FreedomCAR and Vehicle Technology Program

Rogelio Sullivan
Team Leader
Materials Technologies
U.S. Department of Energy

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Our Oil Situation

Data for the Month of April 2004. Net Imports total 20 M Barrels/day.

- **Canada** 2.04 (16.4%)
- **US Domestic** 7.38
- **Venezuela** 1.54 (12.4%)
- **Mexico** 1.56 (12.5%)
- **Nigeria** 1.07 (8.6%)
- **Iraq** 0.77 (6.2%)
- **Other Non-OPEC** 3.0 (24.1%)
- **Other OPEC** 0.78 (6.3%)
- **Saudi Arabia** 1.18 (9.5%)
- **U.K.** 0.46 (3.7%)

World Fossil Fuel Potential

Liquid Fossil Fuel Resources

- **US. Crude**
- **World Crude**
- **US Oil Shale**
- **Alberta Tar Sand**

China, with 13 vehicles per 1000 people, is where the U.S. was in 1913.
US energy security requires reduced dependence on imported petroleum

Lighter vehicles consume less fuel

- Rule of thumb: 10% less mass reduces fuel consumption by 5% - 7%

- Mass reduction is a critical component in all rational energy efficiency strategies, irrespective of power plant and energy source

Carbon fiber reinforced composites appear to be the best materials for significantly reducing vehicle mass, thereby reducing US petroleum demand
Carbon Fiber’s Appeal

- Very high stiffness and strength per unit mass
  - Better fuel economy
  - Increased payload
  - Better dynamics
- Excellent fatigue endurance
- Corrosion resistant
- Excellent dimensional stability
  - Near-zero CTE minimizes thermal expansion/contraction over a wide range of service temperatures (maintains good trim/fit)
- Tailorable/directional properties
- Good electrical, magnetic, thermal response
  - Nonmagnetic
  - Electrically conductive
  - Pitch fibers can have thermal conductivity and thermal diffusion coefficient >> copper
    - Very fast thermal response
    - Conducts axially, insulates radially (thermal analog of optical fibers)
- High elastic energy storage capacity
#1 Priority

$3 - $5 Per Pound

Program Goals:
- Strength: $\geq 250 \text{ KSi}$
- Modulus: $\geq 25 \text{ Msi}$
- Strain: $\geq 1\%$
1. Auto designers are not comfortable with composites in crash critical applications. Full vehicle & subsystem demonstration needed.

2. Many composite processing methods are optimized for performance, not production rate efficiency. Cost optimization of production methods needed.

3. Size of the carbon fiber industry cannot support large scale utilization. Must choose applications and ramp up capacity.

4. Boom or bust nature of the market. Automotive industry needs long term pricing and
North American Vehicle Production
> 18M / year

10 pounds of Carbon Fiber per Vehicle:
180M lb/year

Global Carbon Fiber Sales

Nearly 4X World Capacity
Low Cost Carbon Fiber

Typical processing sequence for PAN and pitch based carbon fibers

Major Cost Elements

- Precursor: 43%
- Oxidative stabilization: 18%
- Carbonization: 13%
- Graphitization: 15%
- Other: 11%

- Automotive cost target is $3 - $5/lb
- Tensile 250 ksi, 25 Msi, 1% ultimate strain
- ORNL is attempting major technological breakthroughs for major cost elements
Carbon Fiber Integration

**Proposed Process**

- **Precursor**
  - Washing/Stretching
- **Stabilization Stage 1**
- **Oxidation Stages 2-4**
- **Carbonization**
- **Textile PAN**
  - Washing/Stretching
  - Advanced Stabilization
- **Plasma Oxidation**
- **Microwave Carbonization**
- **Lignin Precursor**
- **Washing/Stretching**
- **Surface Treatment**
- **Tow Splitting**
- **Surface Treatment**
- **Packaging**
- **Sizing**
- **Selling**
- **Spooling**
- **Surface Treatment**

**Conventional Process**

- **Microwave Carbonization**

May be deleted

Interchangeable
Lignin Based Precursors

- Low-cost, high-volume carbon fibers precursor sources:
  - Regenerated cellulosics, Recycled Polymers, Lignin, Fiber Blends (alloys)
- Materials evaluated available in quantities sufficient to support the passenger transport.

- 10% of U.S. Kraft lignin would make enough carbon fiber to replace 50% of the steel in light transport.
- Environmentally-friendly melt spun fiber
- Oxygenated polymer minimizes stabilization
- Lower emissions in carbonization
- May be integrated into pulp mill
- Melt-spinning is a simple, inexpensive process costing $0.05-$0.10/lb
Preliminary Data - Estimated Selling Prices

<table>
<thead>
<tr>
<th>Material Type</th>
<th>Selling Price</th>
<th>Selling Cost Differences:</th>
</tr>
</thead>
<tbody>
<tr>
<td>K&amp;C</td>
<td>$8.77</td>
<td></td>
</tr>
<tr>
<td>Hexcel</td>
<td>$7.34</td>
<td></td>
</tr>
<tr>
<td>2 Others</td>
<td>$7.70, $6.90</td>
<td></td>
</tr>
<tr>
<td>ORNL</td>
<td>$7.88</td>
<td></td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Selling Price - Model</th>
<th>Base case</th>
<th>Base case with MAP</th>
<th>Base case with microwave oxidation (MO)</th>
<th>Base case with MAP and MO</th>
<th>Modified textile-grade PAN</th>
<th>Modified textile-grade PAN with MAP</th>
<th>Modified textile-grade PAN with MAP and MO</th>
<th>Lignin</th>
<th>Lignin with MAP</th>
<th>Lignin with MAP and MO</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$8.77</td>
<td>$7.97</td>
<td>$7.94</td>
<td>$7.32</td>
<td>$6.43</td>
<td>$5.91</td>
<td>$5.71</td>
<td>$5.44</td>
<td>$5.09</td>
<td>$4.51</td>
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<tr>
<td>Preliminary Data - Estimated Selling Prices</td>
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- K&C: $8.77
- Hexcel: $7.34
- 2 Others: $7.70 & $6.90
- ORNL: $7.88
Estimated Costs for Lignin-Based Carbon Fiber

<table>
<thead>
<tr>
<th>Process</th>
<th>Cost</th>
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</thead>
<tbody>
<tr>
<td>Lignin to Precursor</td>
<td>$0.50</td>
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<tr>
<td>Spinning</td>
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<tr>
<td>Oxidation 2-4 Stages</td>
<td>$0.75</td>
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<tr>
<td>Carbonization 1-2 Stages</td>
<td>$0.65</td>
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<tr>
<td>Surface Treatment</td>
<td>$0.10</td>
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<tr>
<td>Spooling</td>
<td>$0.15</td>
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<tr>
<td>Total</td>
<td>$2.85</td>
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Low Cost Carbon Fiber Plan

- Organic/Lignin Based Precursors
- Microwave Carbonization
- Advanced Oxidation of CF Precursors
- Adv Stabilization of Precursors
- Tow Splitting
- Lignin Purification
- FSD of Textile Precursors
- Carbon Fiber Users Facility
- Feedback Control
- Scale-up of Adv Precursor
- Dev of Standard CF SMC
- Plasma Mod of Surf
Pathway to Technology Commercialization
Successful Implementation
Characteristics

- Technical performance
- Cost targets satisfied
- Budget
- Strong committed leadership
- Timing
- Supply chain
- Committed customer (champion)
- Technical champions
- Logistics/teamwork