Carbon Fibers from Lignin

Presented at:

10th Annual World Congress on Industrial Biotechnology

Creating the Lignin Value Chain

by:

Cliff Eberle
Technology Development Leader Carbon and Composites

Oak Ridge National Laboratory

June 18, 2013
Precursor Fiber Manufacturing

Solution spinning (current PAN process)

Liquid acrylonitrile is polymerized to produce PAN.

PAN passes through a drying step.

PAN is dissolved in a carrier solvent then pumped and filtered.

PAN extruded through a die into a coagulation bath forms filament strands.

Filaments pass through repeated cycles of stretching and washing.

Filaments receive a protective coat of oil and are packaged.

Animation link: [http://www.youtube.com/watch?v=4t1pBvTDNXE&feature=player_embedded](http://www.youtube.com/watch?v=4t1pBvTDNXE&feature=player_embedded)

Melt spinning (future lignin process)

Precursor is pelletized.

The pellets enter an extruder then melt due to heat and pressure.

Molten media feeds into a metering pump and extrusion die to create very fine filaments that solidify and re spooled.

Spin Fibers

Animation link: [http://www.youtube.com/watch?v=nLcZKGwS3zE&feature=player_embedded](http://www.youtube.com/watch?v=nLcZKGwS3zE&feature=player_embedded)
Carbon Fiber Manufacturing

Pre-treatment  Oxidation  Oxidation Stage:
Typically multiple identical ovens operated at different temperatures

Low Temp Carbonization  Hi Temp Carbonization  Surface treatment

Sizing  Packaging

Animation link: http://www.youtube.com/watch?v=c3SZiRYJzH8&feature=player_embedded
Carbon fiber market
Automotive, wind energy, pressure vessels, oil and gas, and all other high-volume energy applications of carbon fiber composites are in the “industrial” market sector.

Cumulative carbon fiber demand by market sector

# Potential automotive market is huge for low-cost carbon fiber

## Carbon fiber potential in 5 years at 50% of current price

<table>
<thead>
<tr>
<th>Global automotive production by car type</th>
<th>Expected vehicle production</th>
<th>Expected use of CF in cars</th>
<th>Demand for CF at 50% of current price (pounds)</th>
<th>Market for CF at 50% of current price ($M)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Super cars</td>
<td>6,000</td>
<td>100%</td>
<td>1.3 million</td>
<td>$7M</td>
</tr>
<tr>
<td>Super luxury cars</td>
<td>600,000</td>
<td>10%</td>
<td>101.2 million</td>
<td>$506M</td>
</tr>
<tr>
<td>Luxury cars</td>
<td>4 million</td>
<td>10%</td>
<td>101.2 million</td>
<td>$506M</td>
</tr>
<tr>
<td>Other/regular cars</td>
<td>92 million</td>
<td>1%</td>
<td>202.4 million</td>
<td>$1,012M</td>
</tr>
<tr>
<td>Total</td>
<td>97 million</td>
<td>305 million</td>
<td>$1,525M</td>
<td></td>
</tr>
</tbody>
</table>

3× current global CF demand for all applications; 10B lb potential automotive demand at full market penetration

Source: Lucintel, ACMA Composites 2012
## Potential low-cost carbon fiber markets

<table>
<thead>
<tr>
<th>Category</th>
<th>Requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Civil infrastructure</td>
<td>Rapid repair and installation, time and cost savings</td>
</tr>
<tr>
<td>Nontraditional energy</td>
<td>Geothermal, solar, and ocean</td>
</tr>
<tr>
<td>Non-aerospace defense</td>
<td>Light weight, higher mobility</td>
</tr>
<tr>
<td>Aerospace</td>
<td>Secondary structures</td>
</tr>
<tr>
<td>Power transmission</td>
<td>Less bulky structures, zero CLTE</td>
</tr>
<tr>
<td>Oil and gas</td>
<td>Offshore structural components</td>
</tr>
<tr>
<td>Vehicle technologies</td>
<td>Necessary for &gt;50% mass reduction</td>
</tr>
<tr>
<td>Wind energy</td>
<td>Needed for longer blade designs</td>
</tr>
<tr>
<td>Energy storage</td>
<td>Flywheels, batteries, capacitors</td>
</tr>
<tr>
<td>Electronics</td>
<td>Light weight, EMI shielding</td>
</tr>
<tr>
<td>Pressurized gas storage</td>
<td>High specific strength</td>
</tr>
<tr>
<td>Thermal management</td>
<td>Thermal conductivity</td>
</tr>
<tr>
<td>Safety</td>
<td>Flameproof</td>
</tr>
<tr>
<td>Filamentary sorbents</td>
<td>High specific surface area</td>
</tr>
</tbody>
</table>

### Common issues
- Fiber cost
- Fiber availability
- Design methods
- Manufacturing methods
- Product forms

### Lignin applicability
A wide range of fiber specs can be useful

**Tensile strength, ksi**

- **Nonstructural ($3−$5/lb)**: Fascias, Liners, Covers, Load floors
- **Semi-structural ($4−$6/lb)**: Door panels, Fenders, Hoods, Roofs, Deck lids
- **Structural ($5−$7/lb)**: Chassis components, Engine cradle, Crush cones, Roofs, BIW

**Tensile modulus, Msi**

- **Functional**
  - Electrodes
  - Capacitors
  - Sorbents
  - Fireproof fabrics

**Data courtesy Plasan Carbon Composites**

**DOE Spec**

1% strain

**Most probable range of lignin-based CF mechanicals**

**E-glass fibers**

**Lignin-based CF SOT**

**Commercial PAN-based CF property range**

**Functional**

- Electrodes
- Capacitors
- Sorbents
- Fireproof fabrics
Lignin Chemistry Is Better Suited to Functional than Structural Properties

Lignin does not readily produce aligned crystallite morphology

Hardwood Lignin

Softwood Lignin

Lignin 50 – 70 wt% C

PAN 68 wt% C

PAN-MA 64-67 wt% C

Filament crystallite orientation
Stable Pricing and Assured Supply Are Essential in Cost-Sensitive, High Volume Energy Applications

Precursor Contribution to Carbon Fiber Cost:

- AN: $0.50 - $1.50/lb
- PO: $0.30 - $0.70/lb
- Lignin: fuel value ≤ $0.08/lb
  
  Raw material cost + Fiber spinning cost

  Yield
  
  PAN: 45 – 50%    PO: 60 – 80%    Lignin: 30 – 50+%  

Total Precursor Cost in Finished Carbon Fiber:

- PAN: $3.40 - $7.80
- PO: $0.90 - $2.00
- Lignin: $1.00 - $6.00

Lignin appears to be the best RENEWABLE precursor option

- AN price tracks oil price
- AN price can fluctuate up to 3X over 2 yrs
- PAN-CF price can fluctuate up to 2X over 3 yrs
- Dow is building plant to produce PO from C2 & higher fractions of shale gas
- Lignin price and availability should be stable
Lignin: A renewable low-cost feedstock

- Major challenges
  - No established supply chain
  - Scale – start small but go big
  - Lignin variability and contamination
  - High-rate, efficient processing
  - Chemical yield
  - Mechanical properties
  - Producing continuous, oriented form
  - Timing - first commercial application is several years away
Acknowledgements

- ORNL Carbon Fiber Technical Team
- ORNL Program Management
- DOE-EERE Vehicle Technologies Program
- DOE-EERE Advanced Manufacturing Office
- ORNL LDRD Program