IOP Institute of Physics

Submission to the House of Commons Science and Technology Select Committee inquiry into graphene

Introduction

1. The Institute of Physics (IOP) is a leading scientific society. We are a charitable organisation with a worldwide membership of more than 50,000, working together to advance physics education, research and application. We engage with policymakers and the general public to develop awareness and understanding of the value of physics and, through IOP Publishing, we are world leaders in professional scientific communications.

2. The IOP welcomes the opportunity to respond to the Committee's inquiry into graphene. Graphene is a success story for UK research and for UK physics in particular. Graphene has opened a new field of 2D material research in which the UK now has first adopter advantages. The range of potential applications to which graphene and other 2D materials can be put to use is vast and growing by the day. In this context, the Government's initial investment in graphene research and commercialisation is very welcome. But this investment, as with wider investment through the science budget, needs to be sustained in order for this advantage to be realised. The UK's advantage in graphene should not be squandered, and may yet reveal greater discoveries and opportunities.

The research obstacles that have had to be overcome for graphene, including identifying research priorities and securing research funding, and the lessons from this for other areas of research.

3. Investment in any novel and developing area of scientific research requires patience. Results and more significantly innovations take time, and this requires sustained funding over a long period of time. Science funding in the UK has been ring-fenced first in cash terms (2010-2015) and now in real terms, although additional areas of investment have been brought inside the ring fence[1]. This combined with the maintenance of the dual funding system – QR (quality related) funding and the research council block grant – has given researchers the freedom to explore new areas of research.

4. Graphene's discovery in 2004 was made in a period of relatively lower government science spending than is made today.[2] But the freedom afforded by the research funding structure allowed researchers to explore new ideas and then to develop

[1] In particular, the science budget from 2016-2020 will include the Global Challenges Research Fund which acts as a contribution to the UK's official development assistance (ODA)

[2] Office for National Statistics - *UK Government Expenditure on Science, Engineering and Technology: 2013* (2013): http://www.ons.gov.uk/economy/governmentpublicsectorandtaxes/researchanddevelopmentexpenditure/bulletins/ukgovernmentexpenditureonscienceengineeringandtechnology/2015-07-17

them. Just as important is that investment has been available for the full innovation cycle. Graphene is very much a product of curiosity-driven research, supported by the research councils, but innovation-focused investment will see it being driven through the innovation cycle towards specific, applied, end-results, in the first graphene-based products. Investment in physics research in particular has been essential to graphene's development, as physics departments including (but not limited to) Manchester, Cambridge and Exeter are taking forward new developments. The flexibility provided by the dual funding system, and the separation between the different types of funding, should be maintained in any future reform of the higher education and research architecture to ensure that graphene and similar developments have the best chance of success.

5. Further, facilities such as the National Graphene Institute (NGI) in Manchester should be treated as true national facilities, and should be funded as such to ensure that the whole community benefits from them. It is important for the success of this investment that this commitment to capital spending on graphene is met with effective resource to ensure that these facilities can be used to their full potential. As the committee noted in its 2015 report, large research facilities in the UK often struggle to run at full capacity.[3] This means that they are not able to be used as efficiently as they could be, and that important research that might be happening is not.

6. Similarly, the process by which decisions on where future large capital investments are made should ensure that they can be used most effectively by researchers. Decisions on investment should be as transparent as possible and occur with as much consultation with the research community as possible. The National Audit Office made similar recommendations in its review of the Department for Business, Innovation and Skills' capital investment in science projects in March 2016.[4]

The factors that have contributed to the successful development of graphene and how these might be applied in other areas, including translating research into innovation, managing/sharing intellectual property, securing development funding, and bringing key stakeholders together.

7. It should be noted that graphene is one of a long line of scientific discoveries made in the UK for which there have been perceived and actual challenges in pursuing commercialisation. The lessons learnt by companies, universities, governments and funding agencies from these experiences, for example the development of plastic electronics – the subject of an inquiry by a previous committee[5] – are being put in to practice with graphene.

[3] House of Commons Science and Technology Select Committee - *The science budget: First Report of Session 2015–16* (2015): http://www.publications.parliament.uk/pa/cm201516/cmselect/cmsctech/340/340.pdf
[4] National Audit Office - *BIS's capital investment in science projects* (2016): http://www.nao.org.uk/work-in-progress/department-for-business-innovation-and-skills-capital-investment-into-science-infrastructure-facilities/
[5] House of Commons Innovation, Universities and Skills Committee - *Engineering: turning ideas into reality* (2009) http://www.publications.parliament.uk/pa/cm200809/cmselect/cmdius/50/50i.pdf

8. The Institute of Physics produced a report in 2014 on the commercialisation of graphene[6] which put forward a number of recommendations, including on investment. These recommendations are still very much relevant today, and included the need to:

    a. Continue funding blue-sky research to ensure that the UK continues to excel at research and allows for new, potentially game-changing, discoveries to spring from the country, upholding it as a global leader in science research.

    b. Have a long-term plan including continued investment by government and formation of a strategy that will support the industry and not remove financial support while the technological development is still in its infancy so that the graphene industry can reach its potential.

9. As noted above, the first of these is central to the Government's stated aims in science. On the second of these recommendations, the Government has shown welcome commitment to graphene as a new and promising area of research developed in the UK. The Government announced in 2011 funding for a 'Graphene Global Research and Technology Hub'.[7] This resulted in capital investment of £50m towards commercialising graphene, including £38m going to the creation of the NGI at the University of Manchester, which opened in 2015. Further investment was made in Exeter and Cambridge. However, beyond this initial investment there is an absence of plans for *continued* investment by government or a long-term strategy to actively support commercialisation. The European Union, for example, has provided £10bn of funding for a "Graphene Flagship" project, launched in 2013, which aims to "to take graphene from the realm of academic laboratories into European society in the space of 10 years".[8]

10. The Government's initial investment does, however, open up myriad opportunities for researchers to work on efforts at moving graphene research from studying properties to exploring applications. The promise that graphene has shown also allowed Manchester to successfully bid for £23m from the European Regional Development Fund to further support the development of the NGI. The University of Cambridge has opened the £30m Cambridge Graphene Centre and Manchester has received funding from investors in Abu Dhabi for the £60m Graphene Engineering Innovation Centre (GEIC) which will focus on applied graphene research. This investment is intended to create a set of academic hubs which in turn will attract business partners to collaborate on new avenues and opportunities for the application of graphene, and in the NGI and elsewhere there are increasing numbers of national and international partners, and spinouts and start-ups working in close proximity to and in collaboration

[6] Institute of Physics (IOP) - *Graphene: Applications and future uses* (2014): http://www.iop.org/publications/iop/2014/file_63330.pdf

[7] Department for Business, Innovation and Skills - *Innovation and Research Strategy for Growth* (2011): https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/32450/11-1387-innovation-and-research-strategy-for-growth.pdf

[8] European Union – *Graphene Flagship*: http://graphene-flagship.eu/

with university-based researchers.

11. While it is true that the UK has lower level of registered intellectual property in graphene research, the UK research environment may have advantages over those countries which have currently registered more patents. The UK environment is more collaborative than other environments where competition to develop patents quickly is a driving factor. There are geographical hubs of graphene research, particularly in the universities of Manchester, Cambridge and Lancaster, and these universities have been working with one another since graphene's discovery in 2004. There are more than 25 research groups in the UK studying graphene, its derivatives, properties, and developing graphene-based technologies. In addition to the above, research is going on in the universities of Leeds, Ulster, Southampton, Exeter, York and Bath, as well as at the National Physical Laboratory.

The benefits and disbenefits of the way that graphene's intellectual property and commercialisation has been managed, including through research and innovation collaborations, and the lessons from this for other areas.

12. Graphene is frequently referred to as a 'wonder material'[9,10,11] and presents a huge range of potential possibilities and applications for future new and improved technologies. The graphene story has a strong connection to the UK and its discovery led to Nobel Prizes for two UK-based researchers, Andre Geim and Konstantin Novoselev. Given all this, it is perhaps unsurprising that media and public interest in graphene has been and continues to be very high. Graphene, perhaps on name recognition alone, has even been the basis of potential investment fraud scams.[12] This interest has led to very high expectations about the rate at which the public expect to see new innovations based on graphene technology. Related to this expectation, particularly in the UK, there have been frequent reports that graphene is not leading to many examples of either patents or applications.[13] The UK is frequently compared to countries such as China and South Korea in the degree to which it is applying to register graphene-related patents. Since 2010, China has been responsible for around 50% of all worldwide patent applications.[14] In 2014, the UK had registered 57 patents compared to 2200 in China, 1700 in the United States and 1200 in South Korea.[15]

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[9] European Parliament - *Graphene: the wonder material of the 21st century* (2015): http://www.europarl.europa.eu/news/en/news-room/20150603STO62104/Graphene-the-wonder-material-of-the-21st-century

[10] Business Insider - *5 Applications For Graphene, The 'Wonder Material,' That Could Change The Way We Live* (2014): http://www.businessinsider.com/graphene-applications-2014-6?IR=T

[11] Science Alert -*Wonder material graphene has been turned into a superconductor* (2016): http://www.sciencealert.com/wonder-material-graphene-has-been-turned-into-a-superconductor

[12] Metropolitan Police - *Graphene Investment Fraud*: http://content.met.police.uk/Article/Graphene-Investment-Fraud/1400021487259/1400021487259

[13] Financial Times – *UK appears behind in race to develop graphene* (2014): https://next.ft.com/content/7d4ce33a-dc56-11e3-9016-00144feabdc0

[14] Intellectual Property Office (IPO) – *Graphene: The worldwide patent landscape in 2015* (2015): https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/470918/Graphene_-_the_worldwide_patent_landscape_in_2015.pdf

[15] IOP, 2014

13. However, although the UK is certainly behind many economic rivals in terms of the speed in which it has registered graphene patents, the figures above do not necessarily mean that the UK is not in a strong position to take advantage of graphene research in the UK and beyond. And the hype that surrounds graphene, as with any new area of research, has often failed to appreciate the context and challenges in how the commercialisation of new technology, including the need to develop absorptive capacity and the stages of technological development required to bring anything to market.

14. These challenges are not specific to research in graphene, and are relevant to the business and research environment more generally, in the UK and elsewhere. Commercialisation is a developmental process and one which takes significant steps over a prolonged period of time. For example, although Samsung in South Korea has topped the patent leader board internationally for many years[16] there have been few commercial products developed by the company as yet[17], and it is worth noting that "patent applications do not automatically correspond to actual inventions and products".[18] For commercial applications to be viable there need to be markets for products. The extent to which the introduction of these products has to come first, and the responsibilities of governments and companies to create infrastructure, are a constant source of policy debate (see for example the development of electric cars). It is perhaps unsurprising then that so far most examples of commercialised graphene are being employed in existing products and technologies (for example tennis rackets[19], bike tyres[20] and light bulbs[21]) with existing and well-established markets.

15. The UK research system, particularly in relation to graphene, is characterised by more collaboration between research hubs than many of the countries pulling ahead in the patent research race.[22] This has meant that although there has perhaps been less pressure to patent research and applications as soon as possible, the UK environment is better suited to longer-term and sustainable developments in graphene. In the UK system, ideas are more likely to be shared and researchers look for opportunities, and are incentivised, to work with one another across universities and research institutes. This allows for better concentration of resources, and more effective development of those ideas and products which present the most promise.

16. On a systemic level, the UK does have further challenges when it comes to commercialising graphene due to a weaker "industrial backbone" which needs to be

[16] IPO, 2015
[17] Extreme Tech - *Samsung's graphene breakthrough could finally put the wonder material into real-world devices* (2014): http://www.extremetech.com/extreme/179874-samsungs-graphene-breakthrough-could-finally-put-the-wonder-material-into-real-world-devices
[18] IOP, 2014
[19] HEAD – *Graphenext*: http://www.head.com/en/sports/tennis/technology/graphene-xt/
[20] Vittoria – *Road tyres (graphene)*: https://www.vittoria.com/tires/road-tire/?graphene=1
[21] University of Manchester – *Graphene's lightbulb moment* (2015): http://www.manchester.ac.uk/discover/news/graphenes-lightbulb-moment
[22] IOP, 2014

developed.[23] The comparatively low levels of business research and development (BERD) investment in the UK, around 1.06% compared to an EU average of 1.28%[24], and the need to develop absorptive capacity are acknowledged challenges for any new and quickly developing area of research. The UK's more collaborative research culture, particularly in graphene, could be crucial to the development of markets for wider graphene products by helping build them 'from the ground up'. However, it may mean that UK companies are initially slower to take advantage of the investment the Government has made in graphene research, such as the NGI in Manchester, and in the short term benefits may be weighted more heavily towards companies from international competitors with larger domestic R&D capabilities.

17. Finally, any new technology also has to move through different stages or 'Technology Readiness Levels' (TRLs), moving from a basic understanding of the principles of the technology through to demonstrations of that technology in actual environments.[25] Graphene as a material is barely a decade old, and so many avenues of research are still in their infancy. The IOP's 2014 report included a further recommendation, which while emphasising the wide range of possibilities that graphene presents, suggested the need for more realism in the way that graphene is treated and communicated. It concluded that there should be "greater communication of real possibilities of graphene and 2D materials … to explain the realistic potential applications to show government and business that there are reasons to invest in graphene".[26]

For further information, please contact
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[23] IOP, 2014
[24] Eurostat figures
[25] Horizon 2020 – *Technology Readiness Levels:*
http://ec.europa.eu/research/participants/data/ref/h2020/wp/2014_2015/annexes/h2020-wp1415-annex-g-trl_en.pdf
[26] IOP, 2014