GRAPHENE AND ESTABLISHING U.S. PREEMINENCE IN THE FIELD

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James M. Tour, Ph.D.

The NanoCarbon Center, Department of Chemistry, Department of Materials Science and Nanoengineering, Department of Computer Science

Rice University, Houston Texas

Chairman Latta, Vice Chairman Harper, Ranking Member Schakowsky and other committee members, I appreciate the opportunity to testify before the subcommittee. I am the T.T and W.F. Chao Professor of Chemistry, Professor of Computer Science and Professor of Materials Science and NanoEngineering in the NanoCarbon Center at Rice University in Houston, Texas.

Today we are here to discuss the topic of graphene. Graphene is a single-atom-thick sheet of graphite, ordered in an array of carbon atoms with a repeated hexagonal pattern. Think chicken-wire! That's what it looks like, chicken-wire, in its atomic arrangement, but on the one-atom-thick scale.

I am fortunate to personally have 625 research publications with 153 of those being on the topic of graphene. I have 41 US plus 71 international patents or pending patents specifically on the topic of graphene, ranking me as the third most prolific graphene inventor in the world. Our research on graphene has led to the formation of several nanomaterials companies for advanced composites, numerous patent suites being licensed to existing medium and large multinational companies for the manufacture and sale of graphene in electrical energy storage devices, more efficient oil and gas extraction methods, and water purification system. Our work has further led to the formation of two graphene-based nanomedicine companies for treatment of traumatic brain injury (the number one disabler of young adults), stroke (the number one disabler of older adults), and autoimmune diseases such as rheumatoid arthritis and multiple sclerosis.

At its size scale, graphene has many superlatives to its name including highest strength which is good for composites, highest mobility which means the high information transfer rate in electronic devices, the highest heat transfer rate which means that it is good at pulling excess heat of computers or machines, and the most efficient gas barriers, which means no molecules can pass through it.

But none of this comes easily when trying to apply it to a product that someone will buy. It is a misconception that a nanomaterial can merely be sprinkled like pixy-dust into a composite or device to show beneficial behavior. The transition from the laboratory to a sellable product is a huge hurdle. But again, with persistence and investment, it can be done.

Finally, from an environmental standpoint, we have shown graphene to be environmentally friendly in many respects. The oxidized forms of graphene, graphene oxide, either decomposes in water to form humic acid, which is dirt, or it is converted by safe earth-abundant reducing-bacteria to afford graphene. Graphene then agglomerates back to graphite, a naturally occurring nontoxic mineral found in products like pencils.

The worldwide market for graphene remains small; it's presently just a cottage industry. Some suggest the worldwide market a few tens of millions of dollars, but I suspect it is presently even less than that. However, its potential is enormous and it will soon capture far greater markets.[1]

There are three topics relevant to my testimony today:

1. The position of the United States as it pertains to basic graphene research and patents.
2. The transition of graphene to the marketplace so as to capture optimal value.
3. Vaulting the US to preeminence in graphene research that leads to patentable advances.

1. The position of the United States as it pertains to basic graphene research and patents.[2]

Patenting, meaning securing the long-term monetary value of this new material, has taken place at a furious pace. Uses in advanced materials is the number one patent-projected use of graphene, with chemical applications being 60% and electronics being 30% of that advanced materials market. The number of graphene patents rose exponentially during the last years 5 years. In 2015 it surpassed the cumulative patent pool of <u>ten</u> <u>related</u> main groups of technologies.

The potential monetary value of graphene intellectual property (namely patents) was greater than that of the other 10 <u>combined</u> related technology groups, when calculated based on text analytics and the number of forward citations a patent has received. That means that the country that dominates in graphene will dominate in high technology advances for decades to come. It's now a space-race!

The approximate number of patents per country is as follows:

China 8000

US 6000

Korea 4000

Japan 2000

Taiwan 1000

Europe (mainly Germany, the UK and France combined total) 1000

Of the top 20 entities that hold graphene patents in the world:

8 are foreign-owned companies (Samsung being the most prolific) vs. only 3 US companies (IBM, Baker Hughes and Lockheed-Martin)

8 are foreign universities (all in Asia, mainly Korea and China) while only 1 US university (Rice University) is in the top-twenty list. Things don't look so good for US industry or US universities on a per institution basis. Samsung (at 637) alone owns almost as many graphene patents as IBM, Baker Hughes and Lockheed-Martin combined (at 736).

Therefore, although the US at 6000 patents trails only China's 8000 patents, the US holdings are more diffuse and there are few graphene patent powerhouses in the US. In direct numbers regarding industrial strength and academic strength, as related to capturing the monetary value, the US is not doing well against Asia. Quality academic publications remains high in the US, but securing intellectual property remains low relative to China and Korea. Thankfully, the US remains far ahead of Europe.

2. The transition of graphene to the marketplace so as to capture optimal value.

Though graphene has extraordinary attributes, none of this is easily captured in scaling to bulk materials. Large-scale production is still hard. Further, in order to have graphene enhance a bulk material two things must be solved for each target application: good dispersion and good interfacial interaction between the nanomaterial and the host material. And all this has to be done while maintaining low enough cost to justify the enhanced performance. This is hard to achieve, but it can be done. For electronics grade graphene, meaning growing graphene as a layer on a metal substrate or by laser writing on polyimide plastic, there are great prospects, but target selection is essential to ensure value and performance in light of the costs.

There is a need for production in bulk for the lower skilled manufacturing jobs in this burgeoning industry, but competition with Asia in this has proven to me hard in the past. But the greatest value comes by being closest to the final customer. The bulk chemical producers' margins are usually thin, and the monetary value winners will not be the bulk graphene suppliers. As an analogy, DuPont's profit margins are much smaller than Apple's margins. Getting closest to the final customer can bring the greatest value. Incorporation of graphene into the final customer products, like smart phone displays and high capacity battery electrodes, will afford the greatest value

3. Vaulting the US to preeminence in graphene research that leads to patentable advances. The country with the best researchers and the easiest route to entrepreneurial success will succeed. US universities are way behind Asian universities in high tech equipment for nano-analysis. Asia has built enormous graphene research facilities with the world's best equipment. At Rice, I often collaborate with researchers in Asia, not for their talent, but to secure access to their equipment. In the past 8 years, the lack of funds for research equipment has severely hampered US access to new and updated facilities.

Grimmer, however, has been the dramatic loss of research funding to U.S. universities, on a per investigator basis, since the outpouring of the stimulus funds in 2009 which came so quickly that no rational spending could be manifest. The situation has become untenable. Not only are our best and brightest international students returning to their home countries upon graduation, taking our advanced technology expertise with them, but our top professors also are moving abroad in order to keep their programs funded. For the past century or more, the U.S. had been the recipient of the world's most talented students, profiting from the brain drain of other nations. Not so anymore. We are losing our best and brightest.

In 2011 and 2014 to congressional subcommittees, saying that if funding of US research did not increase, the United States would experience a brain drain like we have never known. Unfortunately, my projections have come true: we are presently in the throes a brain drain that should be frightening to Americans. Our best students are returning to Asia and even Europe to embark on research careers solely because there are so few academic positions available for them in the United States due the lack of federal research support. Equally alarming is the loss of key US-based nanotechnology faculty to the South Korea, China, Singapore and Australia. I formerly testified that university researchers are industrious folks, and the most astute among them would rather move abroad than to see their prized research programs close. This is now happening. The trolling by foreign universities upon top U.S. faculty has become rampant due to the decline of federal funding levels on a per faculty-member basis. This brain drain is not something from which we can easily recover—the impact of what has already been lost will last decades.

As university research programs shrink substantially or close down, there will be a diminishing supply of US-trained and US-national scientists and engineers. Certainly, we can hire from abroad, but that’s not so easy for some industries, such as in the aerospace sector.

My suggestion is the rapid initiation of a $200MM per year program administered over four years through the standard federal science funding agencies in $5MM to $10MM per year multi-investigator programs wherein there is strong in-kind university and corporate partner matching in dedicated facilities, equipment and personnel. That way the federal money is leveraged to produce 50% more from university development campaigns and industrial partners. Programs like NSF's Innovation Corp assist in the translations of technology to industry.

Next, keep our start-up companies in the US. My last three companies were started abroad, but if the US corporate tax rate were reduced to 15%, we'd gladly remain in the US.

Finally, streamline the Green-Card process for scientists and engineers that receive their PhDs in the US. We need them!

In summary, in the area of graphene research and capture of its intellectual property, the US is not leading, but I think we could lead with a little help from the federal government. It would be a small investment, in the scheme of things, and a major advance for the country. The loss that is unrecoverable for decades is the loss in top talent that has occurred over the past 5 years due to the declination of research support. Personally, I can survive and even thrive for the next 15 years of my career through my network of corporate connections that I have established over the decades. But that cannot be said for the younger and less established researchers in this country. On their behalf, I respectfully urge our congressional leaders to take a long-term vision to reestablish funding to the per-investigator level that we enjoyed 20 years ago and provide the yearly additions needed to keep pace with inflation costs. If our congressional leaders would do that, we'd present strong completion to Asia and we'd win. Please, help us.

References

1. 1.Partridge, M. “The miracle material that could change the world,” *Money Week*, 27 January, 2017, Issue 829, pp 24-26.
2. Seven Sigma Innovation, “Graphene patent and technology landscape analysis. Making sense of an industry disrupting material,” 2016.