and construction of large and complex structures (armored vehicles, ships)*

# Alloy Development of Steels at ORNL Has a Distinguished History

- Fundamental studies of defect physics and radiation damage
- Alloys designed for improvements in resistance to radiation (fission and fusion)
- Steels for high-temperature structural use (nuclear, fossil, industrial)
- Iron-based intermetallics

Super 9Cr-1Mo Steel Alloys

HT-UPS 'Lean' Austenitic Stainless Steels

CF8C-Plus - New Cast Stainless Steel for High-Temperature Performance

3Cr-3TaVW Steels

TMA 6301 and TMA 4701: Heat-Resistant Alloys

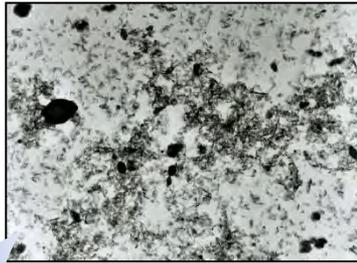
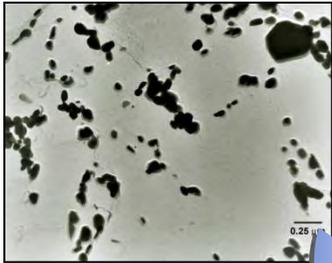
Alumina-Forming Austenitic Stainless Steels

# Modern Materials Science Applied to Steels Yields Dramatic Improvements

Alloy composition is changed to produce a microstructure of fine, stable precipitates

Commercial Bainitic Steel

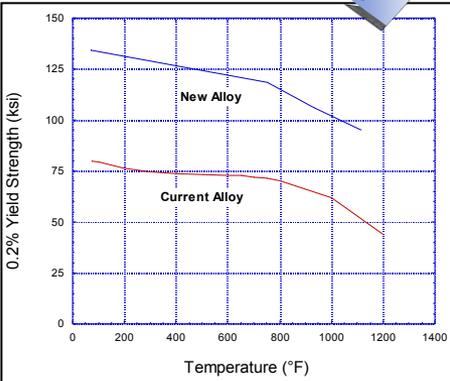
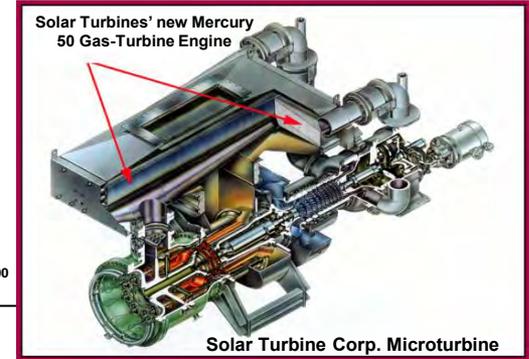
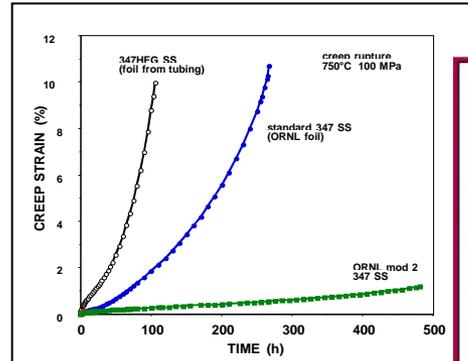
ORNL "Super" Bainitic Steel



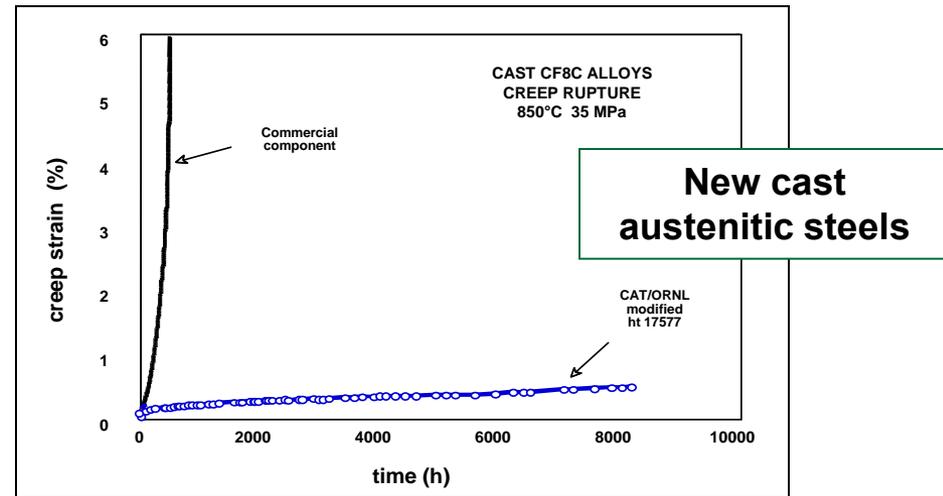
Old

New

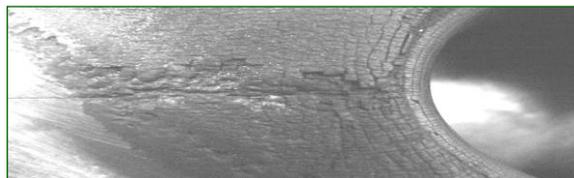
Similar scientific microstructural design produces new austenitic stainless steels for microturbine recuperators



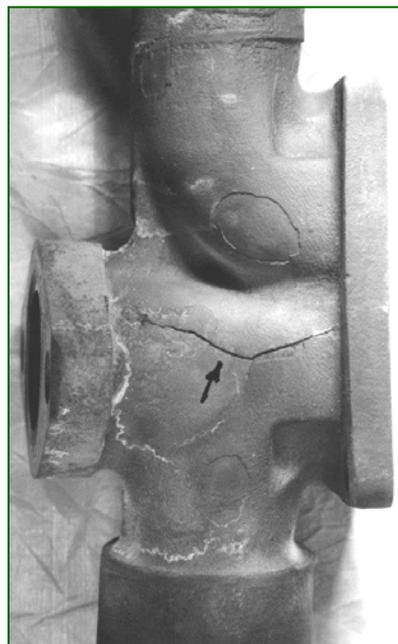
Low chromium steels for chemistry and energy industry applications



# CF8C-Plus Cast Stainless Steel: Higher Temperature Capability and Reliability for Advanced Diesel Engines and Gas Turbines



turbo-housing



exhaust manifold

C-15, HD 14.6L HD On-Highway Diesel Engine

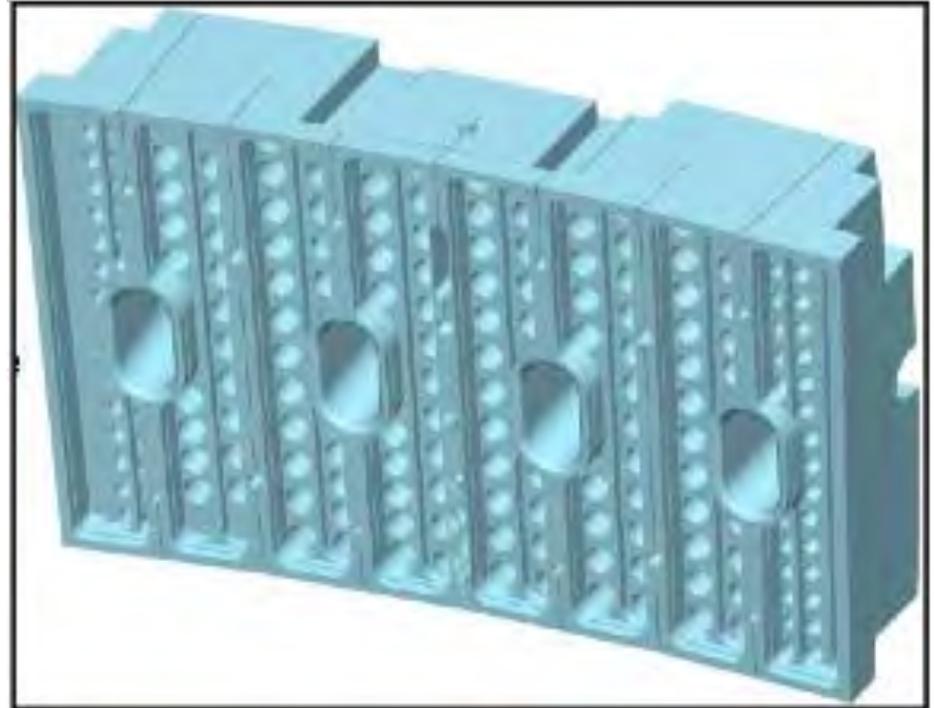


Caterpillar commercialized.

- Cast stainless upgrade for SiMo cast-iron diesel engine exhaust components
- Cast stainless upgrade for CF8C steel gas turbine structural components

# New Modified CF3MN Steel Developed by ORNL in <1 yr for ITER-Fusion Project

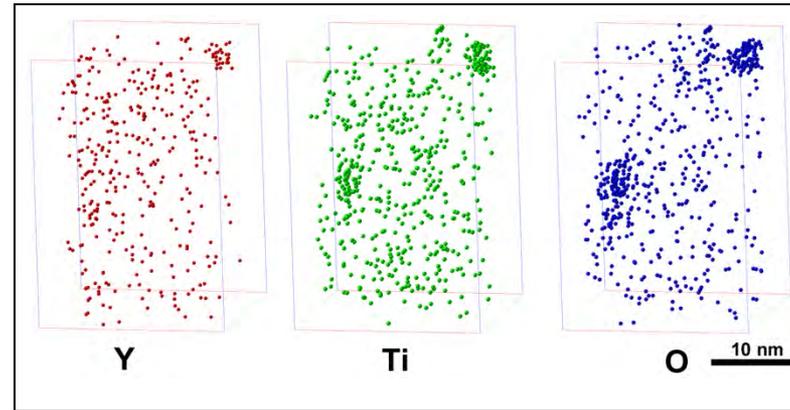
- Complex geometry of the shield module would require considerable machining and heavy section welding of wrought 316SS.
- Casting methods may be viable to considerably reduce time and cost associated with fabrication.
- New cast steels show impact properties comparable to wrought steels.



Shield Module



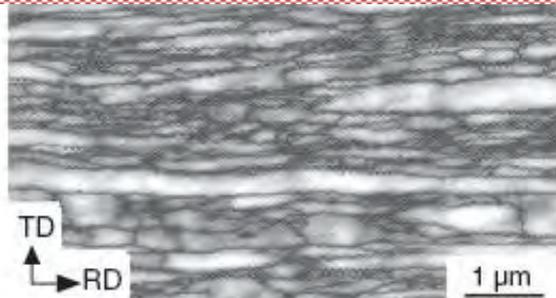
# Tailoring and Stabilizing Nanostructures for Improved Alloy Performance



Miller et al, ORNL

Nanocluster-strengthened steel

Nano → Micro → Meso → Macro

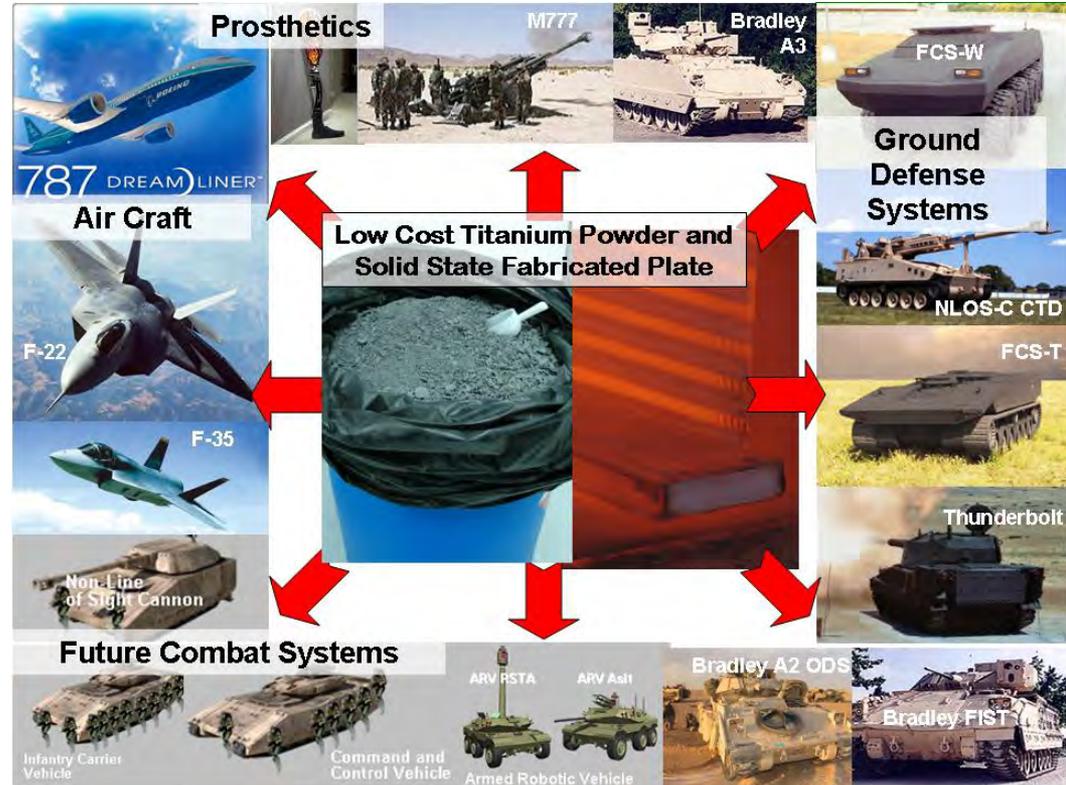


Higher energy absorption from control of cracking and strength

Kimura, Inoue, Yin, Tsuzaki, Science 320 (2008)

# Solid-State Consolidated Low-Cost Titanium and Ti Alloy Powder

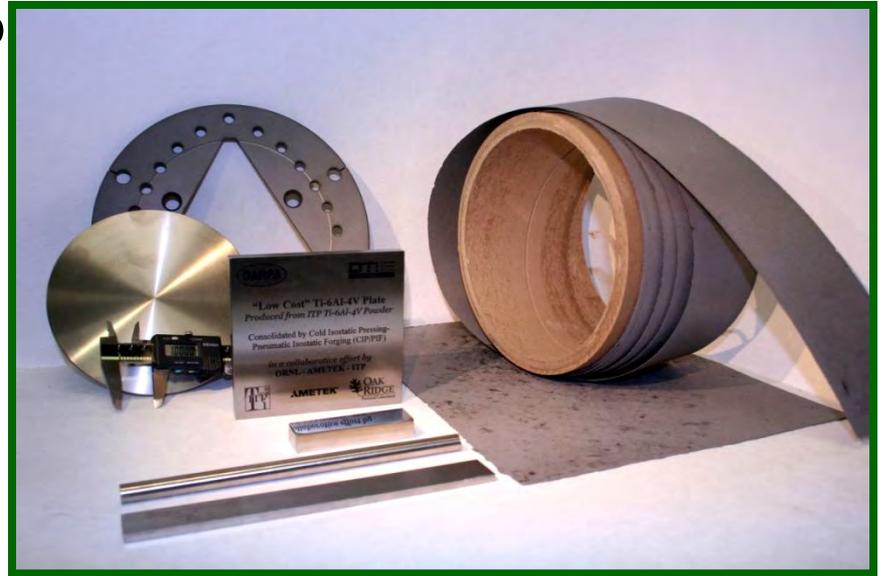
- **Ti Offers Many Attractive Properties.**
  - High Specific Strength
  - Good Elevated Temperature Properties
  - Excellent Corrosion Resistance
  - Excellent Ballistic Resistance
- **Cost and Availability Are a Concern**
  - Lead Times 12 to 18 Months
  - Plate Prices of \$35 to \$50/lb
- **Cost Limits Application to Specific Markets.**
- **New Low Cost Titanium Powders Could Initiate a Paradigm Shift in Titanium's Use in Industry & DOD Application**



**Several of the DOD Applications that Low Cost Titanium and Ti Alloy Products Would Impact**

# Solid State Consolidation of “Low-Cost” Titanium Powders

- Oak Ridge National Laboratory Is Collaborating with Industry to Develop the Solid State Processing Required for Consolidating New Low Cost Titanium Powders
  - Extrusion for Bar
  - Roll Compaction for Sheet
  - Hot Isostatic Forging, Press and Sinter, Vacuum Hot Pressing, and Pneumatic Isostatic Forging for Plate and Near Net Shapes
- Reduced Cost of Plate, Sheet, and Near Net Shapes by 50 to 90%
- Reduced Scrap from 50% for Conventional Material to Less Than 5% for New Low Cost Titanium
- Demonstrated and Exceeded “Wrought” Material Performance Parameters



Solid State Consolidated Plate, Bar, Sheet, and Net Shape Components Produced from New “Low Cost” Titanium Powders



Front and back of V<sub>50</sub>-tested vacuum-hot-pressed Ti-6Al-4V

# DOE's Leader in Carbon Fiber Research

- Develop and demonstrate affordable carbon fiber precursors
- Develop and demonstrate advanced technologies for converting conventional and alternative precursors to carbon fiber
- Advance low-cost composite design and manufacturing capabilities
- Transition technology to industry partners

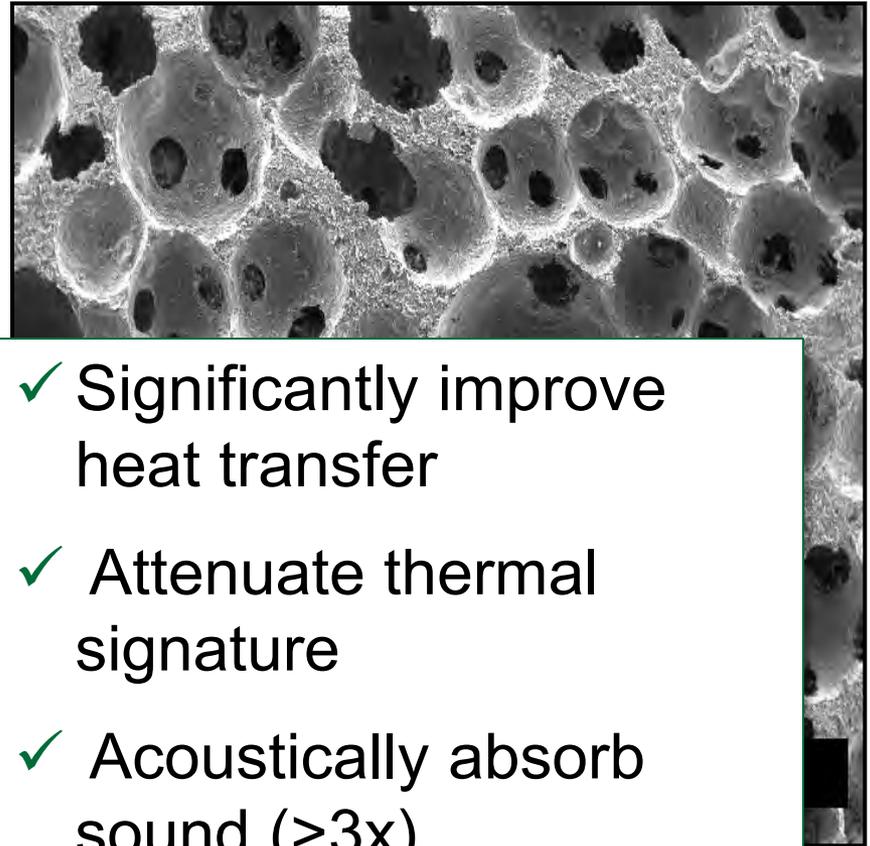


*Fully-carbonized fiber exiting the microwave assisted plasma carbonization unit*



# Carbon and Graphite Foam Materials

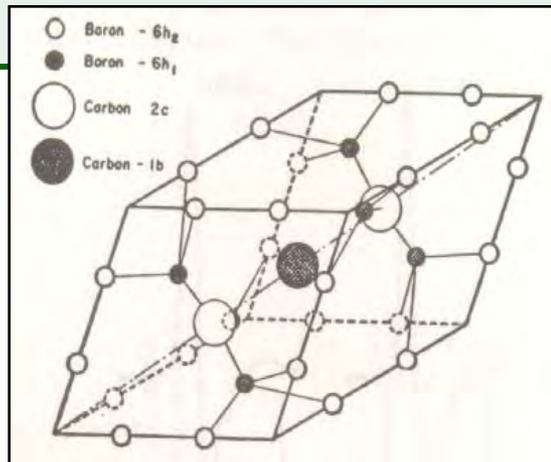
- Highly ordered graphitic ligaments
  - Graphite-like properties
  - As thermally conductive as aluminum, at 1/5<sup>th</sup> the weight
  - up to 180 W/mK
- Dimensionally stable: low CTE - ~2 - 4 min/in/°C
- Open porosity: Permeable to fluids
- Excellent thermal management material



- ✓ Significantly improve heat transfer
- ✓ Attenuate thermal signature
- ✓ Acoustically absorb sound (>3x)
- ✓ Reflect electromagnetic energy

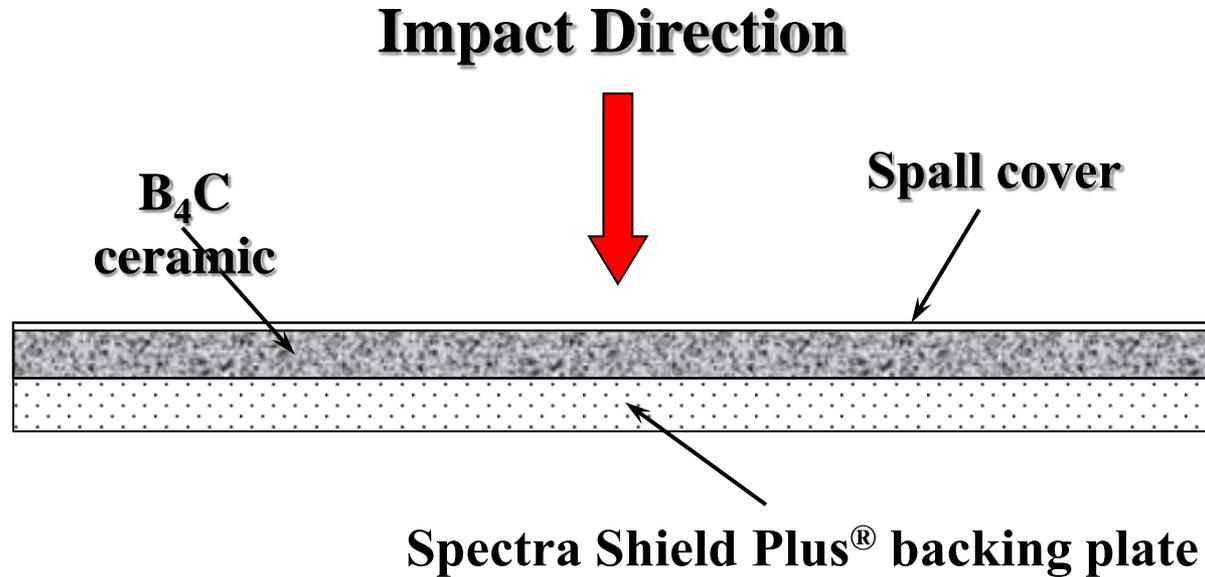
# Longstanding Achievements in Ceramic Science and Development

Mat'l.	Tensile Strength	Armor Mass Efficiency*
RHA Steel	1170	1.0
5083 Aluminum	350	1.0-1.2
Titanium -6Al-4V	970	1.5
<b>Boron Carbide (B<sub>4</sub>C)</b>	<b>350-550 (Flexural)</b>	<b>3.0+</b>



\*Relative weight per unit area to defeat a given ballistic threat.

# Baseline Armor System



- Spall cover limits ejection of fragments from impact surface
- Ceramic deforms and fractures projectile; absorbs energy
- Backing plate captures projectile and ceramic fragments; absorbs remaining energy

Nunn, Hansen, Frame, Lowden

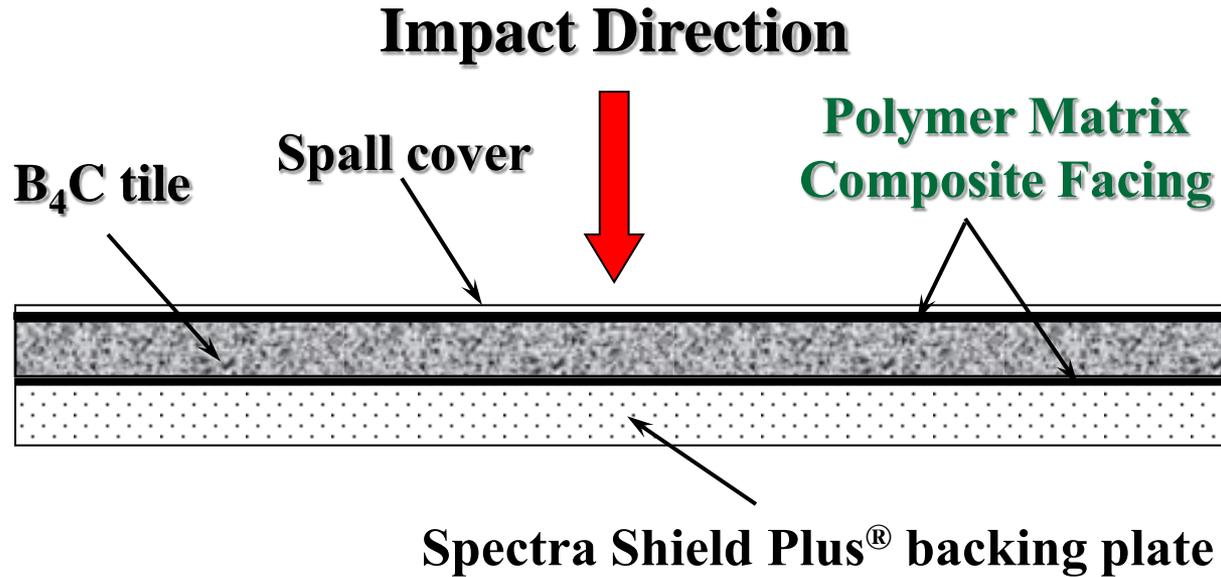
# Ballistic Test Results

## 7.62 mm Projectile

<b>B<sub>4</sub>C Ceramic</b>	<b>Areal Density, psf</b>	<b>V<sub>50</sub>, fps</b>	<b>V<sub>50</sub> Increase</b>
Supplier 1 (baseline)	5.26	2050	---
Supplier 2	5.20	2290	11.7%
ORNL High Strength	5.29	2048	0%
ORNL Fine Grain	5.20	2250	9.8%
ORNL Coarse Grain	4.96	2547	24.2%

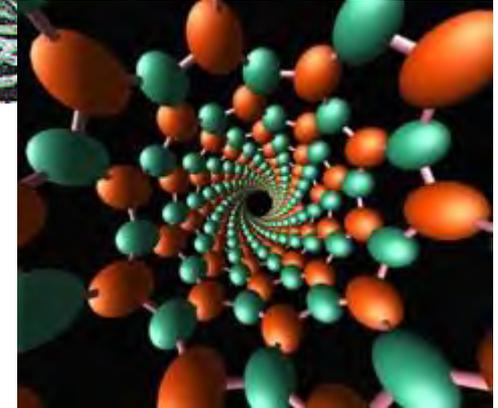
V<sub>50</sub> is the velocity of the projectile at which 50% of the impacts are partial penetrations and 50% are complete penetrations.

# Armor Configuration with Polymer Matrix Composite Facing



# Nanomanufacturing

- DOE's Industrial Technologies Program and ORNL are working to transform nanoscience discoveries into real-world solutions that will lead the next industrial revolution
- Goal is to enable mass production and application of nanotechnologies that could transform industrial processes
- Manufacturing techniques for cost-competitive, large-scale production of nanomaterials and nanostructured materials
- Methods to integrate nanomaterials into intermediate and finished products



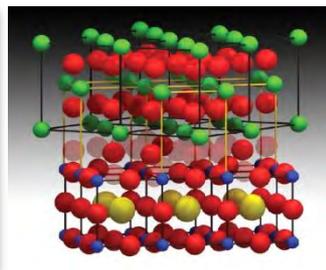
View down middle of a boron nitride nanotube.

*The U.S. government has invested >~\$10 billion in nanotechnology science.*

*Applied research in nanomanufacturing will help realize this technology's vast potential.*

# It's an Exciting Time for Mat'ls R&D at ORNL

- Challenging scientific and engineering issues with strong emphasis on meeting future energy needs and other technical challenges
- Vibrant environment
  - New approaches to material design, testing, processing
  - People + Capabilities + State-of-the-art-facilities
- Opportunities all along the science-to-technology deployment pathways



**Transformative materials science and translation to application**