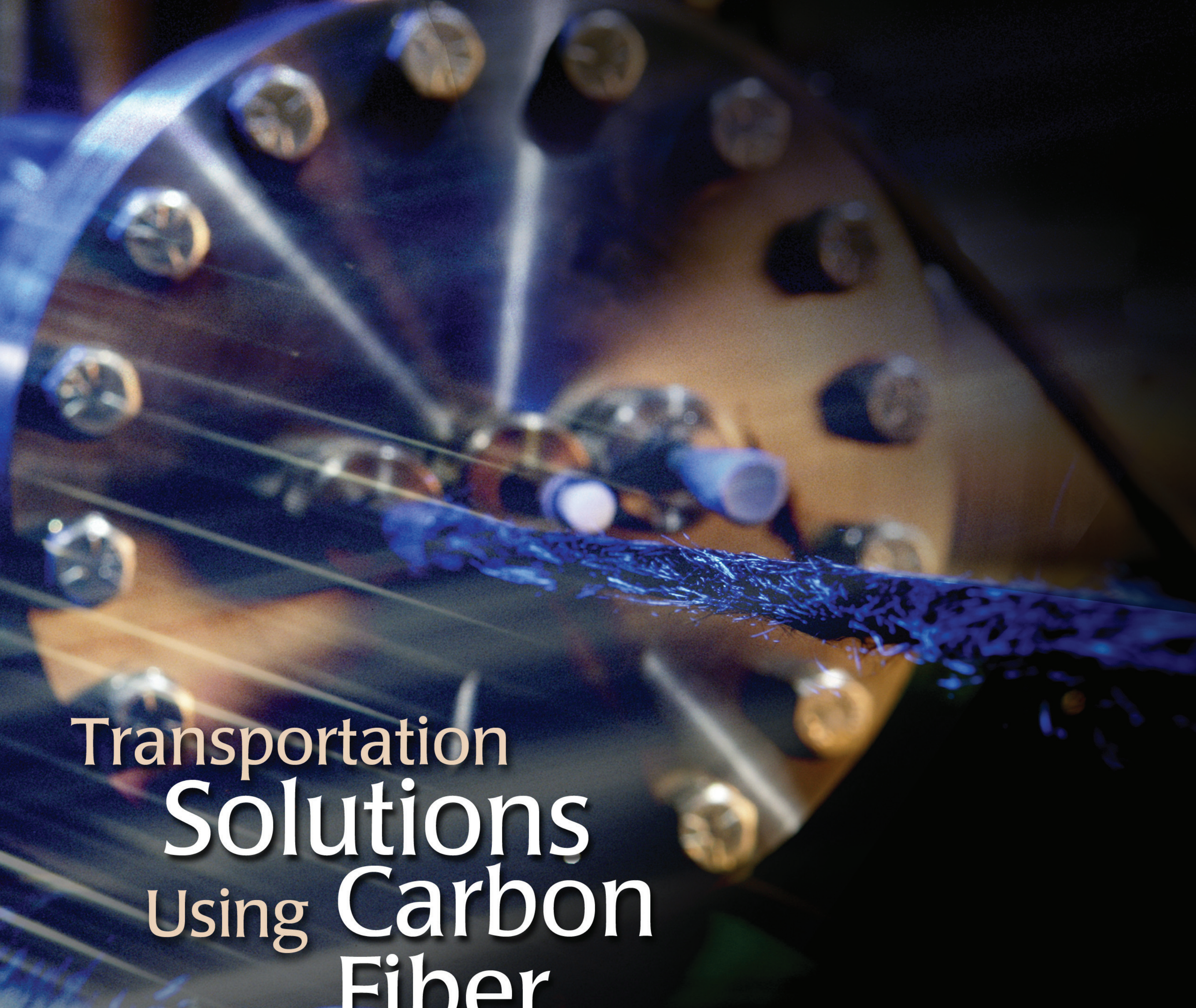


Transportation Solutions Using Carbon Fiber

New technologies to help increase fuel efficiency and decrease America's dependence on foreign energy sources.

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

Advancing Development and Commercialization

Increasing vehicle fuel efficiency and decreasing dependence on foreign oil are priorities of the U.S. Department of Energy (DOE). Oak Ridge National Laboratory (ORNL) is helping meet these challenges by exploring the use of low-cost carbon fiber composite materials in automotive production to decrease vehicle weight and fuel demand. The lab is also studying its use in other applications such as wind energy generation and industrial technologies.

An internationally recognized leader in low-cost carbon fiber research and development, ORNL operates the only general access carbon fiber manufacturing research facility in the DOE laboratory system. For more than ten years, it has worked with government and industry to address commercialization challenges, including cost and manufacturing limitations.

To help overcome these barriers, ORNL is aggressively researching less expensive alternative precursors, advanced technologies for converting conventional and alternative precursors to carbon fiber, and low-cost composite design and manufacturing capabilities.

Precursor to Filament

Lignin is a compound derived from wood. It is a carbon fiber precursor – an alternative to higher-cost, petroleum-based precursors.

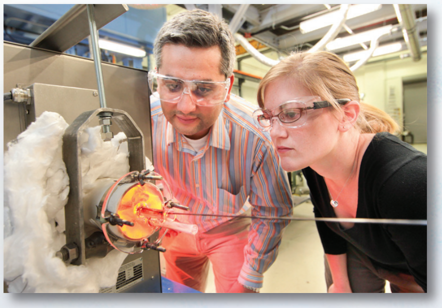
About half of carbon fiber manufacturing costs are associated with precursors. Polyacrylonitrile (PAN), today's most commonly used precursor, is petroleum-based and its price fluctuates with crude oil prices.

To drive down costs, ORNL is investigating textile PAN and polyolefin-based precursors that are lower-cost yet still petroleum-based.

The lab is also researching the capabilities of lignin, an alternative precursor that is a sustainable resource material, the cost of which is largely independent of oil prices. It is a complex chemical compound commonly derived from wood via Kraft pulping. Lignin will become increasingly available as a by-product from cellulosic ethanol production as bio-refineries are built.

To form filaments, processing varies among precursors. Both conventional PAN and textile PAN are chemically processed in a solution to form filaments, then washed, stretched, and packaged. Lignin is precipitated from a liquid then solidified and pelletized. The pellets enter a melt spinning process during which they are melted, extruded into fine filaments, and spooled. Polyolefin filaments are also produced by melt extrusion of the polyolefin resin.

Filament to Carbon Fiber



Carbon fiber tow exits high-temperature carbonization furnace.

During conventional carbon fiber conversion, baled or spooled filaments are steam heated, stretched, oxidized, stabilized, and carbonized by heat treatment that requires up to 120 minutes of residence time.

In contrast, filaments that undergo ORNL's advanced processing through atmospheric pressure plasma oxidation and microwave assisted plasma carbonization require about one-third of the residence time and one-half of the energy of conventional oxidation and carbonization processes.

Whether undergoing conventional or advanced conversion, the finished carbon fiber is then typically packaged by spooling.

Carbon Fiber to Composite Material

Researchers examine carbon fiber preform.

With world class facilities at their disposal, ORNL researchers can address the final stages of the design and manufacturing processes necessary to demonstrate and produce finished carbon fiber reinforced composite parts for the automotive industry. These stages include materials processing and fabrication, resin formulation, materials characterization, and customized mechanical testing.

Today's Research

ORNL's current technologies are the driving force behind future advancements in low-cost carbon fiber research and development.

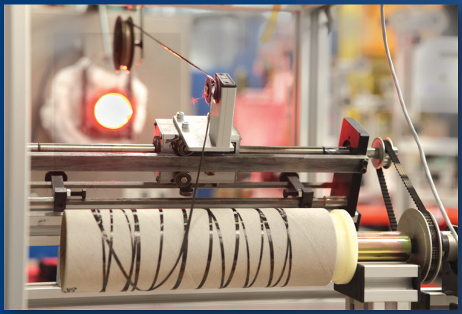
- **Carbon fiber pilot line** is capable of converting 1,000 – 80,000 filament tows of PAN precursor into finished carbon fiber. Potential production capacity is up to 20 pounds per day depending on tow size.
- **Melt-spinning** is the preferred route for producing lignin-based precursor fibers, based on potential line speeds of greater than six-thousand feet per minute.
- **Advanced oxidation and stabilization** enables high volume production and more rapid oxidation of precursors in a continuous and seamless process.
- **Microwave assisted plasma carbonization** efficiently processes fiber by volumetrically depositing energy into the tow and adjusting the mixture of microwave energy and microwave generated plasma along the length of the tow during conversion.

Microwave assisted plasma (MAP) carbonization line.

- **Precursor evaluation system** handles small quantities of material and determines specific processing parameters during the development of new precursors; modular system for varying temperature controls, precise tensioning control, and instrumentation for in situ fiber evaluation.
- **Carbon fiber evaluation** at all stages of processing includes resistance measurement, differential scanning calorimetry, dynamic mechanical analysis, thermogravimetric analysis, full tow tensile testing, single-filament tensile testing, and density measurement.
- **Class 100,000 clean room** allows environmentally controlled fabrication of carbon fiber composite material.
- **Robotic fiber preforming system** for automated production of complex preforms for lightweight composite structures.

Robotic preforming system chops and deposits fibers to make complex preforms.

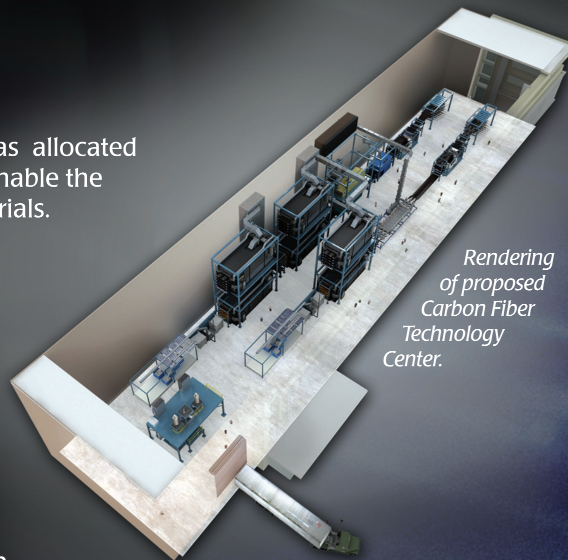
- **Compression molding presses** and injection-compression molding equipment completes carbon fiber composite part consolidation.
- **High-speed intermediate strain rate test facility** is used to evaluate carbon fiber reinforced composite automotive parts.
- **Crashworthiness testing** and modeling evaluates durability and strength of carbon fiber reinforced composite parts.
- **Other technologies** include multi-scale numerical analysis and structural design; customized mechanical testing; adhesive bonding and mechanical joining; constituent and composite materials characterization; materials and process development for high-volume lean composites manufacturing.



Finished carbon fiber being spooled.

Tomorrow's Capabilities

Through the American Recovery and Reinvestment Act of 2009, DOE has allocated $34.7 million to ORNL to establish a carbon fiber technology center that will enable the development and commercialization of low-cost carbon fiber composite materials.



Rendering of proposed Carbon Fiber Technology Center.

Operating at a pilot scale, the facility will demonstrate the scalability of science and technology for lowering the cost of carbon fiber by at least fifty percent and making affordable the use of carbon fiber in high volume applications.

The facility will house a thermal (conventional) carbon fiber conversion line and a melt-spun precursor fiber production line to produce and make available up to 25 tons per year of conventionally converted fibers for potential end users and upper tier suppliers in multiple industries. Space and utility provisions will accommodate the future addition of an advanced technology conversion line with similar production capacity. DOE's Industrial Technologies will fund a pilot scale thermal treatment furnace within the facility for developing additional non-transportation applications for low-cost carbon fiber materials. This new capability will support development of lignin-based fibers for such applications as reinforcement of graphite electrodes for electric-arc furnaces and nanoporous carbon for electric energy storage, water treatment and high efficiency HVAC filters.

The lab will interface closely with industry and academia, providing education and training opportunities that will help foster the development of a highly skilled domestic workforce. By helping strengthen and develop existing and new domestic carbon fiber manufacturers, this facility will potentially enable the U.S. to capture significant market share from foreign competitors while helping seed job growth and economic development in the future.

Facility construction will begin in 2011, with operations projected to start in late 2013.

Supporting Sustainable Transportation

ORNL's low-cost carbon fiber research for a new generation of vehicles is aligned under the lab's Sustainable Transportation Program. The program brings together scientists and engineers, commercialization experts, and technology transfer specialists from across laboratory directorates to address today's transportation challenges. Through partnerships with government, industry, and academia, their research and development efforts are resulting in knowledge discovery and technology development, maturation, and implementation. The program drives four broad and integrated areas of concentration to advance the mobility of people and goods within America's transportation systems: vehicle, energy, information, and infrastructure.

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