Carbon Fiber Technology Facility

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Overview

The Carbon Fiber Technology Facility (CFTF) serves as a national resource to assist industry in overcoming the barriers of carbon fiber cost, technology scaling, and product and market development.

CFTF is intended to be the bridge from R&D to deployment and validation of low-cost carbon fiber

<table>
<thead>
<tr>
<th>Focused on demonstrating the scalability of low-cost carbon fiber</th>
<th>Vehicle Lightweighting</th>
<th>Wind Energy</th>
<th>Gas Storage</th>
<th>Recreational Equipment</th>
</tr>
</thead>
<tbody>
<tr>
<td>• 42,000 ft² facility with production capacity of 25 tons/year of fiber from multiple precursors in various forms</td>
<td>Reduce vehicle weight by using carbon fiber throughout body and chassis</td>
<td>Build turbine components and longer blade designs for applications in wind energy</td>
<td>High-strength, lightweight pressure vessels for storage of gas</td>
<td>Next-level performance for sporting goods and recreational equipment</td>
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<table>
<thead>
<tr>
<th>FY16</th>
<th>FY17</th>
<th>FY18</th>
<th>FY19</th>
</tr>
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<tbody>
<tr>
<td>Total Budget</td>
<td>5.5 M</td>
<td>5.3 M</td>
<td>6.0 M</td>
</tr>
<tr>
<td>VTO</td>
<td>1.5 M</td>
<td>1.3 M</td>
<td>1.0 M</td>
</tr>
<tr>
<td>AMO</td>
<td>4.0 M</td>
<td>4.0 M</td>
<td>4.0 M</td>
</tr>
<tr>
<td>Other</td>
<td>1.0 M</td>
<td>1.0 M</td>
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Projective Objective

**Core Research and Development**
Leveraging ORNL’s Science Capabilities to Solve Challenges in carbon fiber and composites manufacturing.

**Industry Collaborations**
Cooperative research to develop and demonstrate low cost CF manufacturing to reduce the cost promoting and expanding the use of CF and its composites in clean energy applications.

**Education and Training**
Internships, academic collaborations, workshops, training programs, and course curriculum for universities and community colleges.

1. Establish and perform collaborative R&D projects to reduce technical uncertainties in CF manufacturing process

2. Investigate potential alternative carbon fiber precursors

3. Investigate carbon fiber intermediate forms and technical challenges in composite applications

4. Establish artificial intelligence-based framework and correlate process data to product characteristics

5. Investigate and develop in process measurement, sensing and control methods
Technical Innovation

Percentage cost of carbon fiber (Killing)
- Precursor: ~50%
- Conversion: ~40%
- Primary finishing and packaging: ~10%

Percentage energy of carbon fiber conversion (Das)

<table>
<thead>
<tr>
<th>Fiber Type</th>
<th>Conversion Efficiency</th>
</tr>
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<tbody>
<tr>
<td>Conventional Carbon Fiber</td>
<td>~80%</td>
</tr>
<tr>
<td>Textile Carbon Fiber</td>
<td>~70%</td>
</tr>
</tbody>
</table>

Waste Gas Abatement
- ~13%
- ~18%
- ~14%
- ~3%

Intellectual property developed around scalable process for producing low cost carbon fiber. Differential scanning calorimetry (DSC) analysis of the precursors show potential difficulty in stabilizing textiles! ORNL team successfully overcame that deficiency during thermal oxidation of the precursor fibers.
### Technical Approach

**Material Identification**
- Conversion Yield
- Precursor Cost
- Oxidation Time
- Availability
- Precursor Microstructure
  - 10s grams - bench scale

**Fiber Evaluation CF Line**
- Capacity for 1 - 2 tows
- 20k – 80k filaments
- Small Volume
- 100s grams

**Pilot scale CF Line**
- Capacity for 1-5 tows
- 5k -80k filaments
- Preferred tow size ≥ 3k
- 100s grams – 1 kg

**Scale-up CF Line**
- Capacity for 24 – 24K tows
- 3k – 80k tows
- 25 tons/yr
- Highly Flexible instrumented line

### Carbon Fiber Forms

- Continuous Carbon Fibers
- Chopped Fibers
- Milled Fibers
- Oxidized Fibers
- Pre-preg
- Non-Woven Fabric
- Compounded Material

### Carbon Fiber & Intermediate Forms

- Low, Standard and Intermediate Modulus Carbon Fiber

### Collaborative Joint-Industry Projects

- Integrated approach to low-cost carbon fiber manufacturing R&D
- Individual R&D projects
- Collaborative R&D consortia
- Early-stage R&D and technology partnerships
- Industry Collaborations

- Provide sample quantities with favorable properties to industrial partners for testing based on DOE approval
Results and Accomplishments

**Reducing Technical Uncertainties project examples**

Developing Precursor Splicing technique for Precursor to ensure continuous production

- *center-to-end parallel flow
- *Down-flow
- *cross-flow air distribution

Flow Distribution Impact/design parameters

<table>
<thead>
<tr>
<th>Property</th>
<th>Carbon Fiber A - Parallel</th>
<th>Carbon Fiber A - Crossflow</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tensile Strength (ksi)</td>
<td>314.6 ± 18.3</td>
<td>360.2 ± 15.1</td>
</tr>
<tr>
<td>Tensile Modulus (Msi)</td>
<td>35.9 ± 0.4</td>
<td>37.3 ± 1.0</td>
</tr>
<tr>
<td>Elongation (%)</td>
<td>0.89 ± 0.07</td>
<td>0.98 ± 0.4</td>
</tr>
<tr>
<td>CF Density (g/cc)</td>
<td>1.7478 ± 0.0024</td>
<td>1.7565 ± 0.0090</td>
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Team: ORNL-Litzler-Licensee

- Develop a three-dimensional, multi-physics computational model for faster, energy efficient process

3-D Multi-physics model for carbonization process
Team: ORNL – (Srikanth Allu, Srdjan Simunovic)
Harper International

- Preliminary Trials showed 32% reduction in Oxidation time
Team: ORNL-Litzler

- Poor quality precursor = poor quality carbon fiber
- Improve fiber quality for better translation in composites

Impact of Precursor surface finish on Processability and properties
Team: ORNL-Litzler-Licensee

Impact of Precursor Packaging on processability and quality of fiber
Team: ORNL-Litzler-Licensee
Results and Accomplishments

Successful Conversion of Textile Precursor

- Carbon fiber varies in tensile modulus (determined as deformation under strain) and tensile, compressive and fatigue strength.
- CFTF have > 30 varieties of textile precursors from International Sources.
- CFTF successfully developed low, standard, and intermediate carbon fiber using textile-based precursor
  - Low mod. (less than <32 Msi)
  - Standard mod. (33 to 36 Msi)
  - Intermediate mod. (40 to 50 Msi)
Results and Accomplishments

Alternative Precursors and associated conversion

- CFTF have > 30 varieties of textile precursors from International Sources.
- Most recent textile precursor was converted in 24hrs.
- Highest Tensile properties obtained are 402 Ksi, and 36 Msi tensile strength and tensile modulus, respectively.

Example of future alternative precursor

Produce and validate high modulus carbon fibers from high-yield polyaromatic hydrocarbon precursors.
Mesophase Pitch Fibers
Spinning and Carbonization of Mesophase Pitch Fiber ORNL – PI -James Klett

Textile-based precursor conversion

DOE Webinar to US Drive partner companies on 12/4/2018
“Carbon Fiber R&D progress and technology status towards validation and deployment for automotive application – Amit Naskar & Merlin Theodore
Results and Accomplishments

Intermediates– Joint Industry Project examples

Develop commercial relevant Packaging for TCF
ORNL – IACMI - Mc. Coy Machinery - Chomarat – Montefiber - UT

TCF in Prepreg production
ORNL-IACMI – Prolink - CDI
Joint project – CTF 18-015

Pelletization & Compounded Textile Carbon Fiber
ORNL-IACMI – Techmer

- Techmer compounded PA66 with 10%, 25%, and 40% LCCF

Sheet Molding Compound Reinforced by Recycled or Textile Carbon Fibers
ORNL/UTK, Adherent Technologies-AOC-
Ashland, Continental Structural Plastics-
Huntsman-IDI Composites-Michelman-
Vertigo-Volkswagen

Develop Chopping Equipment for chopping TCF at various length with various Sizing
ORNL-IACMI – CRTC-DM&E-
Cygnet Texkimp
- Project# TF18-010
Results and Accomplishments

Composites – Joint Industry Project examples

Pultrusion of carbon fiber wind turbine spar caps has demonstrated cost reductions and improved performance versus infusion.

Use of textile carbon fibers (TCF) will lower that further. Conventional pultrusion is not designed for large tow form typical of the TCF.

Team: TPI Composites, Montefibre, Huntsman, NREL, ORNL, UTK

Fenders
75 secs cycle time
https://www.youtube.com/watch?v=NRk v3fPy CI&t=163s

Textile Thermoplastics Battery Tray Flex Molds
Team: Honda, Valley Industries-IACMI-ORNL-UT

Injection molding → Battery Tray

Flexure samples
IZOD samples
ILSS samples

Injection Molding

Textile carbon fiber Performance Database (Coupon Testing) use in design, modeling and application development
Team: ORNL CFTF-IACMI-ORNL MDF-UT

Bike Form produced using Non-crimp textile carbon fiber fabric and Elium Resin via compression molding
Team ORNL-IACMI-Chomarat

Car hood Mold Printed using the BAAM System

Textile carbon Fiber in Additive Manufacturing
Team ORNL-CFTF-Techmer-MDF
Results and Accomplishments

Data Analytic Framework enable process variables to be tuned and optimized during manufacturing improving quality, efficiency, throughput, better process capability & control thus reducing energy usage and scrap.

Transition

Carbon Fiber Industry Collaboration

- Over 50 Technical Collaborations
- FLC Technology Transfer Award
- New Material Suppliers
- 4 Licensees for Textile precursor to CF
- CFTF Tech Interns to Licensee employees
- Three CRADAS
- Mission and Capabilities
  - Industries are able to adopt new opportunities using CF
  - Enhance their processes and capabilities, thus expand their market growth.

- TRL 1-3
- TRL 3-7
- TRL 8-9

2 - Patents application
Method of Producing Carbon Fibers from Multipurpose Commercial Fibers, (ORNL ID 3583), Pending U. S. Patent Application

6 CFTF staff members hired by Licensee

ORNL, License #1 executed
ORNL, License #3 executed

ORNL, License #2 executed

Technological Non-Provisional Patent application
Method of Producing Carbon Fibers from Multipurpose Commercial Fibers, (ORNL ID 3583), Pending U. S. Patent Application

1st CRADA Approval
Company has an option to negotiate up to an exclusive license for patentable inventions created by ORNL staff under a CRADA

2nd CRADA Approval
3rd CRADA Approved

ORNL, License #4 executed

Federal Laboratory Consortium Excellence in Technology Transfer Award

April – May 2018

Publication Generated

3rd CRADA In progress
3 new capabilities installed
Patent claims allowed
Questions