U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Renewable, Low-Cost Carbon Fiber for Lightweight Vehicles:

Summary Report

October 2013

Renewable, Low-Cost Carbon Fiber for Lightweight Vehicles

Summary Report from the June 4–5, 2013, Workshop
Detroit, MI

Workshop and Summary Report sponsored by the
U.S. Department of Energy
Office of Energy Efficiency and Renewable Energy
Bioenergy Technologies Office

Summary report edited by Joyce Yang, Katy Christiansen, and Sarah Luchner

Preface

The U.S. Department of Energy's (DOE's) Office of Energy Efficiency and Renewable Energy (EERE) invests in a diverse portfolio of energy technologies to achieve a stronger economy, a cleaner environment, and a more secure energy future for America.

This report summarizes the results of a public workshop sponsored by DOE/EERE in Detroit, Michigan, on June 4–5, 2013. The views and opinions of the workshop attendees, as summarized in this document, do not necessarily reflect those of the United States government or any agency thereof, or do their employees make any warranty, expressed or implied, or assume any liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represent that its use would not infringe privately owned rights.

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Introduction

On June 4–5, 2013, the U.S. Department of Energy's (DOE's) Office of Energy Efficiency and Renewable Energy (EERE) hosted a workshop in Detroit, Michigan, to discuss research and development (R&D) related to the manufacturing of low-cost carbon fiber from renewable resources that can be used for vehicle lightweighting. Stakeholders from industry, national laboratories, and universities attended and provided valuable information on topics ranging from the development of renewable feedstocks to the production of carbon fiber and its implementation in vehicle lightweighting.

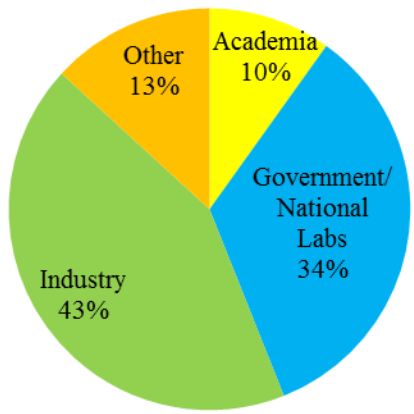

Figure 1: Workshop attendee distribution

Purpose, Need, and Process of the Workshop

The Clean Energy Manufacturing Initiative

DOE recently launched the Clean Energy Manufacturing Initiative[1] to increase U.S. competitiveness in the production of clean-energy products and enhance U.S. manufacturing across the board by increasing energy productivity. The Clean Energy Manufacturing Initiative focuses EERE's clean-energy technology offices and Advanced Manufacturing Office around the competitive opportunity for the United States to be the leader in the clean-energy manufacturing industries and jobs of both today and tomorrow. This initiative will bring together a wide array of relevant DOE and EERE offices, federal agencies, research institutions, and private-sector partners to map out and implement a strategy to ensure that U.S. manufacturers are competitive in the global marketplace.

DOE engages in multiple activities to enhance the Clean Energy Manufacturing Initiative, including dialogues and summits, requests for information, and investments in clean-energy manufacturing. Through the Clean Energy Manufacturing Initiative, DOE's Bioenergy Technologies Office, in coordination with the Advanced Manufacturing and Vehicle Technologies Offices, hosted the Renewable, Low-Cost Carbon Fiber for Lightweight Vehicles Workshop. The purpose of the workshop was to leverage the complementary insight and expertise of EERE's offices to support end-to-end technology development for an enhanced domestic supply

[1] U.S. Department of Energy. Clean Energy Manufacturing Initiative. July 8, 2013. www.eere.energy.gov/energymanufacturing.

chain for low-cost carbon fiber that has the potential to increase energy productivity and the competitiveness of U.S. manufacturing.

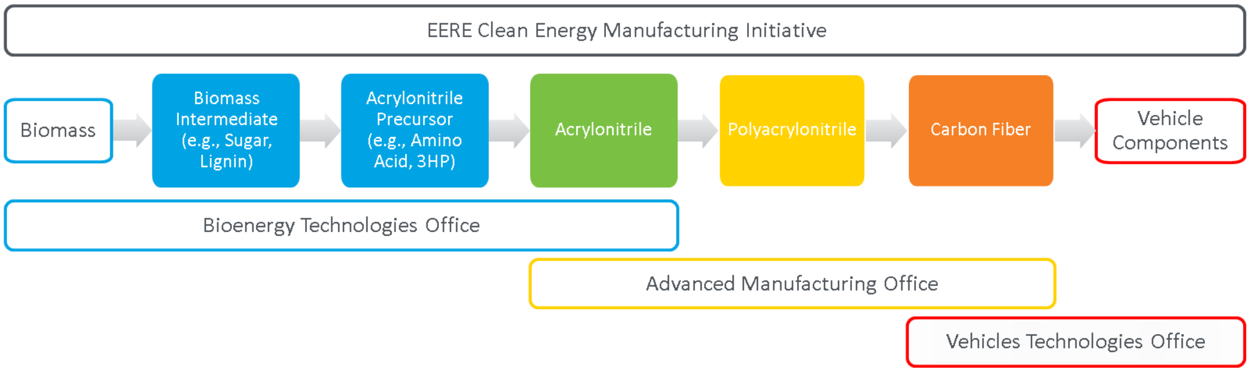

Figure 2: Schematic of renewable carbon fiber production and EERE office involvement

Bioenergy Technologies Office

The availability of affordable feedstocks and robust supply chains are key to successful manufacturing industries. These characteristics are inherent to biomass; therefore, it has the potential to be a commercially viable and low-cost renewable feedstock for the production of carbon fiber. Of all forms of renewable energy consumed in the United States, none rival the amount of energy produced from biomass.[2] Indeed, the United States leads the world in the total size of cultivated land (approximately 1.7 million square kilometers)[3] and the production of agricultural crops, such as soybean and maize. The United States also is the world-leading producer of softwood and hardwood lumber. A recent report issued by DOE estimates a total renewable resource of 1 billion dry tons of agricultural residues, woody biomass, and new energy crops that can be sustainably harvested every year.[4] More than 130 million metric tons of crop residues alone exist today, which is more than sufficient to meet the current and anticipated growth in carbon fiber demand—even at imperfect conversion yields. Due to the relatively low energy density of unprocessed biomass, it is much more efficient to use the material near the source of production, which could advantage local production of carbon fiber or precursors compared to offshore production. It is the mission of EERE's Bioenergy Technologies Office to transform the available domestic biomass resources into fuels, chemicals, and power.

Advanced Manufacturing Office

DOE's Advanced Manufacturing Office supports R&D conducted at the Carbon Fiber Technology Facility (CFTF)[5] at Oak Ridge National Laboratory (ORNL). Through CFTF, ORNL is exploring the production of carbon fiber from different types of precursors, including lignin. ORNL has demonstrated significant progress toward the production of carbon fibers from lignin. Yet, there remain important manufacturing barriers to the deployment of lignin-based carbon fibers in high-performance clean-energy applications, such as

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[2] U.S. Department of Energy. Annual Energy Outlook 2013. DOE/EIA-0380(2013), Energy Information Administration, 2013.
[3] U.S. Central Intelligence Agency. The World Factbook: Land Use. https://www.cia.gov/library/publications/the-world-factbook/fields/2097.html.
[4] U.S. Department of Energy. *U.S. Billion-Ton Update: Biomass Supply for a Bioenergy and Bioproducts Industry*. DOE/EE-0363. Bioenergy Technologies Office and Oak Ridge National Laboratory, 2011.
[5] Oak Ridge National Laboratory. Manufacturing Demonstration Facility, 2013. http://www.ornl.gov/user-facilities/mdf.

lightweighting vehicles. Current barriers to the commercialization of lignin-based carbon fiber include melt processability (especially for softwood lignins); long heat treatment time (especially for hardwood lignins); variability in the feedstock; need for purification and fractionation; inability to reach targets for strength and stiffness of completed fiber; and unproven scale of operation. Similar challenges are anticipated for other precursor materials, such as textile-based polyacrylonitrile (PAN) or polyolefins. A biobased process to make PAN precursor equivalent to the current commercially available material is likely to minimize some of these barriers (i.e., stabilization time), but will also present new processing challenges—such as the development of pure and high-quality acrylonitrile chemicals. The Advanced Manufacturing Office remains interested in developing manufacturing processes for alternative precursor materials as a promising route for lowering the cost of carbon fiber and realizing the anticipated life-cycle energy savings for manufactured products. AMO has also supported the development of conversion processes and manufacturing systems to produce carbon fiber-reinforced composite products, in addition to performing extensive research, development, and demonstration work in a wide range of manufacturing technologies.

Vehicle Technologies Office

Reducing the weight of vehicles is a strategic goal of EERE. Specifically, EERE's Vehicle Technologies Office has been investigating material properties and manufacturing processes to bring about a new generation of lightweight materials, such as alternate carbon fiber precursors. The cost of incorporating carbon fiber composites in standard automobiles is a substantial issue. For widespread market adoption, it is estimated that the cost of PAN composites would need to reach $5 per pound or less.[6] The impact of incorporating these lower-cost composites would have significant positive effects. Lightweight materials could reduce passenger car weight by 50% and improve fuel efficiency by approximately 35% without compromising performance or safety.[7] DOE estimates that through the strategic use of carbon fiber, automakers could cut the weight of cars by up to 70%.[8] Even reducing vehicle weight by only 10% will result in a 4%–5% reduction in fuel use in passenger cars.[9] Assuming that 8.8 million barrels of oil are consumed by passenger cars per day, a 10% weight reduction in all passenger cars will result in an annual saving of more than 5 billion gallons of gasoline in the United States alone.

Current State of Technology

Current carbon fiber technology relies primarily on PAN chemical feedstock, which is derived from petroleum precursors. The cost of PAN can contribute up to 50% of the manufactured cost of carbon fiber.[10] PAN is made by the free radical polymerization of acrylonitrile, typically produced by catalytic ammoxidation of propylene. Propylene is often produced as a co-product in petroleum refinery processes.[11] As such, the precursor is

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[6] Rocky Mountain Institute. "Driving a Clean Energy Future with Ultralight Autos." 2013. http://www.rmi.org/impact_driving_a_clean_future_with_ultralight_autos.

[7] U.S. Department of Energy. Materials Technologies; Goals, Strategies, and Top Accomplishments. DOE/GO-102010-31111, Vehicle Technologies Office, 2010.

[8] U.S. Department of Energy. Light-Duty Vehicles Technical Requirements and Gaps for Lightweight and Propulsion Materials. DOE/EE-0868, Vehicle Technologies Office, 2013.

[9] Pagerit et al., 2006. Fuel Economy Sensitivity to Vehicle Mass for Advanced Vehicle Powertrains. Society of Automotive Engineers. 2006-01-0665.

[10] Kline and Company. "Cost Assessment of Lignin-and PAN-Based Precursor for Low-Cost Carbon Fiber." A discussion with Automotive Composites Consortium. Intelligent Insights (TM), March 14, 2007.

[11] Couch, Keith A., James P. Glavin, Dave A. Wegerer, and Jibreel A. Qafisheh. FCC Propylene Production. UOP LLC, 2007.

subject to the price volatility of crude oil; as the cost of oil goes up, so does the cost of PAN. Industries that rely on or desire to use carbon fibers could experience a renaissance if a replacement for petroleum-derived PAN could be found that offers competitive performance and is available at a lower cost. That resource can be biomass.

DOE is interested in enhanced collaboration between EERE offices to provide viable routes to manufacturing PAN from biomass-derived chemical intermediates. Substitutes for PAN from renewable resources that are less expensive, less volatile in price, and have the same or better properties for the manufacture of carbon fiber are also under consideration for this collaboration.

Workshop Concept and Process

To attain the maximum benefit from the Renewable, Low-Cost Carbon Fiber Workshop, DOE gathered knowledgeable subject matter experts with experience in carbon fiber manufacturing, biomass deconstruction and intermediate production, and industrial chemical production. These expert speakers provided information around the requirements of their respective industries and the areas where renewable carbon fiber would provide benefits. Issues discussed at the event included the technical challenges of carbon fiber manufacturing, including meeting end-product specifications for vehicle structural components; the technical challenges of converting biomass resources to "drop-in" carbon fiber intermediates; and the resources, challenges, and opportunities in unconventional carbon fiber.

Plenary talks given by DOE representatives highlighted the Department's interest and activities in clean-energy manufacturing and development of new technologies. These discussions featured the following speakers:

- Elizabeth (Libby) Wayman, *DOE EERE Strategic Programs*
- Neil Rossmeissl, *DOE EERE Bioenergy Technologies Office*
- Bhima Sastri, *DOE EERE Advanced Manufacturing Office.*

Subject matter experts with diverse experience in manufacturing, biomass, and vehicle components spoke about the requirements of their respective industries and areas where renewable carbon fiber could increase productivity and competitiveness. These discussions featured the following speakers:

- Gary Lownsdale, *Plasan Carbon Composites*
- Cliff Eberle and Mark Downing, *Oak Ridge National Laboratory*
- Darrell Waite, *Old Town Fuel & Fiber*
- Will Schroeder, *ADM.*

Participants were invited to answer a series of questions related to the development of renewable carbon fiber in breakout sessions (*see Appendix B: Workshop Questions*). Three breakouts were held, each addressing different questions and issues: *Technical Challenges with Carbon Fiber Manufacturing and Meeting End-Product Specifications for Vehicle Components from Bio-Derived Materials*; *Technical Challenges with Converting Biomass Resources to "Drop-In" Carbon Fiber Intermediates*; and *Unconventional Carbon Fiber: Resources, Challenges, and Opportunities*. A full workshop agenda is provided in *Appendix A*.
Breakout attendees were divided into three groups and asked specific questions related to the breakout discussion topic. The answers were recorded, and at the end of each breakout session, the comments were

summarized and reported to the group as a whole. The information gathered during those sessions is reported below.

Session 1: Technical Challenges with Carbon Fiber Manufacturing and Meeting End-Product Specifications for Vehicle Components from Bio-Derived Materials

A lignin pathway to carbon fibers has been researched by a number of different entities.[12] Current technologies do not yet yield a lignin-derived carbon fiber with the tensile strength and modulus profiles required for the material to be incorporated into vehicle structural components. A route based on converting cellulosic sugars to PAN appears to offer a “drop-in” route to functionally equivalent materials, which may be more readily commercialized in the near term. Cellulosic sugars can be converted by a combination of microbial and/or inorganic catalysts into a number of different monomers used for carbon fiber production today, including—but not limited to—acrylonitrile,[13] methyl acrylate,[14] and itaconic acid.[15] The discussion for this report will focus largely on acrylonitrile, as it is the primary monomer for producing PAN-based copolymers that are predominantly used as carbon fiber precursors.

A bio-derived acrylonitrile would need to satisfy a number of different technical parameters to be adopted for use in existing manufacturing processes, namely polymerization and spinning, to generate PAN precursor fibers. Workshop participants identified three factors as critical to measure with respect to the acceptability of bio-acrylonitrile—the yield from the raw feedstock (e.g., cellulosic sugars); the source, type, and quantity of chemical impurities; and the degree of pre-polymerization.

Workshop participants expressed the view that if bio-derived acrylonitrile can be made to be chemically and physically identical to petroleum-derived acrylonitrile, then the existing downstream process should produce high-quality PAN and carbon fiber. The functional equivalency of the bio-PAN could be validated and established by measuring the bio-acrylonitrile content, the appropriate reactivity with co-monomers and polymerization catalysts, the resulting molecular weight distribution, the thermal oxidative stability, the uniformity and viscosity of the dope, and the ability to be spooled.

These critical technical performance factors can be evaluated by a number of different existing methods, including—but not limited to—analytical chemistry, thermogravimetric analysis, and other tests for material properties. The amount of material required for testing will vary depending on the step and stage of the overall manufacturing process and technology readiness, respectively. Early-stage testing might require grams or kilograms of materials, and later manufacturing equivalency validation might require metric tons of materials. There is little, if any, tolerance for variability in these technical specifications if the intended end application is vehicle structural components. There may be higher tolerance for variability if the bio-derived

[12] U.S. Department of Energy. "Low-Cost Carbon Fiber from Renewable Resources." In Lightweighting Materials FY 2007 Progress Report, Vehicle Technology Office, 339-376, 2007.
[13] Le Notre, Jerome, et al. "Biobased synthesis of acrylonitrile from glutamic acid." Green Chemistry 13 (2011): 807–809.
[14] Marsden, Charlotte, et al. "Aerobic oxidation of aldehydes under ambient conditions using supported gold nanoparticle catalysts." Green Chemistry 10 (2008): 168–170.
[15] Willke, Thomas, and Vorlop, Klaus-Dieter. "Biotechnological production of itaconic acid." Applied Microbiology and Biotechnology, 56 (2001): 289–295.

carbon fiber will be used for non-structural components, so long as it is still produced cost-competitively to the alternatives.

Ultimately, bio-acrylonitrile and bio-PAN would need to meet existing American Society of Mechanical Engineers and American Society for Testing and Materials standards with manufacturing scaled-up appropriately in order to gain market adoption. The production costs must be competitive with the existing process, especially if the bio-PAN offers no other performance benefit. The bio-derived PAN should seek to minimize the generation of hazardous or toxic byproducts and, overall, aim to have an improved environmental footprint in terms of energy use and material lifecycle (durability, recyclability). The future market volatility of fossil-based PAN is an additional factor to consider in weighing the benefits and costs of a bio-derived route.

Other raw materials used in the production of composites and other fiber precursors besides PAN can be bio-derived. Some of the co-monomers for this approach identified by participants include itaconic acid, methyl acrylate, and vinyl acetate. Pitch, rayon, polyolefins, and bio-oils were also identified as alternative precursors that can be sourced from biomass. Resin components, such as polyurethanes, for the carbon fiber composites offer an additional avenue for biobased chemicals. Functional equivalency or advantages will need to be established in each of these cases, but there are many more ways to incorporate biobased content for material applications.

Session 2: Technical Challenges with Converting Biomass Resources to “Drop-In” Carbon Fiber Intermediates

Technical barriers of utilizing a biomass feedstock to produce drop-in carbon fiber intermediates—such as acrylonitrile—include concerns about the supply chain, security and competitive biofuel fuel uses, regionalized supply, and overall availability. There is wide variability within biomass resources, and the barriers of measuring the purity of these feedstocks might not be well enough known for the applications that produce acrylonitrile and other bio-derived intermediates for the carbon fiber industry. After a known feedstock can be reliably obtained and appropriately analyzed, there may be challenges within the biomass deconstruction processes for the production of carbon fiber intermediates. There will need to be strong communication between suppliers and customers on what specifications need to be met for the deconstructed biomass fractions, whether they are sugars or lignin. Workshop participants noted that it would be beneficial to have a biomass library that details the different sugar and lignin production from different types of raw biomass. Besides sugar and lignin, other intermediates for upgrading to bio-derived acrylonitrile include carboxylic acids, sugar acids, amino acids, levulinic acid, glycerol, propylene, biocrude substitutes for refineries, and condensation products. Overall, there would need to be more crosscutting science between biomass feedstock scientists and polymer chemists/material engineers to better evaluate the potentials of biomass in the carbon fiber industry.

The upgrading of bio-intermediates to acrylonitrile is not a straightforward process, and strategic R&D is needed to reach cost and yield parity with conventionally produced acrylonitrile. The supply and logistics of the biomass to the production facility, and the intermediates leaving the facility, would both require reliable supply and off-take agreements. The CAPEX (capital expenditures) and OPEX (operating expense) of the scaling-up of processes will require better catalyst efficiencies, among other improvements, to make renewable acrylonitrile cost-competitive with current routes. Other than general economic concerns about the new conversion facility required for this process, the environmental issues that may arise from this are currently unfamiliar. Because toxicity of the waste streams is unknown, processing facilities for bio-acrylonitrile may require new environmental certifications, and the carbon efficiency and the release of carbon dioxide (CO_2) and other potential greenhouse gases from these commercial-scale processes have not yet been determined.

The supply chain barriers associated with bio-derived acrylonitrile range from technical challenges to marketing hurdles. As mentioned previously, feedstock supply, logistics, storage, and stability will introduce a significant barrier in producing bio-derived carbon fiber compared to conventionally derived carbon fiber. It may be beneficial if renewable carbon fiber facilities have the ability to utilize diversified biomass resources in order to help mitigate this risk. The commercial validation of these processes for fermenting complex sugars to potential acrylonitrile precursors—such as 3-hydroxyproprionate, lactate, and amino acids—is still unproven, which heavily contributes to the challenges of bringing this technology to a commercial-scale market.

Japan is currently the majority producer of carbon fiber worldwide, accounting for 37% of the supply.[16] North America and Europe account for the majority of the demand for carbon fiber. The role of the United States in the competitive carbon fiber production market needs to be understood and established. There will need to be cost parity between international and national markets, and using biomass feedstocks appears to be a complex technical route. Additionally, when dealing with international imports/exports, export restrictions will need to be considered. In all of these main facets (technical, economic, political, and environmental), commercial production of bio-derived carbon fiber will require collaborative efforts between diverse stakeholders. Many workshop participants stated that it may be beneficial to increase the knowledge base of bio-derived carbon fiber by forming a consortium that will study and collaborate on the abovementioned wide range of barriers.

Session 3: Unconventional Carbon Fiber—Resources, Challenges, and Opportunities

Renewable carbon fiber derived from biomass may not need to be produced through a “drop-in” intermediate. Efforts to create unconventional carbon fiber would likely be longer term, as new processes and equipment would need to be developed. Previous work has sought to use lignin from pulp and paper mills as a feedstock for carbon fiber, with varying levels of success. Current cellulosic ethanol production requirements are leading to the generation of large amounts of lignin, which could be a potential carbon fiber feedstock. A more complete understanding of lignin, including knowledge of different lignin structures and their processability, would improve engineering efforts. Development of lignin-derived carbon fiber would be improved with a catalogued library of lignin types, methods, and chemical and mechanical properties of the tested fibers. Work previously performed at ORNL could inform this library by summarizing what has been tried, what has succeeded, and what has failed, enabling advanced analysis of these results. A key understanding underpinning this information is the comparison of kraft lignin—produced from a chemical pulping process called kraft pulping—with lignin produced through other methods, such as those employed in

[16] Lucintel. Growth Opportunities in the Carbon Fiber Market 2010–2015. Las Colinas, TX: Lucintel, 2010.

the existing and anticipated biofuels biorefineries. Technologies for biomass pretreatment for biofuels production may be able to tailor lignin structure or properties for carbon fiber production. DOE has funded work on lignin-derived carbon fiber, and a review of those previously funded efforts would identify areas where enhanced or focused R&D could yield the greatest benefits.

In addition to lignin, cellulose from plants could be used to regenerate fibers in order to make carbon fiber—in a process similar to that of rayon. Other possible bio-derived precursors that were mentioned during the workshop include fatty acids, olefins, pitch or rosin-like substances, bio-oils, and chitin.

Genetic modification of biomass may also enable new routes to carbon fiber, including engineering plants to synthesize lignin with properties more amenable to carbon fiber production, or other polymers that could be converted to PAN-like materials. Participants suggested that carbon fibers could also be derived from CO_2 or carbon nanotubes in yet-to-be-developed methods.

Much of the previous work on bio-derived carbon fiber has focused on lightweighting vehicles, particularly structural components. Some of the applications for vehicle lightweighting also include components like seat frames, door inner modules, mirror housings, air splitters, front wheel wells, roof inner panels, and bumper beams. It is possible that the properties of carbon fiber needed for other applications may not be as stringent; therefore, expanding the uses for bio-derived carbon fiber. New carbon fiber types could be developed for coatings or in battery materials. Beyond these elements, insulation, flame-retardant materials, dispersants for dyes, tires, interior appearance components, and audio systems could also be made from biomass-derived carbon fiber. The long list of potential vehicle uses emphasizes a need for evaluating the specifications necessary for a variety of possible carbon fiber applications.

Carbon fiber use is not limited to vehicles—almost any industry can use a lower-grade carbon fiber in place of existing materials. Many industries would benefit from lower-cost carbon fiber that could be used as a substitute for existing materials; for example, marine vessels, road and bridge infrastructure, electrical transmission lines, flame proofing, medical applications, selective gas removal filters, fiberglass replacements, fabrics, sporting goods, and acoustics.

Workshop participants noted that the economic tradeoffs of new processes are important to understand. The development of bio-derived carbon fiber will rely on understanding its economic value and tradeoffs relative to those of its petroleum-derived counterparts. Lessons learned from petroleum-derived carbon fiber could also be applied to a bio-derived product to enhance and enable production. Finally, life-cycle assessments will be crucial to understanding the benefits of renewable carbon fiber.

Concluding Remarks

DOE has a clear mandate to employ science and discovery that will not only reduce the United States' dependence on foreign petroleum, but will also mitigate climate change associated with greenhouse gas emissions caused by the consumption of petroleum. Producing renewable carbon fiber from biomass can help fulfill this mandate by accomplishing the following:

- Developing the science and technology required to replace the entire barrel of oil, which includes the products made from petroleum.
- Achieving the higher margins associated with chemicals, which would enable the bioindustry.
- Lightweighting vehicles to increase fuel economy and efficiency while maintaining safety standards.
- Assisting U.S. industry by utilizing non-fossil-based feedstocks that are not subject to the price volatility associated with petroleum.

The focus of this workshop was to gather information from various stakeholders in an attempt to understand the R&D challenges that will need to be overcome in the production of a bio-derived carbon fiber. DOE very much appreciates the input provided by industry, government, laboratory personnel, and academic researchers who made this report possible.

Appendix A: Full Workshop Agenda

U.S. Department of Energy (DOE), Office of Energy Efficiency and Renewable Energy (EERE)
Renewable, Low-Cost Carbon Fiber for Lightweight Vehicles Workshop
June 4–5, 2013
Sheraton Detroit Metro Airport Hotel
8000 Merriman Rd. Romulus, MI 48174

June 4	01:00–01:05 p.m.	Organizer Welcome and Introduction *Joyce Yang, DOE EERE Bioenergy Technologies Office*
	01:05–01:25 p.m.	EERE's Clean Energy Manufacturing Initiative *Elizabeth (Libby) Wayman, DOE EERE Strategic Programs*
	01:25–02:50 p.m.	U.S. RD&D Plenary
	01:25–01:45 p.m.	*Gary Lownsdale, Plasan Carbon Composites*
	01:45–02:05 p.m.	*Cliff Eberle/Mark Downing, Oak Ridge National Laboratory*
	02:05–02:25 p.m.	*Darrell Waite, Old Town Fuel & Fiber*
	02:25–02:50 p.m.	*Will Schroeder, ADM*
	02:50–03:00 p.m.	Organizers Instructions for Breakouts
	03:00–05:00 p.m.	Breakouts—Technical Challenges with Carbon Fiber Manufacturing and Meeting End-Product Specifications for Vehicle Structural Components from Bio-Derived Materials
	05:00–06:00 p.m.	Report Outs
June 5	08:00–08:20 a.m.	DOE Bioenergy Technologies Office Overview *Neil Rossmeissl, DOE EERE Bioenergy Technologies Office*
	08:20–08:40 a.m.	DOE Advanced Manufacturing Office Overview *Bhima Sastri, DOE EERE Advanced Manufacturing Office*
	08:45–09:00 a.m.	Coffee Break/Networking
	09:00–11:00 a.m.	Breakouts—Technical Challenges with Converting Biomass Resources to "Drop-In" Carbon Fiber Intermediates (e.g., PAN)
	11:00–12:00 p.m.	Report Outs
	12:00–01:30 p.m.	Lunch on Own (No Host)/Networking
	01:30–03:30 p.m.	Breakouts—Unconventional Carbon Fiber: Resources, Challenges, and Opportunities
	03:30–04:30 p.m.	Report Outs
	04:30–05:00 p.m.	Concluding Remarks *Joyce Yang, DOE EERE Bioenergy Technologies Office*

Appendix B: Workshop Questions

Breakout 1—Technical Challenges with Carbon Fiber Manufacturing and Meeting End-Product Specifications for Vehicle Components from Bio-Derived Materials

1) What technical parameters should be measured to compare bio-derived PAN to conventional PAN?
2) What types of testing should be done and how much material would be necessary to evaluate and validate bio-derived PAN as a suitable “drop-in” material?
3) What non-technical targets need to be met for bio-derived PAN to be adopted by industry (e.g., cost parity, cost reduction)?
4) What is the tolerance for variability of these technical and non-technical parameters?
5) Are there other precursor materials besides PAN that could be replaced with a bio-derived equivalent?

Breakout 2—Technical Challenges with Converting Biomass Resources to “Drop-In” Carbon Fiber Intermediates

1) What are the technical and non-technical barriers to producing clean feedstocks (e.g., sugars) in sufficient amounts at sufficient quality?
2) What intermediates should be considered for upgrading to bio-derived acrylonitrile and PAN (e.g., glutamic acid, 3HP)?
3) What challenges (technical and non-technical) exist for upgrading biomass resources to acrylonitrile and ultimately PAN?
4) Where do these barriers exist along the supply chain for biomass to PAN?

Breakout 3—Unconventional Carbon Fiber: Resources, Challenges, and Opportunities

1) What are other pathways to carbon fiber from biomass resources beyond “drop-in” intermediates?
2) What previous work on lignin-derived carbon fiber can be leveraged as new sources of clean lignin become available?
3) How can lignin be used in other, non-structural materials for vehicles?
4) What other applications exist or can be created for an unconventional carbon fiber?

Appendix C: Abbreviations and Acronyms

CAPEX	Capital Expenditures
CF	Carbon Fiber
CFTF	Carbon Fiber Technology Facility
CO_2	Carbon Dioxide
DOE	Department of Energy
EERE	Energy Efficiency and Renewable Energy
OPEX	Operating Expenditures
ORNL	Oak Ridge National Laboratory
PAN	Polyacrylonitrile
R&D	Research and Development

Appendix D: Related Links

Bioenergy Technologies Office Carbon Fiber Workshop Web Page:
http://www1.eere.energy.gov/bioenergy/carbon_fiber_workshop.html

Workshop Proposal
http://www1.eere.energy.gov/bioenergy/pdfs/carbon_fiber_workshop_proposal.pdf

Breakout Session Results:

- Session 1: Technical Challenges with Carbon Fiber Manufacturing and Meeting End-Product Specification for Vehicle Components from Bio-Derived Materials
  - http://www1.eere.energy.gov/bioenergy/pdfs/carbon_fiber_workshop_breakout_comments1.pdf
- Session 2: Technical Challenges with Converting Biomass Resources to Drop-In Carbon Fiber Intermediates
  - http://www1.eere.energy.gov/bioenergy/pdfs/carbon_fiber_workshop_breakout_comments2.pdf
- Session 3: Unconventional Carbon Fiber: Resources, Challenges, and Opportunities
  - http://www1.eere.energy.gov/bioenergy/pdfs/carbon_fiber_workshop_breakout_comments3.pdf

Vehicles Technologies Office Workshop Report: Light-Duty Vehicles Technical Requirements and Gaps for Lightweight and Propulsion Materials
http://www1.eere.energy.gov/vehiclesandfuels/pdfs/wr_ldvehicles.pdf

Appendix E: Workshop Attendees

First Name	Last Name	Organization
Nadia	Abunasser	MEDC
Richard	Arnold	RSA/Old Town Fuel and Fiber
Kenneth	Augustyn	SRI International
Ali	Ayoub	NC STATE UNIVERSITY
Gabe	Below	LNE Group
Derek	Berry	National Renewable Energy Laboratory
Mary	Biddy	National Renewable Energy Laboratory
James	Blount	Breakthrough Technologies Institute
Raymond	Boeman	Oak Ridge National Laboratory
Richard	Brotzman	Argonne National Laboratory
Adam	Chabot	INEOS
Katy	Christiansen	DOE Bioenergy Technologies Office
Liesl	Clark	5 Lakes Energy
Michael	Crowley	National Renewable Energy Laboratory
Lynn	Daniels	Advanced Manufacturing Office -- DOE
Sujit	Das	Oak Ridge National Laboratory
Nancy	Dowe	National Renewable Energy Laboratory
Mark	Downing	Oak Ridge National Laboratory
Lawrence	Drzal	Michigan State University-Composite Center
Padma	Durbha	Metalsa Structural Products
Cliff	Eberle	Oak Ridge National Laboratory
Leo	Fifield	Pacific Northwest National Laboratory
Carmen	Franko	Global Composite Solutions
Peter	Fritz	Eaton
Jerry	Gargulak	Borregaard LignoTech
Dr. John	Garnier	Advanced Ceramics Fibers, LLC
Anthe	George	Sandia National Laboratories
Nicholas	Gianaris	Composite Vehicle Research Center MSU
Glade	Gunther	Cytec
Mike	Himmel	National Renewable Energy Laboratory
John	Holladay	Pacific Northwest National Laboratory
Nina	Hsu	Harper International
Cindy	Jiang	AET Integration, Inc.
Stephen	Jones	Faurecia
Nick	Kuuttila	Michigan State University
Jeff	Lacey	Idaho National Laboratory
Ruth	Latham	Ricardo strategic consulting
Alan	Liby	Oak Ridge National Laboratory
Wendy	Lin	GE Global Research
Ryan	Livingston	BCS, Incorporated
Sarah	Luchner	BCS, Incorporated
Mo	Mahmood	Global Composite Solutions
Thirumal	Mariappan	Ingersoll Rand

First Name	Last Name	Organization
Tim	McDonel	INEOS
Scott	McWhorter	Savannah River National Laboratory/DOE
Manish	Mehta	National Center for Manufacturing Sciences
Rich	Moizio	Mitsui
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DOE/EE-0991 • October 2013

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