Renewable Low-Cost Carbon Fibers: a Proposal for a DOE Workshop
A Collaboration between BETO, AMO, and VTO

The availability of affordable feedstocks and robust supply chains are keys to successful manufacturing industries. The U.S. Department of Energy (DOE) recently launched the Clean Energy Manufacturing Initiative (CEMI),[1] to increase U.S. competitiveness in the production of clean energy products and to increase U.S. manufacturing competitiveness across the board by increasing energy productivity. The need to develop and reduce cost for high performance materials for clean energy applications is ever more pertinent as consumers and industrials have an expanding array of traditional energy goods (e.g. natural gas) or clean energy alternatives produced overseas.

Reducing the weight of vehicles has been a strategic goal of the DOE's Office of Energy Efficiency and Renewable Energy (EERE). Specifically, EERE's Vehicle Technologies Office (VTO) has been investigating the material properties and manufacturing processes to bring about a new generation of lightweight materials, such as alternate carbon fiber (CF) precursors and conversion processes. Light-weight materials could reduce passenger car weight by 50 percent and improve fuel efficiency by about 35 percent without compromising performance or safety[2]. The Energy Department estimates that through the strategic use of carbon fiber, automakers could cut the weight of cars by up to 70%[3].

Current CF technology relies primarily on polyacrylonitrile (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 (KLINE & COMPANY, INC. 2007). In addition, the precursor is subject to price volatility of crude oil; as the cost of oil goes up, so does the cost of PAN. The growth of CF composite applications beyond aerospace appears to be hampered at least in part by feedstock cost and availability issues as evidenced by the growing cost of PAN (up by 30% since 2001). 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.

Of all forms of renewable energy consumed in the United States, none rivals the amount of energy produced from biomass.[4] Indeed, the U.S. leads the world in the total size of cultivated land (~ 1.7 million square kilometers),[5] and the production of agricultural crops such as soybean and maize. The U.S. is also the world leading producer of softwood and hardwood lumber. A recent report issued by DOE estimates a total renewable resource of one billion dry tons of agricultural residues, woody biomass and new energy crops that can be sustainably harvested

[1] http://www1.eere.energy.gov/energymanufacturing/
[2] U.S. Department of Energy, 2010. Materials Technologies: Goals, Strategies, and Top Accomplishments. DOE/GO-102010-3111. Vehicles Technologies Office.
[3] U.S. Department of Energy. 2013. Light-Duty Vehicles Technical Requirements and Gaps for Lightweight and Propulsion Materials Workshop Report. Table 6. DOE/EE-0868
[4] U.S. Energy Information Administration, 2013. Annual Energy Outlook Early Release Overview. Table 1.
[5] CIA World World Fact Book, Land Use.

every year.[6] More than 130 million metric tons (MT) of crop residues alone exist today, which is more than sufficient to meet the current and anticipate 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 may confer supply chain competitiveness advantages for U.S. downstream processing and manufacturing technologies. The mission of EERE's Bioenergy Technologies Office (BETO) is to transform the available domestic biomass resource into fuels, chemicals and power.

AMO supports the work at the Manufacturing Demonstration Facility (MDF)[7] at Oak Ridge National Laboratory (ORNL). Through the MDF, ORNL is exploring production of carbon fiber from different types of precursors, for example lignin. While ORNL has demonstrated significant progress toward the production of carbon fibers from lignin, there remain important manufacturing barriers to the deployment of lignin-based carbon fibers in clean energy applications like lightweighting vehicles. Long stabilization time, variability in the feedstock, need for purification and fractionation, lack of supply infrastructure, inability to reach targets for strength and stiffness and unproven scale of operation are currently identified barriers to commercialization of lignin based carbon fiber. Similar challenges are anticipated for other precursor materials. A biobased process to make polyacrylonitrile 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. AMO remains interested in the development of manufacturing processes for alternative precursor materials, as this is a promising route to lowering the cost of carbon fiber and realizing the anticipated life-cycle energy savings for manufactured products. AMO has also supported development of conversion processes and manufacturing systems to produce carbon fiber reinforced composite products, in addition to extensive RD&D work in wide range of manufacturing technologies.

DOE is interested in kick-starting a new EERE collaboration between BETO, AMO, and VTO that seeks to provide viable routes to manufacturing PAN based on chemical intermediates derived from biological feedstocks as a primary objective. Substitutes for PAN from renewable resources that have the same or better properties for the manufacture of carbon fiber are also under consideration for this collaboration.

Important elements of this initiative are to:

1) investigate the feasibility of using cellulosic sugars and lignin to manufacture acrylonitrile or other intermediate chemicals that can ultimately be converted into a polyacrylonitrile carbon fiber precursor that has equivalent properties to commercially available petroleum based PAN precursor.
2) identify and investigate the feasibility of using cellulosic sugars and lignin to manufacture other intermediate chemicals that can ultimately be converted into carbon fiber precursors with the properties required.

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[6] U.S. Department of Energy. 2011. Billion-Ton Update: Biomass Supply for a Bioenergy and Bioproducts Industry. R.D. Perlack and B.J. Stokes. ORNL/TM-2011/224. Oak Ridge National Laboratory, Oak Ridge, TN. 227p.
[7] http://www.ornl.gov/sci/manufacturing/mdf.shtml

3) integrate computational tools through integrated computational materials engineering to accelerate the product development cycle time for low cost structural vehicle composites.

The groups of internal and external stakeholders required to come to together to achieve a successful outcome are generally not aware of each other's technologies, or the synergistic potential that can be realized as teams. Thus, a workshop is proposed for DOE to communicate the elements of this initiative to interested parties, and to bring the disparate stakeholder together to focus discussion on the anticipated key barriers, including (but not limited to):

- the feasibility of using plant-based materials to generate high purity PAN carbon fiber precursors and potentially other carbon fiber precursors,
- the scale-up of purification and other manufacturing processes needed to convert biobased intermediate chemicals into PAN precursor material
- the near-term scalability of biochemical and chemical upgrading to make suitable for conversion
- Optimization of conversion processes from precursor into carbon fiber (e.g. stabilization and carbonization),
- the economic competitiveness and life-cycle energy consumption of the biomass-derived carbon fibers with respect to traditional carbon fibers.

The planned integrated effort leverages the complimentary insight and expertise of the EERE Offices to support end to end technology development with the potential for an enhanced domestic supply chain for low cost carbon fiber with the intended impact of increasing energy productivity and U.S. manufacturing competitiveness.