European Commission

Business Innovation Observatory

Advanced Materials

The graphene revolution

Case study 55

Internal Market, Industry, Entrepreneurship and SMEs

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Advanced Materials

The graphene revolution

Business Innovation Observatory
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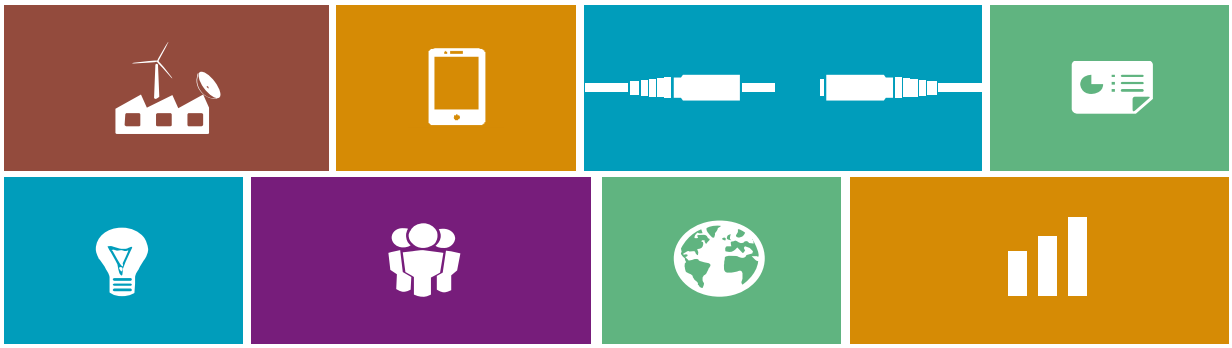


1. Executive summary

Advancements in technology are an important driver of disruptive innovation and economic growth, and the recent isolation of a new two dimensional carbon-based honeycomb lattice product called **graphene** has generated enormous interest and media hype. Research suggests that this newly discovered material is the **strongest**, **most impermeable** and **conductive** material known to man.

These unique properties have immediate market applications by incorporating it into existing products to enhance their strength, electric or thermal conductivity. But it is also hoped that research in the nanomaterial will help revolutionise fields such as electronics, energy storage, lightweight composite materials, or even biotechnology and medicine. Graphene's incredible potential might help it to become to the 21st century, what plastics were to the 20th.

Today, graphene's development is still more **focussed on research and development**, along with **product development**. Graphene will become increasingly used as a component, and then eventually progress towards being incorporated into entire systems further down the line. But with time market focus will shift from research towards industry. An overall EUR 2.2 billion has been so far invested into research efforts and 7,740 patents filed between 2008 and 2012, and today the annual market for graphene in R&D and in product development is estimated at around EUR 12.7 million[1].

The companies presented in this case study are successful on the market thanks to their early capitalising on the discovery of this new material. They cater, or have catered at one time, to the needs of research and partnered with industrial players to incorporate graphene into existing products, or to help to develop new ones. Some companies focus on the synthesis of pristine graphene to be provided to clients early along the value chain. Some produce their own graphene-based product as a result of their expertise in graphene synthesis, while others aim to complement their graphene synthesis by providing advisory services on incorporation of graphene throughout the value chain.

The graphene market is currently driven by a large amount of visibility and hype. This has helped support investment, and to keep up with ever increasing demand for energy, which is due to a rising need for energy storage and release. The technology is however not yet fully mature, and so there is much more research required before graphene can be mass produced. Ultimately the potential of the technology to impact so many different markets limits any particular focus, diluting market uptake.

Several policies could be enacted in order to support this trend in Europe. First, specific solutions should be sought to facilitate compliance with the REACH Regulation. Second, standards could be established for graphene as a material, along with accepted health and safety guidelines and procedures for life cycle analyses. Third, access to research facilities and infrastructure could also be made easier for innovative SMEs. Fourth, coordination initiatives between different public support programmes at the national or regional level could be better supported. Finally and crucially, **investment into fundamental research in nanomaterials should continue** as it provides the basis for the future graphene revolution.

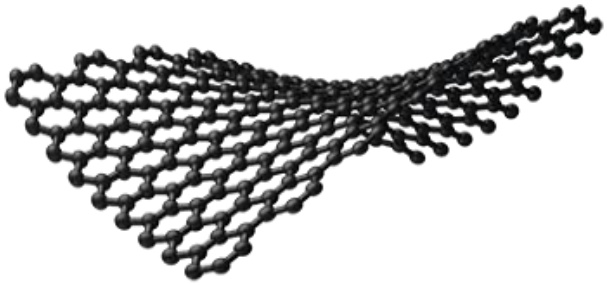
2. The graphene revolution

2.1. Presentation of the trend

Technological advancements in the production and quality of basic materials are a well-known driver of disruptive innovation and growth, particularly new advanced materials. Developments in the material sciences offer new growth prospects arising from new industrial and commercial products and processes. Within the context of this trend, this case study will present the potential for growth arising from the recently discovered material called **graphene**.

Graphene is a two-dimensional, atomic-scale honeycomb lattice formed solely of carbon atoms where one atom forms every vertex (Figure 1). This single-atom thick, but indefinitely wide, aromatic molecule was first isolated and studied in laboratory conditions in 2003 by Geim and Novoselov[2]. Graphene is considered to be the strongest, most impermeable and conductive material known to man and is widely being touted as the material that will become to the 21st century, what plastics were to the 20th.

Figure 1: Graphical representation of the molecular structure of a single layer of graphene



Source: Graphene Flagship[3]

This newly discovered material has garnered huge interest because of its multiple unique properties. To begin with, research has shown that graphene is a **very strong conductor of electricity**. The electronic mobility of graphene is very high, albeit this is dictated by the quality of the graphene and the substrate. It has ten times the conductivity of copper and aluminium and an electrical resistance 35% smaller than copper[4].

Additionally, as a result of its molecular structure and the bonding arrangements between the carbon atoms, graphene is the **strongest material ever discovered**. It benefits from an ultimate tensile strength of $130x10^9$ Pascals and is stronger than Aramid (the material used in Kevlar) or A36 structural steel[5].

Despite being a single atom thick, graphene has the surprising ability of having a **high opacity**, being capable of absorbing a large amount of white light. Thisgives it potential applications in photovoltaics for example. Adding more layers of graphene steadily increases this opacity[6].

Graphene has a huge **variety of potential market applications.** Its electronic conductivity properties makes it ideal as a component in electrical circuitry and it could be used to create ultra-fast electronic transistors, foldable touch screen displays (Figure 2) and light-emitting diodes as well as help increase the efficiency of batteries. Its optical properties give it the potential to have applications in photovoltaic cells, while the material's mechanical properties have garnered interest of the aviation industry given its potential to both strengthen and reduce the weight of aircraft wings. The technology also has the potential to revolutionise the health sector e.g. tissue engineering or drug delivery.

Figure 2: Graphene-based bendable touch screens

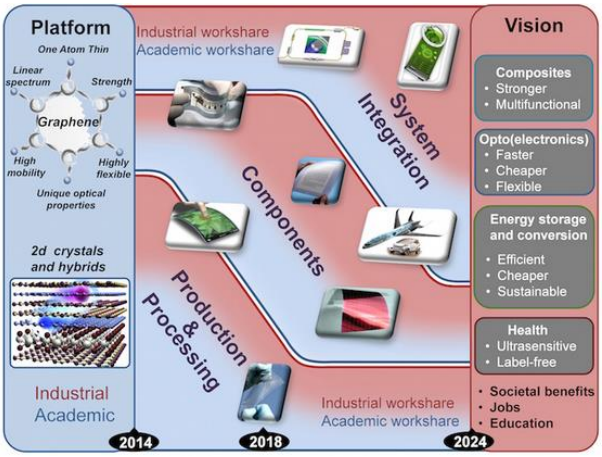
Source: Nature[7]

The graphene market is still in its nascent stage and **heavily R&D oriented**. Recently, the European Research Council (ERC) granted EUR 1 billion investment for the Future and Emerging Technologies (FET) Graphene Flagship project, the largest-ever research initiative in the history of the EU.

There are still several challenges to overcome before large-scale manufacturing of graphene can be achieved. While at the moment most companies involved in the technology are more focussed on R&D, the material stands to become prevalent in industrial applications once mass-produced graphene achieves the same level of performance as samples obtained in research laboratories.

Some companies have already started to offer cost effective means to produce graphene, while others are even offering graphene-based components, while some have developed graphene-integrated products.

Figure 3: European roadmap for graphene science and technology



Source: Graphene Flagship Roadmap[8]

Given that the technology readiness level of graphene is still relatively low and the market is in its early stages according to the technology roadmap (Figure 3), the majority of the companies in the graphene market cater to the academic field, with an objective of catering towards industrial clients as the market develops.

2.2. Overview of the innovative companies capitalising on this trend

Table 1: Overview of the company cases referred to in this case study

Company	Location	Business innovation	Signals of success
Graphenea	Spain	Graphenea has developed leading synthesis and transfer processes to obtain high uniformity monolayer graphene films on any substrate.	- Multiple publications in peer reviewed journals and mainstream media - Named in the 2014 Global Cleantech 100's Ones to Watch List - Media coverage
Graphensic	Sweden	Graphensic supplies epitaxial graphene on silicon carbide. These products are manufactured using their patent-pending "High Temperature Graphene Process", resulting in high quality products for commercial use.	- Associate member of the Graphene Flagship Initiative - Multiple mentions in the national press - Multiple publications in peer reviewed journals and mainstream media.
Directa Plus	Italy	Directa Plus is engaged in the development and marketing of innovative manufacturing processes for the production of a new generation of nanomaterials.	- Identified in 2013 as a top 10 Cleantech SME in Italy by the Cleantech Group - Recently opened its Graphene Factory: one of the largest European pristine graphene nanoplatelets production units - Best Commercialization Award 2015 gained for the revolutionary graphene-based cycling wheel. - Selected amongst the top 5 best eco-innovation projects 2015 by European Commission's GEnluS project (Graphene Eco Innovative Sorbent).
Cambridge Nanosystems	United Kingdom	Cambridge Nanosystems is a spin out of the University of Cambridge. The company has developed means of synthesising pristine graphene through a novel and proprietary production method based on microwave plasma. The company also provides consultancy services on graphene to its partners throughout the value chain.	- Coverage in the British and International media - Opened a factory in the UK to produce their pure graphene - Hosted the 3rd Nano-Carbon Enhanced Materials Consortium on 9 June 2015 - Won the 2015 Business Innovation Award

Problem 1 – Many industrial consumers of graphene are industrial players which require graphene of good quality, but also scalable to meet their requirements for product development.

Innovative solution 1 – Graphenea is a Spanish company that was founded in 2010 and is the current market leader in the synthesis of graphene products for large multinational companies and research groups performing R&D and product development.

While most graphene on the market is provided as graphite, the company's innovative solution to meet the industry's needs is that it provides superior quality graphene that is synthesised as graphene oxide or via chemical vapour deposition. This is of superior quality to what is normally available on the market. In addition, the graphene it produces for consumers can be scaled up to meet the needs of industry which requires graphene in larger amounts for product development than what graphene producers generally produce for the R&D market.

One of the many products offered by Graphenea to supply to the R&D and product development efforts of large multinationals and research groups

Source: Graphenea[9]

Problem 2 – The measurement of resistance standards is an important requirement for resistance standards institutes worldwide. However, the equipment used to do this is cumbersome and requires logistic efforts that make moving it to testing sites lengthy and costly.

Innovative solution 2 – Graphensic, a young start-up based in Linkoping in Sweden has recently put on the market a new portable resistance standards kit. The company arose out of a research initiative at the local university and initially catered to the growing demand for graphene products used in research.

Capitalising on the superior electronic properties of graphene, the company has recently announced their first graphene-based product; a graphene-based resistance standard measurement kit, the GRS. The GRS is a portable resistance standards measurement kit, being of the size of a luggage bag. Its size greatly facilitates performing the resistance standards testing.

Graphensic's portable resistance standard kit is smaller and easier to transport than conventional resistance standards kits

Source: Graphensic[10]

Problem 3 – The graphene market is currently restrained by the limited global capacity of production. The growing demand for this material can only be partially met because graphene cannot be yet mass produced. In addition, different end-consumers have different needs, which requires flexible means to synthesise the material.

Innovative solution 3 – Directa Plus is a technological company specialised in the production of highly engineered graphene based materials, unique in quality and quantity, targeting existing markets and able to meet at any time, thanks to its modular and replicable technology, the large and growing demand for advanced graphene materials.

In 2014 the company built one of the largest European factories for graphene production to be able to meet its partners' specific needs. The production process is simple, scalable and continuous. Using a raw material that is abundant, low cost, eco-friendly, safe, and non-toxic, the company has achieved a production capacity of 30 tonnes per year, with expansion plan up to 300 tonnes per year (the largest in Europe).

In 2014 the company opened its industrial plant to produce four types of graphene-based material, each with its own specific applications and markets[11].

Source: Directa Plus[12]

Problem 4 – The vast majority of graphene is synthesised through graphite exfoliation. This process has some important drawbacks as the use of additives results in an end product that contains impurities.

Innovative solution 4 – Cambridge Nanosystems is a UK spinoff out of the University of Cambridge that has developed a means of synthesising pristine graphene through a novel and proprietary production method based on microwave plasma.

The final product has no additive, catalyst or metal impurities. This method gives a majority of single layer flakes of very high crystallinity and is able to deliver on a commercial scale to the company's industrial partners. The main innovation is based on the fact that the company is capable of synthesising pure graphene without any additives or contaminants. In addition this method reduces methane's emission given its important greenhouse potential.

CamGraph G1 is Cambridge Nanosystem's nanoplatelets product and extremely good nanofiller suitable for electronic inks, polymer, metal composites and coatings.

Source: Cambridge Nanosystems[13]

3. Impact of the trend

Because of its unique properties and potential applications in multiple sectors of the European economy, the potential impact of graphene cannot be underestimated. Together with the increase of its technology readiness level, graphene's potential to generate growth and create employment also grows.

3.1. The market potential

Today, the market focus is on the synthesis and processing of grapheme.

Graphene's market is still R&D focussed and thanks to the hype around this material it garnered investment in research efforts from both public and private sources[14], with an overall EUR 2.2 billion invested and 7,740 patents filed between 2008 and 2012[15]. According to the industry, the annual market for graphene in R&D and in product development is estimated at around EUR 12.7 million[16]:

As it is the case for other advanced materials, the market uptake of graphene will take time. Its commercialization is still in its early phase, but nevertheless more and more companies are being created to develop graphene based materials, graphene production processes and other related activities.

Many of the companies engaged in the graphene market (including several of the showcased companies) have started out of an initial business catering to the demands of research. Therefore they were often, like in Graphensic's case, established as spinouts of university. With time they developed the knowledge in the production of graphene and started developing wider product range.

New niche market applications

While the graphene market is mostly geared towards R&D as well as product development, some companies have begun to offer products with incorporated graphene. Some of these new products have incorporated graphene because of its advantageous properties, but some just for pure marketing reasons given the hype associated with the technology.

Companies have capitalised on the popularity of the advanced material. In addition to its properties, the material also has an inherent marketing value. Graphensic has done this in the resistance measurements standards market. Their portable resistance standard, while superior to competing technologies, benefits from the desire of customers to be seen as "first movers" in the resistance standards market[17].

In 2014, the cycling products supplier Vittoria released a new range of bicycle race wheels built from graphene-enhanced composite materials produced by the Italian company Directa Plus. These new wheels are marketed as the fastest wheels in the world[18].

An example of the varied but ultimately niche applications of graphene is demonstrated by the products of Cambridge Nanosystems. The company's best applications include high performance rubbers used, for example, in large infrastructure projects which adapt to the thermal expansion of the material. Graphene is also incorporated into de-icing paints with strong potential applications in wind turbines, or in aviation.

Graphene synthesis using methane also presents an important potential solution to reduce greenhouse gas emissions as methane is an important contributor to climate change. As the demand for graphene scales up, Cambridge Nanosystems' indication to license out its production method could become an important asset in the ever-important issue of climate change management as other grapheme producers employ this means of synthesising graphene.

Other examples come from companies which have already begun to incorporate the material in existing products, for example IBM produced the first integrated circuit based on a graphene transistor[19].

Other applications include the textile industry, water treatment (as a chemical absorber to treat oil spills), elastomers for rubber tyres, gear lubricants. Graphene's use in products such as touchscreens exploits its conductive nature. The material has also found its way into better, lighter batteries and in a few months' time the first graphene light bulb will be sold[20].

3.2. The social potential of the trend

Researchers are working on joining other atoms with graphene to provide an even wider range of its applications in electronics. Because of its molecular structure, graphene could also be used in water purification, or desalination. Moreover its pliability could allow for applications in wearable technology, while the interactions between electronics and the carbon lattices and the resulting quantum phenomena could be used in so-called quantum computers. Graphene can also enhance the durability of condoms (the Bill & Melinda Gates foundation has invested EUR 90,000 into research on this topic).

While the market of graphene's applications is growing, the future of this advanced material most likely lies in the replacement of existing materials in a huge variety of sectors – electronics, photonics, energy generation and storage, sensors, metrology, as well as in bioengineering[21]. As we develop a better understanding of the material's properties and of how to best synthesise it in its different forms, its potential applications become more apparent.

Within the electronics sector, graphene's electrical field effect and a new kind of quantum Hall effect are being studied. This stands to make the material ideal for use in transistors, sensors and other electronic components. That could possibly lead to reduction in the reliance on rare-earth materials used in electronics which Europe nowadays needs to import, particularly from China. It also opens up the possibility for fast spin currents and the use of 'spintronics' to replace conventional electronics for data processing and transfer. The material is not good at controlling or switching electric current, so for instance making faster computers with it remains difficult[22].

Thin films of graphene (just one atom thick) can be manipulated as strong, flexible, lightweight sheets and can be functional as an electrode in liquid crystal devices. This can have a massive impact on the touch screen technology: graphene could be used to make bendable touch screens to replace the rigid ones that permeate the mobile phone and tablet market.

Electrochemical energy-storage devices are also potentially one of the areas where graphene could generate disruptive growth. Graphene has recently seen applications as an active material and as an inactive component in storage solutions from lithium-ion batteries and electrochemical capacitors to emerging technologies such as metal–air and magnesium-ion batteries[23]. This is of great importance as conventional energy storage solutions such as batteries and capacitors are increasingly struggling to keep up with the current rate of electronic component evolution[24]. While it is possible to store a large amount of energy in certain types of batteries, these are often very large, heavy, and both charge and discharge their energy relatively slowly. Capacitors, on the other hand, are able to be charged and release energy very quickly, but hold much less energy than a battery. Graphene incorporated into capacitors offers important possibilities for improved energy storage with potentially high charge capacity and discharge rates that could be made far more cheaply than conventional super-capacitors. This has important considerations for the development of European capacity to generate energy from renewable sources as supercapacitors could help support the needs for energy storage to account for the intermittency of renewables.

At its current state of technology development, the graphene industry can potentially become a source of jobs in the area of synthesis and processing of graphene as well as along the stages of the value chain where it is incorporated. It could have environmental benefits through the support of renewable energy generation, or through the use of methane as a substrate for the synthesis of graphene (as done by Cambridge Nanosystems). In addition if any of the potential applications of the technology that are anticipated by the experts in medicine, electronics, energy storage, etc., will be fulfilled that will have even bigger economic impact.

4. Drivers and obstacles

The development of the graphene market depends on a series of drivers and obstacles. The market is currently driven by a large amount of visibility, which attracted investment. Also the issue of energy storage and release related to ever increasing demand for energy is a big driver. The main obstacles are related to the fact that the technology is still not mature, and requires a lot of additional research before graphene can be mass produced. In addition, paradoxically the huge potential of the technology limits the focus of the real applications, diluting the market uptake.

4.1. Graphene is riding high on the hype wave

The primary factor driving the graphene market at the moment is the hype related to this advanced material. It is a typical phenomenon for breakthrough innovations which experience changes in visibility as these become more established in the market.

Figure 4: The Gartner hype cycle

Source: Graphene Tracker[25]

Since the discovery of graphene in 2004 there has been a sizeable amount of coverage about the technology by mainstream media, followed by a rush in patenting of graphene-related IP[26]. The visibility of graphene as an emerging technology has only become more prominent following the investment of EUR 1 billion into graphene research by the European Commission.

This increased visibility provides opportunities for commercial gain simply from the use of graphene for marketing reasons rather more than its properties, as previously mentioned. It is quite possible that upon reaching the "peak of inflated expectations" the investment might drop with reduced visibility and some sceptics suggest that the hype is bound to die down at some point[27]. If the technology follows the hype cycle, this sizeable investment would suggest a promising future once the technology becomes more established.

"The graphene market is benefitting from riding the hype wave at the moment"
*– **Graphensic***

4.2. Need for better energy storage

The processing power of computers has been increasing exponentially in accordance with Moore's law[28]. At the same time the ability to supply the necessary energy to power them has failed to keep up the pace. The decrease in battery life in mobile phones over the last decade is a good example – as technology has improved the computing power of mobile phones, battery life has gone from a week to a day.

Growing demand for mobile phones, computers and other electronics with greater processing power requires more energy. And that is where graphene could play a role. Its potential to improve lithium-ion batteries that power most consumer electronics, or even replace it is a prospect that attracts many investors[29].

4.3. The technology still needs the spark to allow for mass production

The graphene market is limited by one primary factor: material is still difficult to produce in large quantities necessary to satisfy the requirements of any large scale incorporation of graphene into a new product or system. For example, the potential applications of graphene in electronics such as the replacement of silicon circuitry or the use of graphene in aircraft wings, require important supplies of graphene to meet existing demand for conventional materials for these uses.

Together with the progress in research companies such as the ones showcased in this study will continue to fine-tune their ability to synthesise graphene through the variety of available methods. In addition, as the market develops and graphene becomes more incorporated into the value chains of the multiple markets it caters to, the impetus behind driving investment into mass production of graphene is bound to make it a reality. Companies such as Cambridge Nanosystems have recognised this huge potential and have seen the value in licensing out their unique method to synthesis graphene out to the market once it becomes more mature[30].

4.4. Entry to the value chain is too spread out and not focussed enough

The hugely varied number of possible applications for graphene and the hype surrounding it so far has been more of a burden rather than an advantage. When the technology can potentially revolutionise the value chains in so many industries, there is a loss of focus as to how it really penetrates the market.

In addition, many of the applications outside of the niche markets that graphene caters to, such as the electronics industry, are already heavily invested in a particular type of material which forms a sizeable, and difficult to replace, part of the value chain. Silicon is a prime example of this. Silicon forms the backbone of the electronics industry, not because it necessarily performs better, but mostly because it performs well enough and is cost effective. On top of which, some serious investment has been made into optimising its performance making it more difficult for graphene to easily replace it[31].

"The moment you say your technology can do everything, that's when your technology seems less credible to the market". – ***Cambridge Nanosystems***

5. Policy recommendations

Given the potential benefits of nanotechnology it is important to develop this area further and encourage the commercialisation of valuable application areas. Of course this process must be done in a safe and responsible manner, as the use of nanomaterials raises questions regarding potential unintended risks to humans and the environment.

It is important to establish frameworks that foster the responsible development of nanotechnology, such as ensuring adequate numbers of 'nano-skilled' individuals and, while work is ongoing, to examine health and safety issues, understand aspects of the material lifecycle and consider how nanomaterials are dealt with at the waste management stage.

A series of policy recommendations can be made to support innovative companies in the graphene market.

Specific solutions to facilitate compliance with the REACH Regulation [1] should be sought. Standards could be established for graphene as a material, along with accepted health and safety guidelines and procedures for lifecycle analyses. Access to research facilities and infrastructure could also be made easier for innovative SMEs, and a greater coordination could be supported between different public support initiatives at the national or regional level. Finally, investment should continue into fundamental research in nanomaterials as these provide the basis from which the graphene revolution can really start.

5.1. Solutions to comply with the REACH regulation

A problem faced by the innovative small companies in this sector lies in the cost associated with compliance with the REACH regulation. Under this regulation, companies proposing new chemicals need to register the substances by submitting a dossier containing a range of test data to the European Chemicals Agency (ECHA). Fulfilling those requirements can be costly and start-ups face difficulties to afford these costs.

REACH already provides for exemptions from registration obligations for companies as long as the placement on the market or the utilisation of a substance remains below 1 tonne per year – this is also applicable to graphene. The exemption includes in particular the utilisation for research and development purposes. Further exemptions are possible for the so-called product and product oriented research and development (PPORD). When higher volumes are involved, data requirements for registration are tiered depending on the tonnage placed on the market, and all companies placing on the graphene market are obliged to work together in a so-called substance information exchange forum. This forum allows them to share all costs, thus reducing the burden on individual companies. In addition, the Commission has significantly reduced registration fees for SMEs with the purpose of reducing this burden.

Specific technical guidance should be developed to seek the least burdensome solution to comply with the registration requirements for graphene. Data concerning the toxicity and hazards of graphene could be generated with the support of

[1] REACH is a regulation of the European Union on the Registration, Evaluation, Authorisation and Restriction of Chemicals. It was adopted to improve the protection of human health and the environment from the risks than can be posed by chemicals, ensure the free circulation of chemicals on the Internal Market, support alternative test methods, while enhancing the competitiveness of the EU chemicals industry.

EU or national research programmes and then made publicly available.[2]

5.2. Help establish accepted standards of graphene and enforce them

The market for graphene is nascent. There is a large and growing variety of graphene products available on the market. Therefore there is still little in terms of regulation and accepted standards for these materials in Europe.

To boost the market standards should be fostered in order to protect bona fide suppliers of graphene from companies that would offer cheaper products at the cost of quality, without the consumers consent. This could be achieved by legislating on defined standards of the different types of graphene across the common market, and by empowering a body to enforce these regulations.

*"The main problem affecting the graphene market is the confusion related to the lack of a clear knowledge about the material, the process and the specific proposition of graphene producers. There is currently a serious risk of oversupply in the graphene market." – **Directa Plus***

In addition, there is a need to coordinate the efforts to establish health and safety legislation and lifecycle analyses requirements for graphene. Lifecycle analyses are costly and need to be certified by an independent body, which is problematic when there is a lack of accepted standards for graphene.

5.3. Facilitating access to research facilities and infrastructure

Nanomaterials are a knowledge-intensive sector, and graphene is no different. Many of the companies showcased in this study were once or are engaged in research activities at a local university or research centre, whether through conception or through the development of their product or services. Those companies continue to place a large emphasis on the development of their intellectual property, especially taking into account the fact that, there is still a lot more research required before graphene will become a well-established material. Therefore facilitating access to research is needed. As a first step promoting access to the necessary research facilities or equipment for nanotech companies should be considered.

*"We actively foresee collaboration and information with national and international research infrastructures, with the aim to create a common chain of value. The only problematic aspect is the cost of the use of research infrastructure. A public support initiative, at national and European level, could clearly speed up the cooperation growth." – **Directa Plus***

Knowledge-intensive companies, geared more towards the synthesis of graphene, such as Graphenea, experience difficulties in securing laboratory time with equipment such as electron microscopes. This could be achieved by subsidising the purchase of specialised equipment for nanotech research, or subsidising the cost for operating them, or even through the creation of contract research agreements between the research facilities and the nanotech companies conducting research on graphene.

5.4. Foster and assist in the coordination of support and network initiatives

Many of the up and coming companies in the graphene market expressed that it was important for them to establish a network early in their foundation as well to engage with clients.

Many companies, including the showcased ones either spun out of research initiatives, or were created by visionaries who brought in researchers with expertise that they previously knew. Once created, it also becomes important to easily approach the different public support initiatives dedicated to such innovative SMEs, as well as to network with potential clients and partners.

Graphensic, a spin-out of a research initiative in Sweden, had to identify and approach each public support programme individually, which proved to be very inefficient. Cambridge Nanoscience had the opposite experience: the cluster environment of the university town fostered networking to allow the founders to meet and create the company, and then just as easily approach business angels and other investors.

More support for networking initiatives could be foreseen. This could be done through by regional authorities, or technology transfer offices which could run more networking events, orientation sessions or business coaching events for start-ups in order to educate them about available support.

*"There were a lot of support initiatives available to us, but there was no dedicated group there to tell us where to find them..." – **Graphensic***

5.5. Continue to invest in fundamental research in nanomaterials

While it may be tempting to concentrate investments into applied research and the transfer of the technology into markets, in reality graphene still requires a lot more

[2] Several projects concerning nanosafety are already financed under the 7th Framework Programme: NanoSAFE and NanoREG for example. http://nanoreg.eu/ and http://www.nanosafe.org/scripts/home/publigen/content/templates/show.asp?L=EN&P=55&vTicker=alleza

research. In a visit to the European Parliament, Konstantin Novoselov (one of the co-discoverers of graphene) commented[32]: "*The main advice is to invest in fundamental science and to believe in fundamental science. The breakthroughs in technologies in the long term are much more promising than small incremental research*".

Meeting the requirement for 'nano-skilled' individuals to drive the grapheme market needs to be met through investment in fundamental research in the fields relevant to nanoscience.

As well as driving the aforementioned research efforts and pushing the boundaries of our knowledge of graphene's properties, research has knock on impacts on the labour market through exposure of graduate and undergraduate students in these fields. Investment into research would also give the STEM sector students more opportunity for practical laboratory work, research, and development of their theoretical background. All of which would provide the dual benefit of increasing the employability of young graduates in the European labour market, while at the same time providing the developing graphene industry with the necessary skilled labour.

6. Appendix

6.1. Interviews

Company	Interviewee	Position
Graphenea	Jesus de la Fuente	Founder and CEO
Graphensic	Amer Ali	CEO
Directa Plus	Giulio Cesareo	President and Managing Director
	Tiziana Sardo	Sales representative
Cambridge Nanosystems	Jérome Joaug	Co-founder and Managing Director

6.2. Websites

Company	Web address
Graphenea	www.graphenea.com
Graphensic	www.graphensic.com
Directa Plus	www.directa-plus.com
Cambridge Nanosystems	www.cambridgenanosystems.com

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