B. Low-Cost Carbon Fiber Development Program

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Contractor: Hexcel Corporation
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Objective

- Define technologies needed to produce a low-cost carbon fiber (LCCF) for automotive applications at a cost of \$3.00 to \$5.00/lb for quantities greater than 1M lb/year. The required carbon fiber properties are tensile strength greater than 400 ksi, modulus greater than 25 Msi, and strain-to-failure greater than 1%.

Approach

- Develop new precursors that can be converted into carbon fiber at costs below the costs of current processes.
- Explore processing by methods other than thermal pyrolysis.
- Develop technologies leading to significant improvements in current production methods and equipment.
- Develop alternative methods for producing carbon fiber from pitch, polyacrylnitrile (PAN), or other precursors.
- Reduce precursor cost by the use of commercially available energy-efficient precursors and high conversion yields.
- Improve precursor production economies of scale and throughput.
- Introduce novel LCCF production methods.

Accomplishments

- Evaluated proposed research areas through laboratory trials and refinement of manufacturing cost analyses:
  - PAN-based precursors: large-tow benchmark, commodity textile acrylic tow, chemical modifications, acrylic fibers spun without solvents, and radiation and nitrogen pretreatment of PAN-based materials.
  - Precursors other than PAN: polyolefins—polypropylene (PP), linear low-density polyethylene (LLDPE) and high-density polyethylene (HDPE); polystyrene; and polyvinyl chloride (PVC) pitch.

- Scaled-up promising technologies to pilot line trials.
- Assessed the technical and economic feasibility of the proposed research areas.
- Down-selected the most promising technologies to meet the program objectives:
  - Commodity textile acrylic tow with chemical modification or radiation pretreatment.
- Developed detailed manufacturing cost models for the downselected technologies.
- Completed the engineering feasibility studies for large-scale production line.
- Completed the economic analysis to predict product production costs.
- Awarded a short-term (1-year) project to develop carbon fiber roving for the P4 process to meet the immediate needs of the Automotive Composites Consortium (ACC) development programs.
- Completed the program final report for Phase I project.
- Revised the Statement of Work (SOW) for a proposed long-term (3-year) follow-on project to distinguish development tasks from scale-up tasks and to reflect the cost sharing by Hexcel in the requested funding. The follow-on project is built on the results of the current LCCF project to develop product forms from commodity textile-acrylic-based carbon fiber for the ACC programs [under review by Oak Ridge National Laboratory (ORNL)].

Future Direction

- Start working on the proposed long-term Phase II project.
  - Long-term (3-year) program to build on the results of the LCCF program to develop product forms from commodity textile-acrylic-based carbon fiber for the ACC programs.
  - Support requests by ORNL and ACC development programs.

Introduction

The goal of this project is to define and demonstrate technologies needed for the commercialization of low-cost carbon fibers (LCCFs) to be used in automotive applications. Lighter-weight automotive composites made with carbon fibers can improve the fuel efficiency of vehicles and reduce pollution. For carbon fibers to compete more effectively with other materials in future vehicles, their cost must be reduced. Specifically, this program targets the production of carbon fibers with adequate mechanical properties, in sufficiently large quantities, at a sustainable and competitive cost of $3 to $5/lb.

Project Deliverables

At the end of this multiyear program, technologies for LCCF production will be defined. This definition will include the required materials and facilities and will be supported by detailed manufacturing cost analyses and processing cost models. Laboratory trials and pilot-scale demonstrations will be performed to support the defined technologies.

Planned Approach

This project was divided into two phases:

Phase I: Critical review of existing and emerging technologies, divided into two tasks:

Task I.1. Literature review and market analysis.

Task I.2. Laboratory-scale trials and preliminary LCCF manufacturing cost assessments of the proposed technologies. Phase I led to further refinement and down-selection of the most promising technologies for Phase II.

Phase II: Evaluation of selected technologies using pilot-scale equipment and cost models. Phase II was divided into three tasks:

Task II.1. Pilot-scale design for the evaluation of selected LCCF technologies. This included modifications of a polyacrylonitrile (PAN) spinning pilot line and two different carbon fiber conversion lines (a single-tow research line and a multitow pilot line) and the construction of continuous sulfonation processing equipment.

Task II.2. Experimental evaluation of down-selected LCCF technologies, including commodity textile-tow PAN (with chemical modification and radiation and/or nitrogen pretreatment) and polyolefins linear low-density polyethylene [(LLDPE) and polypropylene (PP)].

Task II.3. Large-scale feasibility study of selected LCCF technologies.

Conclusions of FY 2001 Results

(October 1, 2000 to September 30, 2001)

1. Further work on acrylic fibers spun without solvents, plasticized PAN, polyvinyl chloride (PVC), and polystyrene were halted because of technical, environmental, and cost issues.
2. The following most promising LCCF technologies for Phase II were evaluated and selected: commodity textile PAN-based precursors (as-received and with pretreatment using chemical modification, radiation, and nitrogen prestabilization technologies) and polyolefin precursors (LLDPE and PP).
3. A large-tow PAN precursor technology benchmark was used as a metric to evaluate the proposed technologies in terms of their potential to meet the LCCF program's cost targets. The difference between commodity textile PAN and large-tow precursor, based on carbon fiber cost, is approximately $1.80 vs $3.10/lb.

Conclusions of FY 2002 Results

(October 1, 2001 to September 30, 2002)

1. Demonstrated the technologies for using chemical modification and radiation pretreatments of commercial commodity textile (28K) tow to produce LCCF that meets the project targeted properties and estimated cost predictions.
2. Developed manufacturing recipes for the conversion of commodity textile acrylic fibers into LCCF, using the technologies of chemical modifications and radiation treatments.
3. Developed estimated carbon fiber cost projections using chemical modification and radiation pretreatments of commercial commodity textile acrylic fibers.
4. Demonstrated the conversion of LLDPE to LCCF that meet the targeted properties and estimated cost predictions. Due to the issues of sulfuric acid recycling and the available precursor, we concluded that the LLDPE-based technology would need more development efforts to compete with modified textile PAN-based technologies.
5. Commenced the engineering feasibility study of the production lines to produce LCCF based on commodity textile acrylic PAN using chemical modification and radiation pretreatment technologies.
6. Started the plans and statements of work (SOWs) for the long-term and short-term follow-up projects.
7. Updated and refined cost models to reflect the accomplishments in FY 2002.
8. Produced four papers [three published during Society for the Advancement of Material and Process Engineering (SAMPE) 2002, in Baltimore, Maryland, and one for the Global Outlook for Carbon Fiber 2002, in Raleigh, North Carolina] and a presentation during SAMPE 2002, in Long Beach, California.

Conclusions of FY 2003 Results

(October 1, 2002 to September 30, 2003)

1. We completed Task II.3, the large-scale feasibility study, for the selected technologies and the economic analysis for predicting product costs, based on subscale work done during this project using textile acrylic fiber, either chemically modified in an acrylic fiber manufacturing process or using radiation pretreatment in-line with the carbon fiber process.
2. We proposed a follow-on project built on the current project's results with the following goals:
   - Scale-up and verify the defined technologies.
   - Define product forms.
   - Develop and implement techniques to manufacture product forms.
   - Integrate results in ongoing automotive research with other activities by Department of Energy (DOE)/Oak Ridge National Laboratory (ORNL) and U.S. Council for Automotive Research (USCAR)/ Automotive Composites Consortium (ACC).

Conclusions of FY 2004 Results

(October 1, 2003 to September 30, 2004)

During this period we developed and completed two short-term projects for manufacturing and delivering carbon fiber roving to meet the immediate needs of the ORNL and ACC development programs for the P4 process. The first project was the manufacturing of 500 kg of AS4C-1925 (1.0%) 36K (12 × 3K). The second project was the spinning and manufacturing of 7 rovings of AS4C-1925 36K made from 0.5K, 1.0K, 1.5K, 3.0K, 3K, 6K, and 12K subtows (50 kg each).

The first project proved to be more time-consuming. This project turned out to be more difficult than expected due to problems experienced winding the 12 individual 3K tows to a single winder. The fiber was produced on the carbon fiber Pilot Line by running the AS4C 3K fiber through a sizing bath, then bundling the individual tows together, and collecting them as a 36K tow made up of 12 individual 3K tows. After a large amount of effort, the required 200 spools of 2.5 kg each were produced. A summary of the test results is shown in Table 1.

For the second project 500H (holes) and 1000H spinnerets were ordered. The 0.5K, 1.0K, 1.5K, and 3.0K PAN fibers were spun on the production line at Hexcel facilities in Decatur, Alabama. Then, 0.5K, 1.0K, 1.5K, and 3.0K fibers were converted to carbon fiber on Fiber Line 4 at Hexcel Carbon Fiber facilities in Salt Lake City, Utah (Table 2). The 3K, 6K, and 12K fibers were collected by running through a side-sizing bath during standard AS4 fiber production. The fibers were sized using 1925 size at 1.0% and collected on center pull cores into 72 × 0.5K, 36 × 1.0K, 24 × 1.5K, and 12 × 3.0K made from experimental PAN, and 12 × 3K, 6 x 6K, and 3 × 12K made from commercial PAN. The operability was good except for the 0.5K fiber. Also, the properties of the fiber were very good. The required numbers of spools were produced. A summary of the fiber properties is shown below.

Table 3 gives the fiber shipped to the National Composites Center (NCC).

These fibers were used for some pre-production trials and then in July 2004 were used to make flat panels for physical and mechanical testing. This work was directed by Jeff Dahl of Ford Motor Company. In September 2004, we received some results from the testing that had been done. A chart of the tensile strengths of the panels for the different fiber types is presented in Figure 1.

Table 1. Test results

Fiber lot No.	ST03026
Fiber density, g/cm^3	1.790
Fiber MPUL, g/m	0.201 (3K) 2.412 (36K)
Sizing content, %	1.01
Tow tensile strength, ksi	634
6-1 tow tensile modulus, Msi	32.8
Tow tensile elongation, %	1.76

Table 2. Line 4 run of P4 fiber—lot No. 2622-4A, AS-1925 36K

PAN filament count Lab request No.	**0.5K** D0245	**1.0K** D0246	**1.5K** D0237	**3.0K** D0248	**Std. ESAF 6K** D0256
Fiber density, g/cm^3	1.784	1.787	1.787	1.787	1.782
Fiber MPUL, g/m	0.2143	0.2222	0.2213	0.2188	0.7786
Sizing content, %	1.07	0.95	0.91	0.95	1.17
Tow tensile strength, ksi	638	642	635	653	661
6-1 tow tensile modulus, Msi	35.2	33.9	33.4	33.7	34.0
Tow tensile elong., %	1.69	1.74	1.75	1.78	1.78

Notes: (1) Tows bundled to 3K for testing (1 × 3.0K, 2 × 1.5K, 3 × 1.0K, 6 × 0.5K); (2) bundles for some of the 0.5K and 1.0K tows were not quite 3K; (3) standard ESAF 6K PAN was bundled to 12K before sizing. MPUL = mass per unit length.

Table 3. Test results

Fiber lot No.	Fiber type designation	Number of spools	Total weight (lb)	Total weight (kg)
2622-4A	AS-1925 36K (72 × 0.5K)	23	112.2	50.9
2622-4A	AS-1925 36K (36 × 1.0K)	23	140.8	63.9
2622-4A	AS-1925 36K (24 × 1.5K)	29	174.0	78.9
2622-4A	AS-1925 36K (12 × 3.0K)	28	172.9	78.4
2684-5E-P4	AS-1925 36K (72 × 0.5K)	21	102.7	46.6
2674-5E-P4	AS-1925 36K (12 × 3K)	29	155.7	70.6
26712-7J-P4	AS-1925 36K (6 × 6K)	30	142.0	64.4
	Total	183	1000.3	453.7

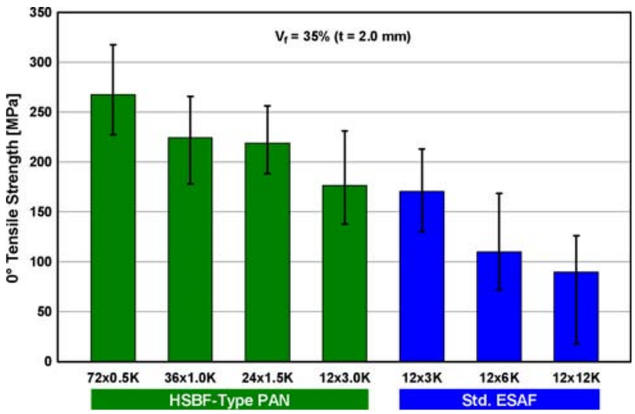

Figure 1. Tensile strength of different fiber types.

Figure 1 shows much higher tensile strength measured for panels made using the smallest filament bundle counts. The differences are quite dramatic, with the tensile strength of the 72 × 0.5K fiber being nearly three times greater than the tensile strength of the 3 × 12K fiber. While some differences were expected between the fiber types, this magnitude of difference was surprising. The differences are thought to be due to the quality of the composites made and the more uniform distribution of reinforcing filaments resulting from using the small bundle count fibers.

We completed an order for oxidized PAN fiber that was requested by ORNL. Three sets of four 2.3-lb spools were shipped to ORNL. Spools of partially oxidized fiber were collected on Line 4 and sent to ORNL to support its advanced oxidation project. ORNL had requested fiber with specific oxidized density ranges. A winder was placed at these locations and fiber collected. Four spools were collected at each location; each spool was about 2.3 lb.

Sample No.	Oxidation density
11365-54-1	1.245
11365-54-2	1.293
11365-54-3	1.335

The following is a summary of the efforts during this reporting period.

1. We completed the two short-term projects for manufacturing and delivering carbon fiber roving to meet the immediate needs of the ACC development programs.
2. We participated in meetings with Meridian Automotive systems, National Composites Center (NCC), ACC to provide input on the LCCF program status and LCCF applications for development programs that are supported by ORNL and DOE.
3. We are participating in the Delphi’s Advanced Composite Support Structures (ACSS) Program. This is the development program for cross-members for Class-7 and -8 trucks. Our tasks are to support the program in material requirement and to advise based on Hexcel past experiences from the lessons that Hexcel gained in the development of the rails for Class-7 and -8 trucks.
4. We developed and provided partially oxidized PAN fiber to ORNL to support the microwave research efforts at ORNL.
5. We requested and we were granted a no-cost extension by ORNL.
6. We completed and submitted the mid-year and quarterly reports as requested by ORNL.
7. We completed and submitted the current project final report to ORNL in September 2004.

8. Based on the submittal of the initial follow-on project proposal, ORNL, after reviewing the Kline Report (see 4.B) and consultation with the material technology team, decided to consider the follow-on project. Therefore, we revised and submitted the SOW for the proposal to reflect the request by ORNL for cost sharing.

Final Report Executive Summary

In October 1999 the U.S. Department of Energy's Office of Transportation Technologies (DOE-OTT), through the Oak Ridge National Lab (ORNL), awarded Hexcel Corporation a multiyear contract to define and develop technologies needed for the commercialization of low-cost carbon fibers (LCCFs). The goal of the technical evaluation was to demonstrate a technology suitable for the commercial manufacture of $>10^6$ lb/year (>455 MT/year) of LCCFs with adequate mechanical properties for lighter weight, energy-saving automotive composite applications. Specific LCCF program targets follow:

- tensile strength > 2,800 MPa (400 ksi);
- tensile modulus > 172 GPa (25 Msi);
- strain to failure > 1%; and
- market price = $6.60 to $11/kg ($3 to $5/lb).

To meet the LCCF program targets, Hexcel developed a multistep, risk-mitigating approach (Phase I) that addressed three areas:

1. Identification of precursors and technologies that may lead to significant reductions in current carbon fiber production costs;
2. Demonstration of the selected technologies at research-scale and pilot-scale levels; and
3. Large-scale engineering feasibility studies of the technologies deemed most likely to meet LCCF targets.

A follow-up project would build on the results of this first project to develop production technologies and specific product forms required by DOE/OTT and various automotive manufacturers (USCAR/ACC).

Extensive internal and external literature searches uncovered a large number of materials and conversion technologies that could serve as potential LCCF development routes. The technologies identified fell in two broad categories: (1) those based on the use of polyacrylonitrile (PAN); and (2) those using polymer/precursor materials other than PAN. Among PAN-based routes, the use of low-cost textile acrylic fibers as LCCF precursors provided the most viable pathways. Among non-PAN-based routes, technical and cost considerations narrowed the choices to four candidates: polyethylene, polypropylene, polystyrene and polyvinyl chloride.

Research-scale trials and preliminary cost model estimates led to three viable routes for the development of continuous-tow LCCFs with mechanical properties meeting LCCF targets:

(1) Chemical modification of textile acrylic fibers. Uncollapsed textile acrylic fiber gels are exposed to an aqueous NaOH solution during the spinning process to induce functional group hydrolysis and hence speed up the stabilization process.

(2) Radiation pretreatment of textile acrylic fibers. This involves exposing textile acrylic fibers to an E-beam radiation dose of 30 Mrad prior to oxidation to induce stabilizing cyclization reactions.

(3) Sulfonation of polyethylene fibers. Commercial polyethylene fibers pass through a bath of hot concentrated sulfuric acid in order to induce cross-linking reactions that render the fibers infusible and carbonizable.

The technical viability of the textile acrylic fiber-based technologies was also demonstrated through pilot-scale experiments. Large-scale engineering feasibility studies defined manufacturing facility and processing costs needed to make 1,820 MT/year (4×10^6 lb/year) of LCCF in two carbon fiber production lines. Detailed economic analysis indicated that the carbon fiber manufacturing cost could be reduced from ~$13.20/kg (~$6.00/lb) for large tow textile PAN to ~$9.9/kg (~$4.50/lb) with either chemical or radiation pretreatments. These mill cost estimates are based on standard carbon fiber manufacturing model parameters, and exclude any return-on-investment (ROI). Should ROI be included, additional processing improvements would be needed to reach the LCCF cost targets in an economically sustainable manner.

Future Work

We will begin work on the proposed follow-on project when it is approved by ORNL. It is built on the results of Hexcel's LCCF current project with the following objectives: (1) scale-up and verify the defined technologies and (2) integrate into ongoing automotive research activities by DOE/ORNL and USCAR/ACC. The goals of this future work follow.

1. Develop plans for integration of ongoing development activities that include the following subtasks: define requirements, finalize integration plans, and review and approval by all parties.
2. Scale-up and verification of chemical modification technology from the current project that includes the following subtasks: modification of textile acrylic fiber line at Sterling, verification of scaled-up chemical modification process, modification of carbon fiber pilot line at Hexcel, and verification of conversion of chemically modified acrylic tow.
3. Development of carbon fiber products forms that include the following subtasks: develop precursor materials for microwave processing, develop techniques to split textile acrylic tow, develop splitting techniques during/after carbon fiber conversion, and develop methods for manufacture of specific product forms such as chopped fiber, prepreg, fabric, and P4 roving.

A plan that addresses the above goals into three major tasks was developed. The following is a summary of these tasks.

LCCF Development Program—Follow-on; Major Tasks and Milestones

The major tasks and milestones are planned to provide the following:

1. Precursor fiber and carbon fibers for various applications as required by ORNL; for example, such as, precursor fiber for oxidation studies and oxidized/stabilized precursor for microwave processing.
2. Carbon fiber of various forms: continuous tow, chopped fiber, prepreg, woven fabric, and roving for P4 process for various automotive applications.

Three major tasks are outlined to meet the goals and objectives. The following are the tasks and milestones.

Task 1. Develop Plans for Integration of Ongoing Development Activities

The objective of this task is to develop the plans to integrate the SOW of this proposal with ongoing research activities by ORNL and ACC. In this task, the quantities, requirements, and specifications of various product forms will be identified and verified to meet the needs of ACC/ORNL development programs.

The following are the milestones for Task 1.

Task 1.1. Develop a Draft of the Integration Plans

The goal is to develop plans to assure that the needs of providing precursor materials and carbon fibers will meet the requirements of ongoing development work by ORNL and ACC. These plans will be developed first and approved by the all parties before commencing Task 2 and Task 3 of the proposal. The first step in developing the integration plan is defining the requirements.

Task 1.2. Define Requirements

First, the requirements for precursors and carbon fiber to meet the needs of the ongoing research activities by ORNL and ACC will be defined. These requirements will address the identification and specifications of the following materials forms:

1. Precursors for oxidation studies and oxidized/stabilized precursors for microwave processing.
2. Carbon fiber product forms (continuous, chopped, roving, etc.) for the automotive industry that includes surface treatment, sizing systems for above product forms, and make-up and packaging.

Task 1.3. Finalize Integration Plans

In this subtask the drafted integration plans will be provided to team members for review and comments before a formal presentation and review meeting.

Task 1.4. Review Meeting

Task 1 will be concluded with a review meeting of the team members for approval of the integration plans and the detailed SOW for Task 2 and 3. This will give the “green-light” for commencing Task 2 for the scale-up and verification of the chemical modification technology from the current project, and Task 3 for the development of the product forms for automotive applications.

Task 2. Scale-up and Verification of Chemical Modification Technology

Task 2 objectives are the scale-up demonstration and verification of production technologies for producing the textile fiber with chemical modification and the conversion into carbon fibers.

Task 2.1. Modification of Textile Acrylic Line (Sterling)

This subtask consists of the modification of Sterling's textile line to implement and incorporate the application of chemical modification in-line. Within the scope of this task, the engineering design requirement for installation will be developed, and modification equipment will be integrated in the line before verification and scale-up trials run are performed.

Task 2.2. Verification of Scaled-up Chemical Modification Process

Once the modification of the textile line is completed, and equipment is debugged to ensure operational performances, the next step is to verify scale-up of the chemical modification processing on the large textile fiber. Several trials will be performed to verify processing conditions, develop manufacturing procedures, and to manufacture materials for conversion into carbon fiber at Hexcel facilities.

Task 2.3. Modification of Carbon Fiber Pilot Line (Hexcel)

In a parallel effort, modifications of Hexcel's Carbon Fiber Pilot Line (which is a semiproduction line) will be implemented to handle textile acrylic fiber. Equipment operational and processing procedures will be developed for the conversion of the chemically modified textile fiber to carbon fiber.

Task 2.4. Verification of Conversion of Chemically Modified Acrylic Tow

Once the implementation and the equipment modifications at the two facilities are completed, verification trials will be performed to establish the operating procedures for conversion of the chemically modified textile fiber at Sterling facilities into carbon fiber at Hexcel facilities. First, the converted carbon fiber will be characterized to verify that it meets the mechanical and physical properties established in the current project.

Task 2 will include preproduction verification trials to ensure that the scale-up process produces modified textile and carbon fibers that will meet the objectives and requirements for Task 3, the development of carbon fiber product forms.

Task 3. Development of Carbon Fiber Product Forms

Task 3 objectives will be planned and directed based on the integration plans that were developed and approved by the team members in Task 1. The scope for Task 3 will include the development and providing of textile precursor fiber and carbon fiber for the integration into ongoing activities by ACC and ORNL. Precursor fibers will be manufactured to support ongoing research activities for oxidation studies and oxidized/stabilized precursors using microwave processing. Carbon fiber products of various forms such as continuous tow, chopped fiber, prepreg, woven fabrics, and roving for P4 process are expected to be supplied to support development activities for automotive components as defined in Task 1. The development of splittable tow to produce carbon fiber roving for the P4 process will be the major effort in this task. The results of the ongoing evaluation of various roving configurations for the P4 process will guide the carbon fiber roving development effort in this task. The following are the milestones for Task 3.

Task 3.1. Develop Precursor Materials for Microwave Processing

Based on the conclusion of the integration plans of Task 1, the requirements (quantities, forms) of the textile fiber for the microwave processing will guide the scope of work for this subtask. Precursor materials will be manufactured at Sterling, and any other preprocessing (stabilization) will be performed by Hexcel to meet ORNL requirements. The scope of this subtask will be developed and defined for integration into ongoing research activities for oxidation studies and oxidized/stabilized precursors for microwave processing as would be required by ORNL. This subtask may depend on the next subtask efforts of developing techniques to split textile acrylic tow.

Task 3.2. Develop Techniques to Split Textile Acrylic Tow

Subtask 3.2 will focus on developing technology to split large textile acrylic tow into small tows that may meet some of the product forms requirement as defined in Task 1. The challenge in this subtask is the feasibility of integrating precursor tow splitting technologies within the precursor manufacturing process and equipment. Equipment configurations and processing methods will put constraints and limitations on the tow size that can be achieved. Hexcel will work with Sterling Fiber to direct, develop, and plan these efforts. The results of subtask 3.2 will have a direct impact on the efforts in subtask 3.1 and subtask 3.3

Task 3.3. Develop Splitting Techniques During/After Carbon Fiber Conversion

Depending on the results of subtask 3.2 and requirements for the products forms as defined in Task 1, the scope of this subtask will be defined in order to develop technologies and methods for splitting tows during/after carbon fiber conversion. The requirement for the specific automotive carbon fiber products forms (subtask 3.4) will direct the scope of work for subtask 3.3.

Task 3.4. Develop Methods for Manufacture of Specific Carbon Fiber Product Forms (Chopped Fiber and Prepreg, Fabric, P4 Roving)

This subtask will concentrate on the development of methods for manufacturing carbon fiber for specific automotive carbon fiber products forms such as continuous tow, chopped fiber, prepreg, woven fabrics, etc. The defined/selected carbon fiber product forms (Task 1) for automotive applications will focus the scope of this subtask and the technology development for splitting the modified textile tow during/after carbon fiber conversion. Textile and carbon fiber conversion trials will be performed to manufacture the specific carbon fiber product forms to meet the integration plans as will be defined in Task 1.

The SOW and the estimated request for funding proposal for the follow-on project, including the cost share by Hexcel, were revised and submitted to ORNL for consideration and evaluation. The proposal is for 3 years. Hexcel planned this follow-on project scope based on input and results of the joint working relationship with Sterling Fiber of Pace, Florida, during the LCCF project. [Editor's note: In December 2004, DOE and ORNL decided not to pursue the follow-on project at this time and to concentrate DOE's funding of the longer-term higher-risk but potentially lower-cost option discussed in 5.A.]