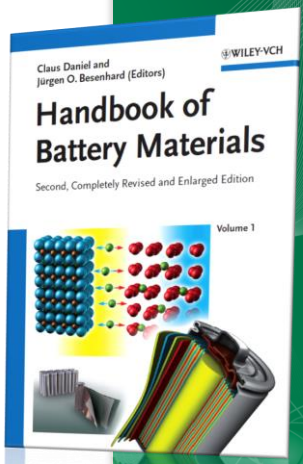
AIChE
American Institute of Chemical Engineers
Knoxville - Oak Ridge Local Section

ORNL's Energy Storage and Advanced Manufacturing Initiatives



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U.S. DEPARTMENT OF ENERGY

OAK RIDGE NATIONAL LABORATORY
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Sustainable transportation R&D in diversity of technologies

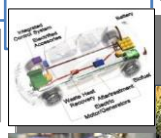
Accelerating electrification
- Wireless power transfer
- Advanced battery materials, processing, and modeling
- Battery manufacturing R&D

Efficient vehicles
- Lightweighting
- Advanced electric/ combustion, and hybrid powertrains
- Trucks as well as autos

Alternative fuels
- Drop-in biofuels for legacy cars
- Renewable fuels for advanced engines
- Natural gas

Intelligent systems and operations
- Managing congestion
- Efficient operations in commercial vehicles
- Data for decision-making
- Communications

New technologies and processes for:
- Safe, secure, and affordable vehicles for passengers and freight
- Domestic production of transportation fuel
- Reducing environmental impacts of transportation
- Predictable, reliable transport schedules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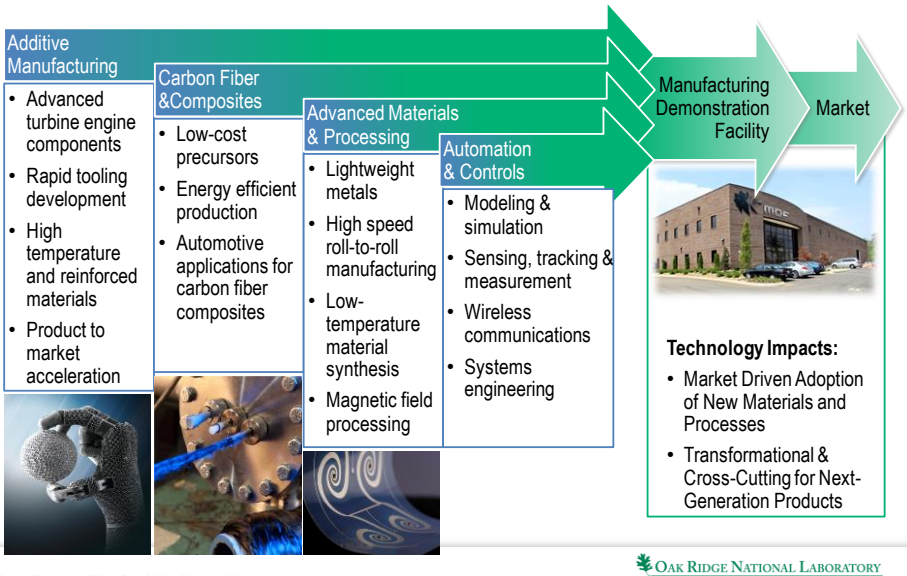
Advanced Manufacturing R&D



Energy storage

Battery R&D Motivation

2011 Chevrolet Volt

4D Hatchback
Mileage: City: 35 mpg Hwy: 40 mpg
Fuel Type: P Engine Type: 1.4L

Make/Model: Chevrolet Volt
Segment: Eco
Powert
MSRP: $40,280
Invoice
Depreciation: $27,540.00
Fees & Taxes: $-4,615.00
Insurance: $5,684.00
Interest: $3,687.00
Maintenance: $2,113.00
Opportunity Cost: $276.00
Repairs: $1,406.00
Electricity Price: $0.12
Fuel: $2,692.00
Price of Fuel: $4.00

Five-Year Ownership Cost: $38,783.00

2011 Chevrolet Cruze LTZ

4D Sedan
Mileage: City: 24 mpg Hwy: 36 mpg
Fuel Type: R Engine Type: 1.4L Inline 4-cyl MFI DOHC 16-valve Turbocharged DCVCP ECOTEC VVT (LUJ)

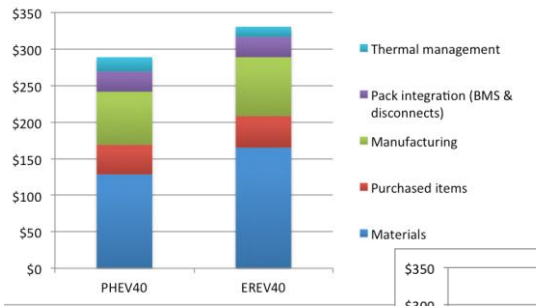
Make/Model: Chevrolet Cruze
Segment: Compact Sedan
Powert
MSRP: $21,975
Invoice
Depreciation: $14,466.00
Fees & Taxes: $1,661.00
Insurance: $5,529.00
Interest: $1,983.00
Maintenance: $2,465.00
Opportunity Cost: $487.00
Repairs: $1,600.00
Electricity Price: $0.12
Fuel: $11,592.00
Price of Fuel: $4.00

Five-Year Ownership Cost: $39,785.00

Source: GM-Volt.com, LLC

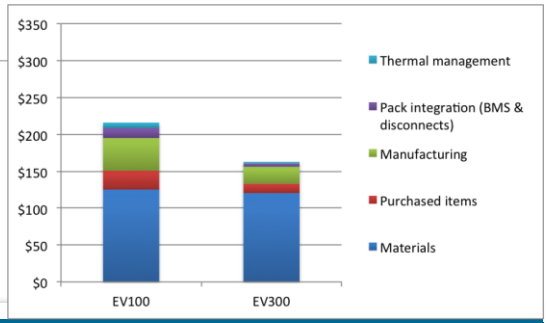
PHEV and EV Cost Estimates, $/kWh

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



- Estimates from ANL's BatPaC model.
- Based on 2020 production year and annual battery production of 100,000
- Chemistry is graphite anode, NMC441 cathode, EC-EMC-$LiPF_6$ electrolyte
- All batteries have liquid cooling

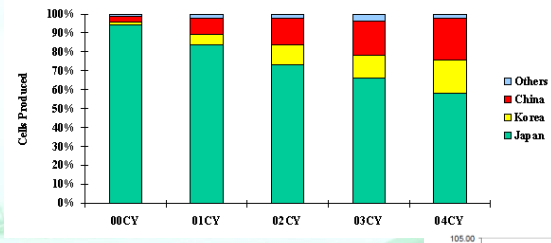
- Manufacturing = electrode processing, cell assembly, formation, module and battery assembly
- Purchased items = cell terminals and packaging. module and pack jackets



David Howell

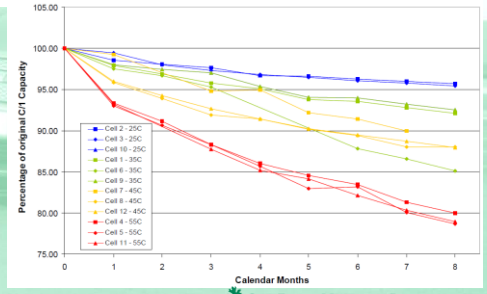
ORNL is addressing two problems:

1. Batteries not being manufactured in the U.S.
2. Batteries not lasting long enough or performing well enough



Work with U.S. battery manufacturers together to make them competitive with their U.S. operations

Study degradation mechanisms and develop new materials and concepts for batteries



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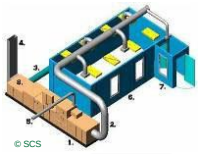
Lithium ion battery manufacturing state of the art technology overview

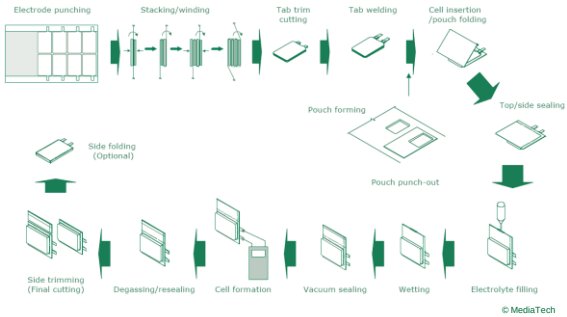


Electrode processing

Cell assembly

Post processing

Raw materials → Slurry processing and mixing → Coating → Drying



Formation

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DOE Battery Manufacturing

R&D Facility

funded by DOE Vehicle Technologies Office and Advanced Manufacturing Office

Oak Ridge National Laboratory's newest energy storage research facility is the nation's largest open access battery manufacturing R&D facility and will assist manufacturers in satisfying the demand for hybrid-electric and electric vehicles that are safe, affordable, and go the extra mile.

It is unique and complimentary to Argonne and Sandia National Laboratories cell assembly facilities with development of joint work plan

- Pouch cells of up to 66x99x12mm and 6Ah
- Focus on manufacturing R&D, drying, alternative heating technologies, solvent less processing, alternative assembly methods, new cutting, materials handling, and filling methods.
- Production yield issues

It features

- 700 sqft dry space with <0.5% R.H.
- 700 sqft adjustable 1-15% R.H.
- Located in manufacturing R&D park together with additive manufacturing, room-temperature materials synthesis, roll-to-roll processing, direct powder feed rolling, robotics R&D
- In easy to access off-site location specifically designed for industrial collaborations.

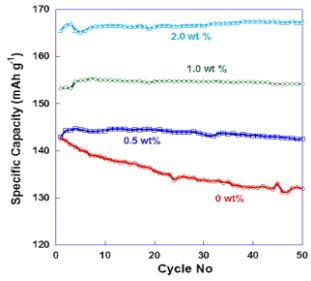
Aqueous electrode processing for lithium ion batteries US Patent pending 2013/0108776 A1

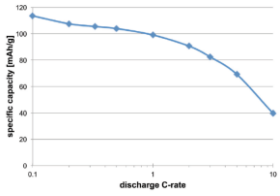
- **Elimination of toxic organic solvents**
  - **Organic solvent free processing**
  - **Near theoretical capacity cycling**
  - **Extended cycle life**
- **Reduction of processing cost for electrodes**
  - **Aqueous processing via slot-die coating could reduce electrode coating cost by up to 75% and eliminate expensive, toxic NMP solvent.**
  - **Estimated 20% pack cost reduction.**

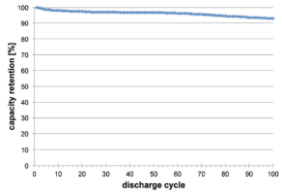
US Patent pending US 2013/0108776 A1, pub. May 2, 2013; J Power Sources, 196, 2452–2460 (2011); J Electrochem Soc, 159, A1152–A1157 (2012); Langmuir, 28, 3783–3790 (2012); J Electrochem Soc, 160, A201–A206 (2013); J Colloid Interf Sci, Under Review, 2013

Aqueous electrode processing for lithium ion batteries US Patent pending 2013/0108776 A1

- Control of dispersion chemistry
- Surface charges
- Mixing protocols
- Water removal







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2013 R&D 100 Award Winner

SYMMETRIX HPX-F

SYMMETRIX HPX-F, a nanocomposite separator for lithium-ion batteries, addresses market demands by lowering battery cost and improving safety through the replacement of polymer separators. Using lower-cost ceramics and mineral fillers in the separators improves thermomechanical properties, making the battery less likely to overheat or ignite due to shorting. This breakthrough membrane technology could find application in electric vehicles, grid storage, portable electronics, filters, barrier fabrics, transdermal drug delivery, and toxic chemical absorption.

The ORNL team consisted of *(seated)* Curt Maxey, Claus Daniel, David Wood, Beth Armstrong; *(standing)* Jianlin Li, Amit Shyam, Harry Meyer, Ralph Dinwiddie, Wally Porter, Cristian Contescu, Edgar Lara-Curzio, Hsin Wang; *(not pictured)* Rosa Trejo, and Jane Howe. Also not pictured are Kirby Beard and Ann Edwards, the joint developers from Porous Power Technologies, LLC.

POROUS POWER™ TECHNOLOGIES

The project was funded by the Advanced Manufacturing Office and Vehicle Technologies Office within DOE's Office of Energy Efficiency and Renewable Energy and by Porous Power Technologies, LLC.

J Power Sources 196 (2011) 7779– 7783; J Electrochem Soc, 146 (3) 947-954 (1999); ORNL/TM-2012/613, DOI 10.2172/1059845

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Industrial partners with active battery projects in collaboration with ORNL

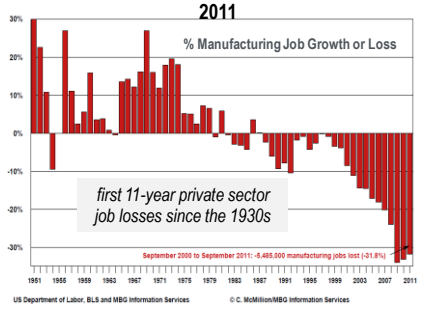
Advanced Manufacturing

Manufacturing matters

- 12% of U.S. GDP
- 12 million U.S. jobs
- 60% of U.S. engineering and science jobs
- 57% of U.S. Exports
- Nearly 20% of the world's manufactured value added

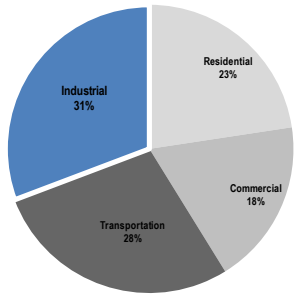
Jobs

31.8% of all manufacturing jobs lost from 2000-2011



Energy

31% of all 2010 U.S. total energy consumption



*Includes total primary energy direct use and electricity use in end-use sectors including losses
Source: *Annual Energy Review 2010*, US EIA

We are focusing ORNL resources to support manufacturing initiative

- Manufacturing and materials R&D to:
  - Reduce the energy intensity of U.S. industry
  - Support development of new products
  - Strengthen our nation's competitiveness and economic vitality
- Leveraging ORNL's distinctive core capabilities
  - Advanced materials
  - Advanced characterization
  - Neutron scattering
  - High-performance computing

U.S. DEPARTMENT OF ENERGY | Advanced Manufacturing

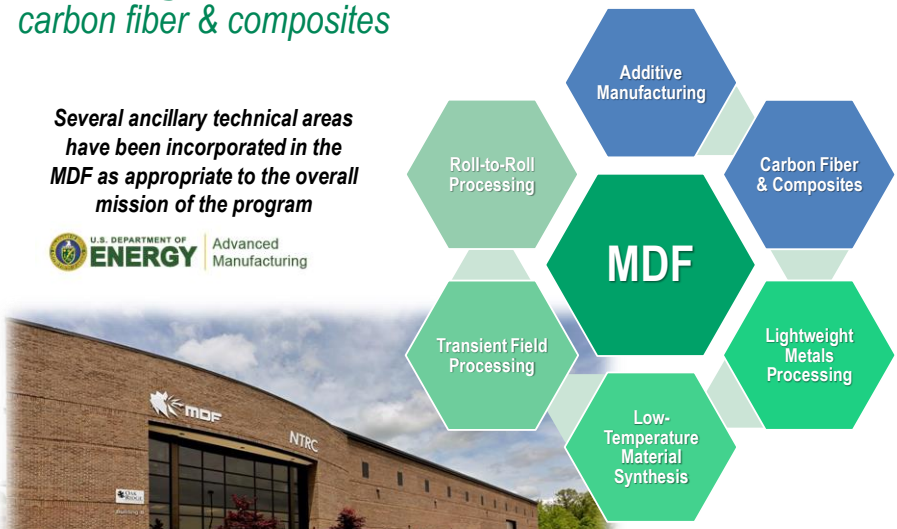
***Manufacturing Demonstration Facility (MDF)*: a multidisciplinary DOE-funded facility dedicated to demonstration of next-generation materials and manufacturing technologies for advancing the US industrial economy**

www.ornl.gov/manufacturing

ORNL's MDF is primarily focused in two key areas– *additive manufacturing and carbon fiber & composites*

Several ancillary technical areas have been incorporated in the MDF as appropriate to the overall mission of the program

U.S. DEPARTMENT OF ENERGY | Advanced Manufacturing



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Additive Manufacturing

MDF Manufacturing Demonstration Facility

7 Metal Machines

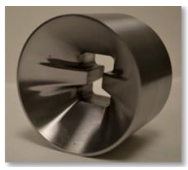
Electron Beam Melting

- Developing in-situ characterization, feedback and control
- Precision melting of powder materials
- Processing of complex geometries not possible through machining

Ultrasonic Additive Manufacturing

- Simultaneous additive and subtractive process for manufacturing complex geometries
- Solid-state process allows embedding of optical fibers and sensors

Laser Metal Deposition



- Site-specific material addition
- Application of advanced coating materials for corrosion and wear resistance
- Repair of dies, punches, turbines, etc.

6 Polymer

Fused Deposition Modeling

- Development of high-strength composite materials for industrial applications
- Precision deposition of thermoplastic materials

Working with AM equipment providers to develop high-performance materials, low-cost feedstocks, processing techniques and in-situ characterization and controls to enable broad dissemination of technologies

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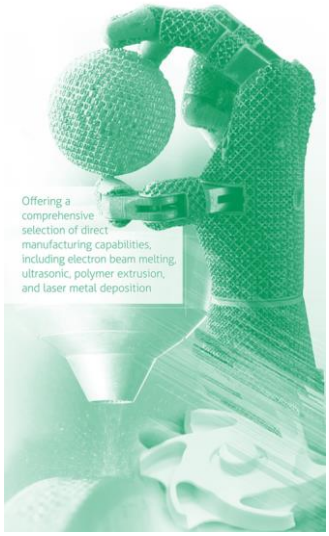
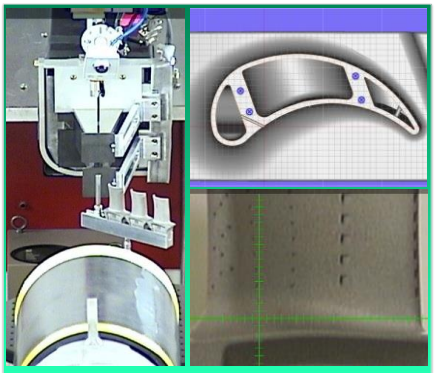
Additive Manufacturing (AM)



Leveraging key resources at ORNL to accelerate technology implementation

- Developing advanced materials
  - Titanium alloys, Ni superalloys, stainless and ultra high-steels
  - High-strength, carbon-reinforced polymers
- Implementing advanced controls
  - In-situ feedback and control for rapid certification and quality control
- Understanding material properties and geometric accuracy (advanced characterization)
- Exploring next-generation systems to overcome technology barriers for manufacturing
  - Bigger, Faster, Cheaper
  - Integrating materials, equipment and component suppliers with end users to develop and evolve the supply chain

Neutron characterization of AM

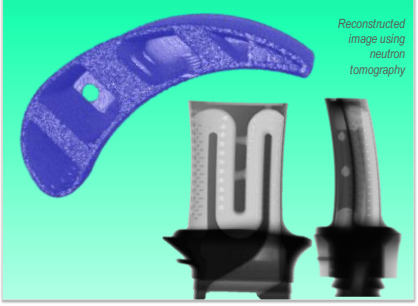


- Successful Inter planer spacing measurements on complex geometry
- Developing capabilities for residual stress mapping
- In-situ measurement during processing, HT, mechanical testing

Residual Stress Measurements

Neutron Imaging and CT

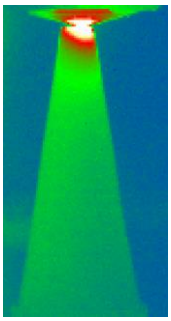
- Neutrons offer higher contrast and better resolution than x-rays
  - Resolution Capabilities
    - Currently at HFIR: 50 μm
    - Proposed VENUS: 1 μm
- Ability to study micro/macro cracking phenomena related to residual stress during processing



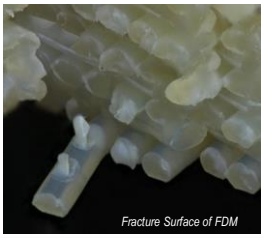
Polymer Additive Manufacturing

Three focus areas:

1. In-situ characterization and control
   - Thermography to understand impact of temperature variations in the oven and head on part quality
   - In-situ vision system for tip and part monitoring
2. Development of high strength materials
   - Target is specific strength exceeding 110 MN-m/g (6061-T6)
   - Multiple materials under investigation
     - Primospire 250, CF reinforced PEEK, PAEK, Nylon 66
3. Increasing z-strength to achieve isotropic mechanical properties
   - Exploring impact of magnetic field processing on deposition of filled materials, z-dithering, and active flow control



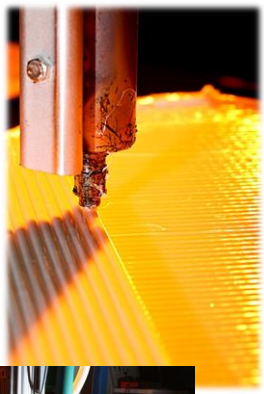
Thermal image of FDM

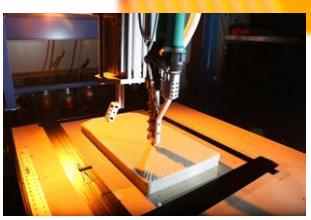


Fracture Surface of FDM

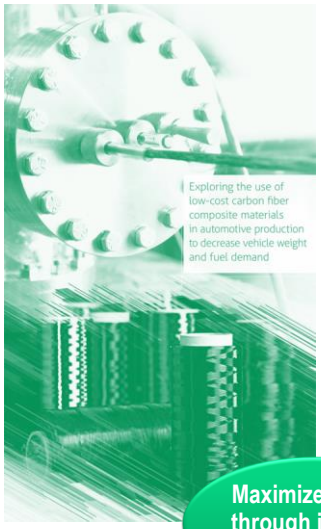
Large-Scale, Out-of-the-oven Additive Manufacturing

- Collaboration between ORNL, Lockheed Martin and Equipment Manufacturer
  - Pelletized feed of four separate materials
  - Research focus includes
    - Materials – low CTE, high strength materials
    - Deposition – new methods of deposition and control
    - Multiple-robot coordination (8' x 8' x 8' gantry, Kuka Robot)
- Will enable manufacture of large systems (tooling, UAVs, robotics…)





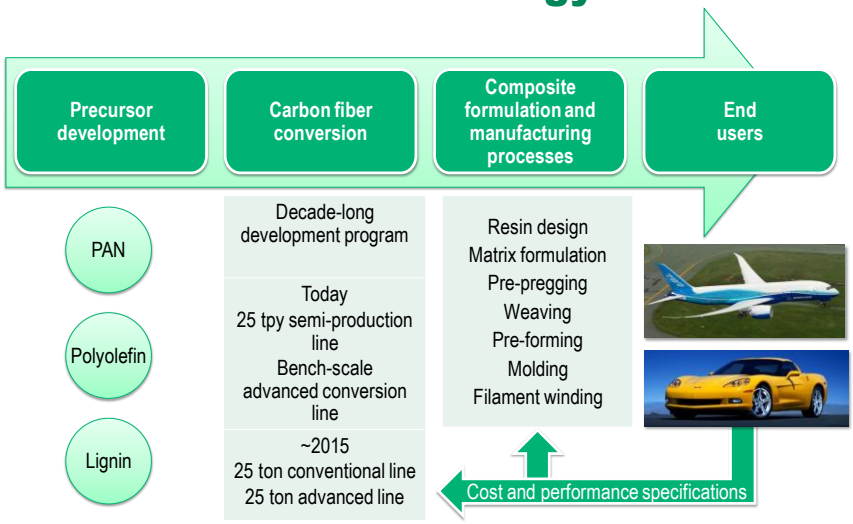
Carbon Fiber and Composites



- Enable deployment of low-cost technology in high-volume applications
  - Low-cost raw materials
  - Low-cost fiber manufacturing processes
  - High-rate, robust composites manufacturing processes
- Develop and transition to industry technology with significant impacts on U.S. and global energy security

Maximize impact through industry partnerships

Building a sustainable carbon fiber commercialization strategy



Carbon Fiber Technology Facility

- **42,000 ft^2 facility, equipped using $34.7M in DOE funding**
  (awarded in 2009)
  - November 2011: Facility occupancy
  - October 2012: Installation complete
  - Q4 2012: Start-up testing/commissioning
  - Q1 2013: First fibers off the line (using "standard" PAN precursor material)
- **Production capacity:**
  - 390-ft. long processing line
  - Custom unit operation configuration
  - 25 tons/yr of fiber from multiple precursors in various forms
  - Allows industry to validate conversion of low-cost precursors at semi-production scale

Facility dedication with Governor Bill Haslam, Asst. Sec DOE EERE Dave Danielson

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

Carbon Fiber Composites Consortium—

A public-private partnership enabling innovations in carbon fiber and composites

- 3M Company
- ABC Group Sales & Engineering
- Advanced Composites Group
- Alpha Industries
- ATK Launch Systems
- BASF Corporation
- Chomarat NA, LLC
- Composite Applications Group
- Continental Structural Plastics
- Cytec Carbon Fibers
- Dow Chemical Company
- Despatch Industries
- Faurecia
- Fibria
- Ford Motor Company
- General Electric
- Global Composites Solutions
- Graftech International
- Hanwha Azdel
- Harper International
- Hills, Inc.
- Innovation Valley Inc.
- Innventia
- INOAC USA
- Lignol Innovations
- Materials & Chemistry Laboratory
- Metalsa Structural Products
- NFT, Inc.
- NovusFolium
- Plasan Carbon Composites
- Sabic Innovative Plastics
- SGL Carbon Fibers
- Sodra Innovation
- SSOE Group
- Steelcase
- Swift Engineering
- Toho Tenax America
- United Technologies Research Center
- United States Enrichment Corp. (USEC)
- UT-Battelle
- Virdia, Inc.
- Volkswagen Group of America

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Dow and Ford partner with ORNL to scale up low-cost carbon fiber

- Dow and Ford team up to bring low-cost, high-volume carbon fiber composites to next-generation vehicles
  - Reducing weight of new cars and trucks by up to 750 lbs by the end of the decade
  - Foundational work at ORNL on low-cost precursors key to automotive applications
  - DOE and state of Michigan fund $13.5M research agreement to develop lower cost carbon fiber production process using polyolefin in place of conventional polyacrylonitrile (PAN) as feedstock
  - Novel process could reduce production cost by 20%
  - High-volume commercial launch anticipated outcome

Working with ORNL's MDF

Manufacturing Demonstration Facility

- **Identify opportunities aligned with ORNL's MDF technology thrust areas**
- **Discuss ideas with MDF director**
- **Jointly pursue funding to support collaborative activity**

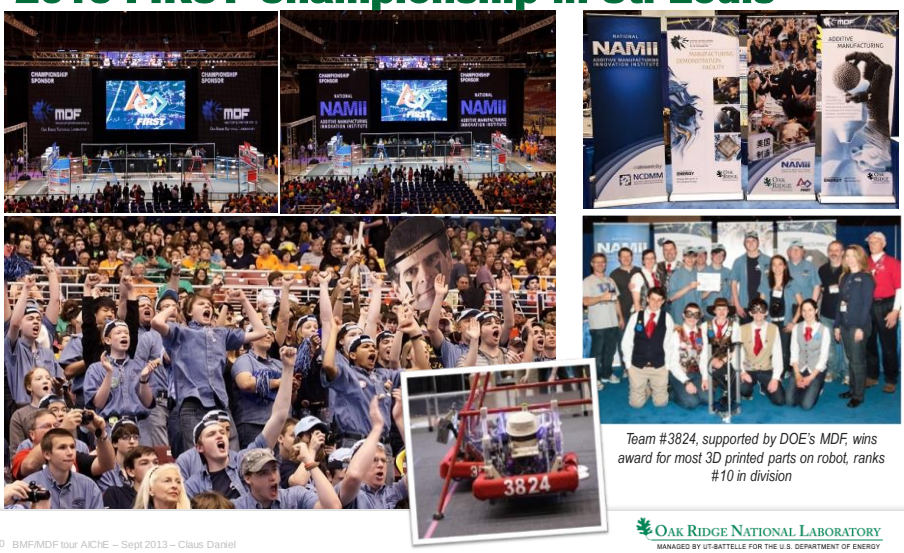
	Assess	Assist	Collaborate
Type of Agreement	User Agreement (Non Proprietary)	Work for Others Agreement (Proprietary)	Cooperative Research & Development Agreement
Length of Engagement	Up to 12 months	As defined by agreement	Longer-term basis of a year or more
Cost to Company	NO COST	Full cost recovery	Cost-share required
Intellectual Property Rights	Each party owns its own inventions. Jointly developed inventions will be jointly owned.	Companies own intellectual property made or created using corporate funds as a result of these engagements.	Companies own inventions they make during the collaboration and have an option to negotiate an exclusive license in a specific field of use to inventions made by ORNL.
Protection of Generated Information	Information generated is publicly available.	Companies paying for services with corporate funds can treat all generated data as their proprietary information.	Commercially valuable information generated under a CRADA may be protected for up to 5 years, depending on funding source.

Science, Technology, Engineering & Mathematics (STEM)
ORNL helps kick off 2013 FIRST

FRC FIRST® Robotics Competition

Science, Technology, Engineering & Mathematics (STEM)
DOE's MDF Partners with NAMII to Showcase Additive Manufacturing at 2013 FIRST Championship in St. Louis

FIRST



Team #3824, supported by DOE's MDF, wins award for most 3D printed parts on robot, ranks #10 in division

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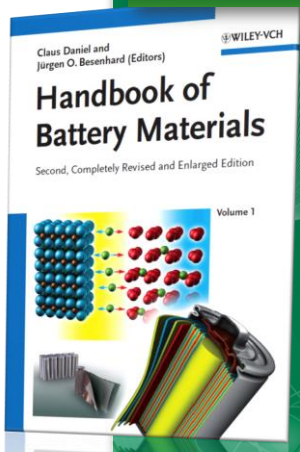
AIChE
American Institute of Chemical Engineers
Knoxville - Oak Ridge Local Section

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy
Vehicle Technologies Office
Advanced Manufacturing Office



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U.S. DEPARTMENT OF ENERGY

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