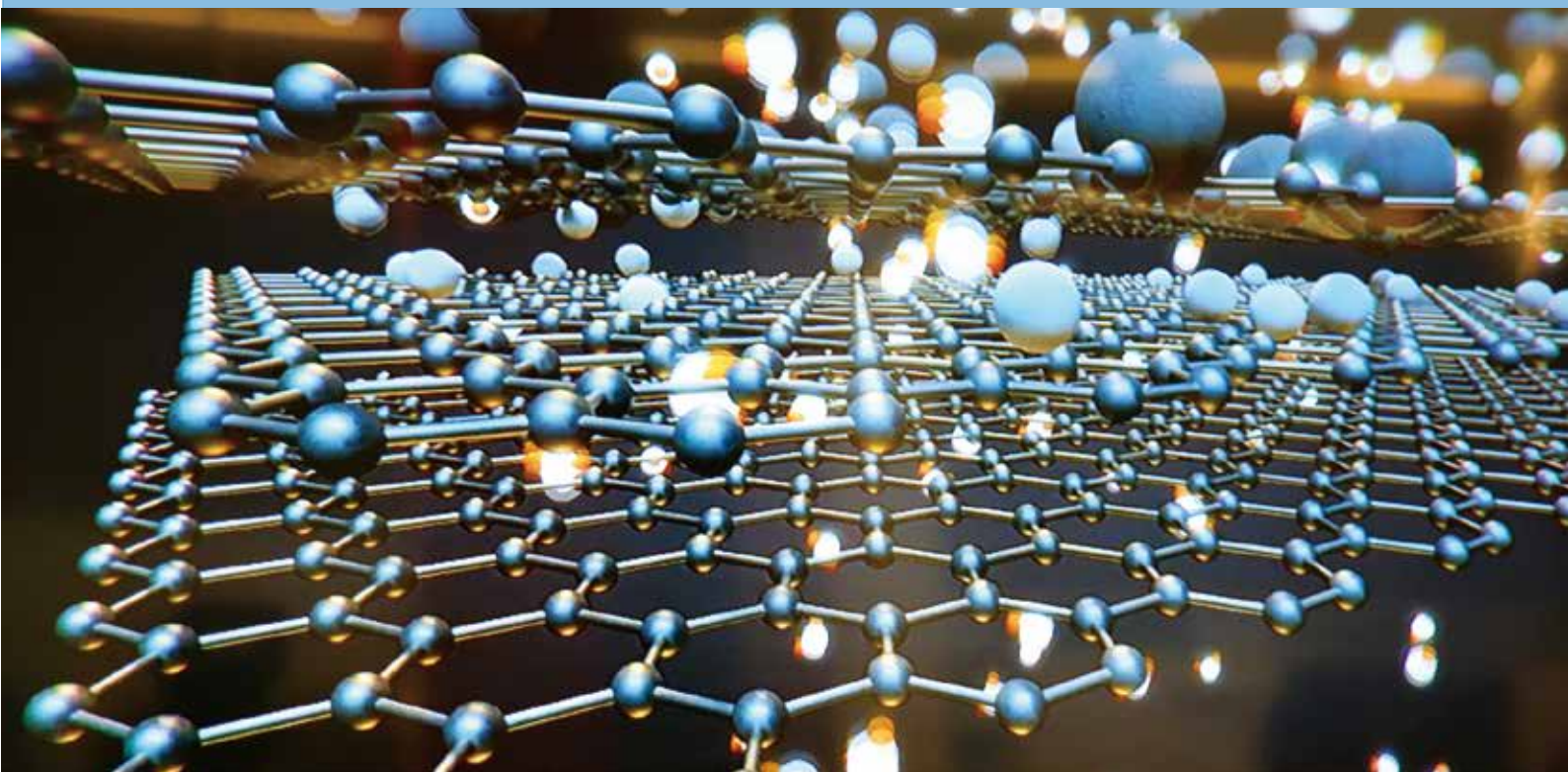


Key Challenges to China's Graphene Industry and Recommended Strategies to Tackle Them¹

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Abstract: Upon reviewing the key issues of China's graphene industry and analyzing the major obstacles to its sound development, this article presents the following coping strategies: 1) speed up the building of a national innovation center for the graphene industry; 2) establish a nation-level graphene industry alliance; 3) focus on the bottleneck technologies of graphene materials production, increase support and cultivate core competitiveness; 4) give full play to the advantages of our social system, strengthen the top-level design and rational planning, and promote the differentiating, specializing and clustering development process; and 5) foster an ecosystem that stimulates innovation, and establish an industry-education-research collaborative innovation system appropriate for China's domestic conditions.



An illustration of graphene, a sheet of carbon atoms formed in hexagonal shapes. (Image by seagull from Pixabay).

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Emerging as one of the strategic materials that will lead a new round of global high-tech competition and industrial transformation, graphene is highly valued by countries/organizations worldwide. In 2013, the European Union (EU) launched a 10-year project called “the Graphene Flagship”. The UK has established the National Graphene Institute (NGI) and the National Graphene Engineering Innovation Center (GEIC), striving to build its leading position. The United States, Japan, South Korea and Singapore have respectively formulated special plans to compete for the next trillion-scale newly emerged

industry. With the world’s largest basic research and industrial forces of graphene, China is at the forefront in the field. Still, it faces many challenges, including a lack of strategic layout, insufficient momentum in its driving locomotive, a weak industrial foundation, and a scattered innovation system. Facing a significant historical opportunity, the graphene industry is at a critical juncture. Therefore, we recommend swiftly mapping out a proper top-level design in line with the nation’s interests, giving full play to our institutional advantages of making long-term plans and converging our efforts on major tasks.

I. Advances of the Global Graphene Industry and Where China Stands

The graphene industry is now at a booming stage. Many relevant research advances have been put into industrial scale-up exploration, which has sent demonstrative graphene products to the market. Europe is the birthplace of graphene and the first region to lay out a plan for the graphene industry. Integrating industry-education-research resources through the Graphene Flagship, Europe has taken an internationally leading position in the research and development (R&D) of cutting-edge graphene technologies. It is followed by the United States and South Korea, whose features and strengths are the deep involvement of organizations and big corporations, such as NASA, IBM, and Samsung. Countries like Japan, Australia, and Singapore have also been working on cutting-edge graphene technologies for a long time.

China is one of the most active countries in the research and application development of new graphene materials. It started early in related basic research and has essentially kept pace with the world. Since 2011, the number of academic papers published by Chinese scholars has steadily topped the global ranking. By March 2020, Chinese scholars had published 101,913 academic articles, accounting for 33.2% of the world total, and frequently published original studies in top academic journals such as *Nature* serial and *Science*. China takes the lead in producing high-quality

graphene materials. Its representative studies include large-scale preparation of single-crystal graphene wafers, wrinkle-free ultra-flat graphene film growth technology, ultra-clean graphene and super graphene glass. Breakthroughs in graphene application research include graphene optical fibers, graphene composite nanofiltration membranes, graphene oxide membranes for seawater desalination and surface phononic graphene.

China pays the same amount of attention to the graphene industry as advanced countries and has the world’s most enormous scale of graphene enterprises. By February 2020, China’s total number of graphene enterprises reached 12,090, leading the world in the massive production of graphene materials. In 2018, China’s annual production capacity of graphene powder amounted to 5,100 tons, and its annual production capacity of chemical vapor deposition (CVD) membranes totaled 6.5 million square meters. By the end of 2018, the total number of graphene-related patents applied by China reached 47,397, accounting for 68.4% of the global total. After nearly ten years of rapid development, China’s graphene industry has spread across many provinces, having initially formed a spatial distribution pattern of “one core, two belts, and multiple sites”. As the “one core”, Beijing has gathered R&D forces for graphene core technologies. As one of the “two belts,” the eastern

coastal area has obtained first-mover advantages, and talents and market advantages. The Heilongjiang-Inner Mongolia area, as the other “belt”, is committed to giving full play to the edges of its graphite mineral resources. The “multiple sites” refer to places such as Chongqing, Sichuan, and Shaanxi that are scattered but have unique characteristics and advantages.

Overall, the development of China’s graphene industry is not on the same channel as developed countries/regions such as Europe, the United States, and Japan. China focuses on today’s graphene product market, while other countries center on high-end application research and development oriented to the future market.

II. Key Issues of China’s Graphene Industry

2.1 Severe low-level homogeneous competition and lack of overall layout as well as top-level design

By March 2020, China had established 29 graphene industrial parks, 54 graphene research institutes, and eight graphene innovation centers. However, most of the projects have not undergone rigorous scientific verification, and many of them are simply repeated constructions. Due to technology and market reasons, nearly 80% of the downstream products are concentrated in areas such as electric heating, public healthcare, anti-corrosion coatings and conductive additives, which are featured with low technical thresholds and serious homogeneous competition. China’s graphene industry is in a state of disorderly development, lacking overall coordination and long-term planning at the national level. In particular, China’s investment in graphene frontiers and revolutionary technologies noticeably lags behind developed countries.

2.2 Insufficient driving power, dominance by small/micro businesses, and limited ability in sustainable development

Most domestic enterprises engaged in graphene production and application development are small/micro start-ups. Due to their limited comprehensive strength, they often focus their attention on short-term application products featuring small input and fast payback. Their insufficient wherewithal causes a lack of core competitiveness and sustainable development capabilities. Unlike developed countries, the powerful

enterprises in China, particularly the state-owned key enterprises, are hardly involved in the game. In addition, China’s overall foundation in the high-tech industry is relatively weak, especially regarding the technical division and industrial support, which is significantly different from that of foreign countries. This scenario compels small/micro enterprises to have a relatively complete set of functions of their own, which seriously keeps them from leveraging their unique advantages and competitiveness in the long term.

2.3 Scattered innovation systems and insufficient fusion among industry, education and research sectors

China has the world’s largest graphene research force and the most active industrial participants, but a good synergy between the two is still missing. Resulting from the current performance evaluation mechanism, universities and research institutes are often oriented towards publishing papers rather than actual market demands. As a result, their research output is hard to find its place in the market. In addition, most enterprises are eager for quick rewards, ignoring R&D of core technologies, and therefore lack core competitiveness. Graphene has attracted growing attention from the capital market as a star new material. Many listed companies and investment institutions are enthusiastic about getting involved in the graphene industry. However, these elements of innovation are fighting as lone wolves, without interplays with each other, and yet to form a joint force; also, the industry-education-research pipeline needs further improvement.

III. Coping strategies

3.1 Make rapid moves to construct national graphene innovation centers, to integrate the relevant innovation resources across the country

The time is ripe for establishing national innovation centers for the graphene industry. It is imperative to build national teams to lead and serve the national graphene industrial innovation. The innovation centers should integrate the backbone enterprises and research teams representing the highest level of China's graphene research, high-tech R&D, and industrial application. At the same time, it shall attract social capital and engage leading central enterprises, state-owned enterprises and private enterprises to jointly build China's graphene flagship.

3.2 Forge a national graphene industry alliance and construct graphene's standard system

There are as many as 12 graphene industry alliances in China. They are competing against each other, uttering confusion, and lacking authority and professionalism, which further aggravates the chaotic development of China's graphene industry and affects the country's global reputation in this field.

Therefore, we suggest setting up a "National Graphene Industry Alliance" endorsed by the authorities so that it can truly represent the country and end the current chaotic situation. The alliance can take charge of the overall layout, and spur the formulation of a standardization system of the country, including national, industrial and association standards for graphene materials and products.

In particular, the alliance shall swiftly improve the standards for the definition, testing, and application of related products in the downstream application fields, including electric heating, public healthcare products, anti-corrosion coatings, battery conductive additives, graphene composite materials, etc. It is necessary to accelerate graphene research, formulate entry standards, and regulate different aspects of the industry, from the overall layout, production processes and equipment, environmental protection, to quality management,

etc., so that graphene applications and products have standards and norms to follow. We also recommend strengthening international exchange and cooperation, actively participating in the formulation of international standards, and ensuring that the domestic graphene standard system is in line with the international one.

3.3 Focus on crucial technologies, increase support and cultivate core competitiveness

Graphene materials are the cornerstone and the "bottleneck" of China's graphene industry. Currently, China ranks first in the world for the production capacity of graphene materials and shows even a risk of overcapacity. However, due to unsatisfactory technologies and unstable production processes, there are many problems and even a crisis of trust in the current domestic graphene industry. Therefore, it is necessary to integrate resources, increase investment, and commit to long-lasting hard work to break through core technologies for graphene material production.

At the same time, China should actively plan and explore graphene's "trump" applications instead of focusing only on its "seasoning" functions that receive effect instantly. The true sense of newly emerged strategic materials manifests in two ways. One is to create a new industry; the other is to bring a transformative leap to the existing industry. And graphene materials have both. We recommend setting up a special national program for graphene, which will be coordinated by the "National Graphene Industry Innovation Center" to secure the development following a proper overall layout to the nation's interests and build the core competitiveness of the graphene industry in the future.

3.4 Give full play to institutional advantages and strengthen top-level design

The characteristics of graphene materials determine that the industry's development must be a long-lasting arduous practice. Therefore, it is necessary to do an excellent job in strategic and overall planning and design, which is exactly a field where China can

demonstrate its institutional advantage. In the temporal dimension, China should formulate a development roadmap for the graphene industry and steadily promote its sustainable development through five-year, ten-year, and twenty-year plans. It is necessary to unify the critical research directions of graphene with the strategy of building China into a manufacturing power and focus on the development needs in many vital fields, such as new-generation information technology, aerospace equipment, energy-saving new energy vehicles, and biomedicine. Regarding the spatial dimension, China should make the national graphene industry layout scientifically and rationally, promote its differentiated, characteristic, and clustered development, and avoid low-level, repetitive construction and vicious competition.

3.5 Release policy dividends and cultivate innovation ecology

The graphene industry is a rapidly expanding high-tech industry that needs timely and practical policy

guidance. Therefore, it is important to maximize the release of policy dividends and create an innovative cultural environment and high-tech R&D ecology. The core factors for developing high-tech industries are talents who can innovate and master core technologies. To what extent the nation can motivate these talented people to practice their creativity determines the core competitiveness of the future graphene industry. However, the current performance evaluation and assessment of talents, as well as S&T achievements, discourage our researchers from pursuing technology transfer. China has successively introduced new talent and S&T evaluation policies, and such reform is believed to bring new development impetus to the graphene industry. We suggest more intensive support be given to institutional explorations aimed at coordinated industry-education-research innovation. There has been a lot of exploration and practice in various provinces. It is imperative to establish a coordinated innovation system that suits the nation to integrate industry-education-research resources based on experience exchanges and buildup.