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Strategies and Tools for Navigating and Thriving in Uncertain Times

Innovation in the Lab: Emerging Material Could Provide the Breakthrough that Nanotech Needs

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Developers of carbon nanotube- and nanoparticle-based materials technologies receive more R&D dollars from government agencies and private investors than emerging nanoplatelet materials technologies, such as graphene. But several factors are in favor of this emerging nanomaterial — not the least of which are claims by its developers that it could one day be produced at $5 per pound.

The graphene nanoplatelets are made from exfoliating graphite to produce graphene sheets that can be used as filler for composite matrices.

The potential for producing low-cost nanocomposites that use graphene nanoplatelet filler, and the perceived property advantages and benefits provided by the material over competing advanced materials, have generated attention for graphene as a material with real business potential.

The cause of graphene nanocomposites is also being bolstered by the continuous improvements and advances in chemical processes to exfoliate graphite to create graphene sheets or nanoplatelets suitable for incorporation into nanocomposites that could be used in aircraft, cars, fuel cells, batteries and other devices and systems.

Sector Challenges and Strengths

Problems of price and performance — mainly achieving reliability and consistency during production — are key challenges for the adoption of carbon nanotubes, which, on the one hand, can be viewed as a competitor to graphene. On the other hand, the two materials are very complementary.

That said, graphene nanoplatelet development is clearly in far earlier stages of development than carbon nanotube-based materials when viewed within the technology development cycle. The route to commercialization, as is the case with many newly emerging materials, may be filled with challenges. Carbon nanotubes, although currently ahead of graphene in the chance for commercial rewards, are having difficulties in effectively competing with well-established advanced materials, such as carbon fiber, in the effort to penetrate commercial applications.

Commercial Potential

Carbon fiber producers are so confident of the demand for materials that they are expanding operations. Toho Tenax, which supplies products to Airbus and is among the world's largest producers of carbon fiber, launched a 2,700 ton per year production line for general industrial applications at its Mishima Plant in Japan in May 2008 and it has another 1,700 ton per year line scheduled for start up in Germany in August 2009, making its total capacity 13,500 tons per year. Toray Industries, a supplier to Boeing, expects to increase the baking capacity of its plants in Japan, the United States and France to a total of 18,900 tons per year in 2009.

All of this expansion, however, is not necessarily bad news for carbon nanotube and nanoplatelet producers and developers. They are likely to participate in the same market applications as carbon fiber producers and these bullish expansion plans are indicative of generally strong demand in the sector — a demand that will one day benefit graphene platelets and carbon nanotubes.

The worldwide demand for pan carbon fiber is expected to increase from a healthy 50,000 tons per year in 2010 to greater than 65000 tons per year in 2012. Producers could top 100,000 tons of supply per year in 2018.

Materials and Technology Strengths

Frost & Sullivan's analysts expect that there will be room for inorganic nanoparticles, nanotubes and graphene nanoplatelets in different nanotech applications. Where barrier properties are needed, such as an oxygen barrier in medical equipment, graphene could be most suitable. Graphite nano-scale fillers also have an opportunity as a replacement of carbon black used to make conductive plastics. Less volume of graphene than carbon black is likely to provide a desired solution, allowing needed levels of conductivity without the levels of embrittlement caused by larger quantities of carbon black. Applications that require wire-shape components, such as the connection between electronic components, would benefit more from carbon nanotubes, for example, than graphene nanoplatelets, and automakers have found that nanoclays are suitable for step assists and other structural parts in automobiles.

Multi-walled carbon nanotubes (MWCNT) are being explored as potential real world solutions by automotive, aerospace and recreational market participants. As prices are pushed downward and producers develop more cost effective methods of production, buyers are showing increasing interest, according to nanotube producers.

The price of MWCNTs has steadily decreased. Prices ranged from $250-350 per kilogram as recently as 2005, depending on the quantity ordered. Current pricing is $100-150 per kilogram — less than half of 2005 costs. This downward trend will continue. Market participants predict that MWCNTs pricing will decrease between 20% and 30% in 2010-2011, bring the price down to $70-120 per kilogram. Increased capacity and production from MWCNT suppliers to satisfy demand will couple with increased competition and drive down prices.

If nanoplatelets can be produced at $5 per pound as predicted, it will provide major disruption in the nanocomposites marketplace. An unmet need that currently encourages graphite nanocomposite development and production is the demand for sizable quantities of graphene nanomaterials quickly enough for materials scientists to be able to experiment with it and develop prototype components. As one leading graphene developer and patent holder put it, companies who were enthused over the capabilities of graphite nanocomposites were crestfallen when told it would take a month to produce a kilogram.

There are some signs, however, that graphene developers will follow the lead of their nanotube developer predecessors and others who worked to produce larger quantities of carbon nanotubes for materials scientists to work with. For example, two leading academic scientists have helped form spin-off companies to scale up graphene production. Research conducted by the global technology division of Frost & Sullivan, Technical Insights, found that the primary future applications for graphene nanocomposites may include the following:

> Markets with greatest potential for graphene, and for that matter, carbon nanotube-based and nanoparticle-based nanocomposites, include recreation, automotive and aerospace applications. Advances in graphite exfoliation, such as the chemical process developed by Prof. Rod Ruoff at Northwestern University, and the proprietary processes developed by Dr. Lawrence Drzal at Michigan State University, will spur greater interest in the research and development of graphite nanocomposites. Similarly, as spinoff companies such as Vorbeck Materials Inc. and XG Sciences scale up production of graphene nanomaterials, the product developers will be able to experiment with making components of graphite nanocomposites.
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> Because leading universities develop virtually all graphene nanomaterials, scientists working at different schools are partnering to share human and laboratory resources to conduct R&D. A good example of this is Princeton University, whose Dr. Robert Prud'homme and Prof. Ilhan Aksay formed a graphene nanocomposites team that included L. Catherine Brinson, Rodney S. Ruoff and SonBinh T. Nguyen of Northwestern University; Jun Liu of Sandia National Laboratories (now at Pacific Northwest National Laboratory), as well as Ahmed Abdala, Douglas H. Adamson, Michael J. McAllister, David L. Milius and Margarita Herrera-Alonso of Princeton.
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> Prof. Rod Ruoff of Northwestern has formed his own collaboration with Drs. Erik Thostenson and Tsu-Wei Chou of the University of Delaware, and will soon include Prof. Don Paul at the University of Texas at Austin.
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> The field of graphene nanocomposites appears to be dominated by American firms at the moment. Despite vigorous research in Europe and Asia, researchers in the United States have

obtained patents, and are launching startups to exploit graphene's potential as nanocomposite filler.

Development Challenges

The major challenge to the commercialization of graphite-polymer nanocomposites is the lack of sufficient volumes of product for materials scientists to experiment with and to demonstrate their processability and dispersability in polymer matrices, and to develop engineering data and design guidelines. Graphite nanoplatelets have only been produced in laboratory quantities, and their production must be scaled up in order for them to be developed, eventually, in pilot plant volumes. Making graphite nanoplatelets has been known for 90 years, but an economical process of producing them as well as understanding the technical requirements for effectively dispersing them in water, resins and polymers has been missing.

Like other new materials, it is also important that developers become familiar with the properties of graphite nanocomposites for different applications, because as a specialty material, it behaves slightly differently in every application. For example, the need for a stiff epoxy composite is different from what is needed to make an elastomer tire. There are also some specific technical challenges that must be overcome to develop graphite-polymer nanocomposites.

One key challenge is to understand the surface chemistry and morphology of graphene materials that must be tailored to the nanocomposite application that they will serve. For example, adding them to nylon versus epoxy requires different kinds of understanding. Another challenge is to provide mechanical, electrical conductivity, or thermal properties, or a combination of any or all these by improving the interface of the nanoplatelet with the matrix material. Indeed, there is a need for more basic material research by synthetic chemists, particularly with strong polymer backgrounds, and physicists, and other materials specialists, to fully exploit the potential of graphene fillers for composite applications.

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