

Graphene – the race is on, but what's real?

✘ There are already a diverse number of applications for graphene and the graphene market will be real and significant. Currently graphene sells for \$100 to \$200 a gram but the market is counted in terms of kilograms. That size of the market is projected to increase rapidly as graphene is industrially produced. However, neither are guaranteed. The following questions need to be answered: what is the profit in making graphene and what is the market size.

What is the profit? It is important to recognize that graphene production techniques and processes are public domain. This means that no company or, no select group of companies, is going to dominate the market through trade secrets and patents although they could through the control of the resources that make the graphene.

On the low end of the graphene market is bulk material used as a filler to provide strength and conductivity in future day-to-day composite products probably using additive manufacturing techniques (3D printing). The current market for carbon fiber composites was \$16,479.4 million in 2013, and is expected to grow at a rate of 12.8% annually from 2014 to 2019 with bulk carbon costs on the order of half a dollar per gram. Graphene could replace these products if sold at lower costs. The prime candidate for lower quality bulk graphene is cheap readily available amorphous graphite as graphene is easiest to make when the distance between the graphene layers of the graphite are wider and the crystals are smaller. Thus, the cost of bulk graphene will quickly come down to the cost of the raw materials, the cost of production and a small profit margin. With the winners being dictated by those with the cheapest graphite, labour and energy costs. Profit margins on the bulk material are likely to be minimal but significant

profits will be made through large volumes. As China and Mexico are the sources of most the amorphous graphite they will probably also be centers for bulk graphene production.

The highest quality graphene needs the best precursor graphite and significant quality control for use in applications that are being developed that require graphene. This material will probably command margins of 20-30%; assuming a market structure similar to cell phones. Sales price is likely to be in the range of over a dollar a gram. Like the bulk graphene, the technology will not be the deciding factor as to who produces the premium products; that will be the supply of premium grade graphite, the training of the people and access to other technologies. To move to higher quality graphene will require larger pre-cursor crystal size and structural integrity that is not present in amorphous graphite. The best graphite for this purpose will likely be crystals that are flat, ordered and with few displacements of the graphene layers in the parent crystals. This graphite crystal is found in almost all graphite deposits; however, this quality must be found at high grades meaning after processing. Not all deposits are amenable to this type of processing. This restriction probably means that most high quality graphene sources will be either Class 2A, or Class 1-W (A or B, with or without vanadium) deposits. Companies without access to these or similar graphite sources will be forced into the lower margin graphene markets. In other words, it is the graphite source that will dictate the final product.

Many companies are moving into the graphene production side of the business rather than the mining. These companies must secure a source of high quality graphite just like any other potential graphene producer and the source they obtain along with the expertise that they have will determine which market, if any, they are able to operate in. Some of the largest chemical and materials companies in the world have rigorous graphene research programs and are likely to squeeze smaller

players out of the market unless niche markets can be found.

What is the market size going to be? The market will be significant. Putting numbers on it is probably not possible at the current time, however, orders of magnitude estimates can be made. Graphene at 1-2% by weight could be used in composites resulting in a market of hundreds of thousands to even millions of tonnes at varying grades graphene right from the cheapest to the most expensive. Graphene may replace graphite in the highest quality batteries or in biological replacement parts meaning another six or seven figure number of tonnes. It could be used in wires, flat screen monitors or within LED lights; but these markets are much smaller as only milligrams of graphene may be required per device. If a price point of approximately fifty cents a gram is achieved the market could be on the order of the entire current graphite market. At the top of the premium scale will be superconductor like materials, super strong composites and the graphene used in the electronics market. While this market will not be large in comparison to the bulk market the profit margins will be significantly higher both for the graphene manufacturer and for the mining company providing the precursor material.

What is the timeline on these markets? Early manufacturers of graphene will probably enjoy a few years of good profits before competition forces the price down. If a price of about fifty cents per gram can be achieved the time scale to this full market could be on the order of five years for application development, another five years for significant impact on the markets with saturation occurring within about a year to twenty year period wherein the market enters a mature rather than expanding phase. This is a faster development than lasers, LEDs or cell phones as this material has the potential to be disruptive to a significant portion of the materials we currently use: plastics, metals, transparent, conductors, even within the chemical industry as, for example, drug delivery materials or catalysts, plus many more wide classes of

applications.