Graphene and Related Materials

FET Consultation Workshop, Brussels 20th January 2020

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Executive Summary

The European Commission has launched the FET Flagship initiative on Graphene and Related Materials (GRM) in 2013. This was almost ten years after graphene was first isolated in 2004. GRM research and innovation has taken great strides since then. Whereas most new materials take decades, sometimes centuries to develop (aluminium and silicon being good examples), GRMs are already being used in several products after 15 years. This fast push to higher TRL levels was strongly supported through the collaborations and synergies created by the Graphene Flagship. But there remains much to be done to fully benefit from and build on the successes of the past years, and enable new GRM-enabled technologies.

In the context of the preparation of the next Framework Programme Horizon Europe, the EC has organised an open consultation to identify the most important research challenges in the area of GRM in the coming years. Experts in the field, both from within and from outside the Graphene Flagship, gathered in Brussels on 20th January 2020 to discuss scientific and technological challenges as well as cross-cutting activities such as GRM capacities, standardisation and safety that support the take-up by European Industry in this field.

They gave specific challenges (detailed in this report) regarding material and production, electronics, optoelectronics/photonics, health & biomedical applications, energy generation and energy storage. They underlined the crucial role of manufacturing and processing value chains, supported by standardisation activities and validation services. They also stressed the importance of work on health and safety issues and working with regulatory bodies. Regarding the funding scheme, the experts expressed their concern about lost synergies and duplication of efforts in case the activities would be continued as a set of smaller projects.

Many GRM based technologies have the potential for green manufacturing technologies due to the typically low-emissions, low energy consumption and the possibility to avoid hazardous materials (e.g. solvents). This should be supported by solid, scientific and benchmarked proof on GRM potential in the sustainable solutions in each of the application areas.

1. Introduction

The Graphene Flagship, launched by the European Commission in 2013, was built on seminal, fundamental research on GRMs performed in Europe, and has enabled Europe to translate its world-leading status in fundamental research into technological leadership.

Since its launch, the Graphene Flagship has driven fundamental and applied research in Europe around a common roadmap and has led to the development of tens of new prototypes, product launches and the creation of 12 innovative companies. Strong collaborations between academia, SMEs and large enterprises across the European Union were at the centre of this success.

As the Horizon 2020 Framework Programme for Research and Innovation (2013-2020) is coming to an end, the European Commission is setting priorities and gathering input material for the first work programme of the new Horizon Europe Framework Programme for Research and Innovation (2020-2027).

Experts from academia and industry (both involved and not involved in the Graphene Flagship) were invited to Brussels on 20 January 2020 to discuss the future challenges of GRM research and innovation. The objectives were to identify the key research challenges that would take the research in the field further as well as cross-cutting activities such as GRM capacities, standardisation and safety that should enable take-up by European industry.

Participants shared their contributions ahead of the meeting regarding the main challenges to be addressed in relation to technologies based on GRM (graphene and related materials), their impact on science and technology in socio-economic terms, major bottle-necks and key stakeholders in these areas. The Graphene Flagship also produced a vision paper presenting its views on the future challenges and needs to be address in the coming years (see annex 3).

The discussion centred on areas including material and production, electronics / optoelectronics / photonics, health & biomedical and finally energy generation / storage and sustainable technologies.

The participants addressed possible ways to maximise the impact of GRM technologies on European Industry (material production, wafer scale integration and other capacities), European services for GRM (material database, validation and standardisation) and GRM related regulations and issues concerning toxicity and safety.

Finally, a plenary discussion was held on the needs to ensure a coordinated approach of GRM development, building on what has been achieved so far notably within the Graphene Flagship, and how industry take-up can be accelerated.

3. Workshop: GRM Challenges and Impacts

During the first part of the workshop, participants were asked to identify challenges for GRM in dedicated areas and specify where GRM technologies could have the biggest impact for European industries and society. The sections below present the conclusions.

3.1 Material and Production

Reliability and reproducibility are still the greatest challenges for GRM materials and production. The production value chain can thrive only when end users feel confident that they can consistently get materials of the required quality, properties and quantity that are relevant/adequate to/for their applications. For example, while transparent electrodes and sensors require thin film graphene, energy storage devices (supercapacitors and batteries) or even polymer composites require large quantities of graphene nanosheets or platelets, and photonics and spintronics require grown defect free graphene. This relies notably on the establishment of reliable material characterization and analysis according to the different routes, using both bottom-up and top down approaches, to synthesise GRM.

To address these challenges

- Materials calls should target:
  - Scalability in exfoliated GRM
  - In situ characterisation for improved synthesis
  - Developing characterization and labelling protocols for qualifying GRM along the value chain

- Production calls should target:
  - Integrated direct crystal growth
  - Low-defect wafer-scale graphene
  - Additive manufacturing (ie. Printed GRM components that can be integrated into the product directly in the production process)

3.2 Electronics and Optoelectronics / Photonics

GRM are well placed to solve significant challenges in electronics, optoelectronics and photonics, namely the need for lower power consumption with improved performances devices.

The main challenges for GRM adoption in these fields are the speed performance and bandwidth of modulators, a lack of sensitivity and efficiency, and a lack of integration in current technologies.

In these application field as well, progress on material quality and production is a prerequisite.

GRM also play a role in related but radically new approaches, such as spintronics and quantum technologies.

3.2.1 Optoelectronics/Photonics

Graphene based photonic components (photo detectors and optical modulators) should be developed for optical high-speed communication, passive optical networks and datacom.

The performance of established semiconductor and conventional detector and modulator technologies reaches its technological limits and these components become bottlenecks for further network evolution towards higher bit rates. Based on its theoretically predicted properties, graphene could offer solutions which would support photonic communication systems featuring extreme high-speed performance (of up to several Tbit/s per optical channel). Moreover, graphene based optical modulators promise to offer superior energy efficiency, significantly reducing the requirements of energy-hungry modulator drivers or even making them redundant. Such technologies will be needed for future 6G networks supporting wireless THz-communication.

The following improvements are needed to enable graphene-based devices to reach their capabilities:

- Further improve key figures of merit for GRM (charge carrier mobility, optical transparency); provide material featuring defined and well reproducible quality
- Improve crystallographic quality, higher charge carrier lifetimes, reduce electrical contact (graphene/metal) sheet resistance
- Develop highly reproducible and cost-efficient component manufacturing processes (high component yield) which support co-integration with Si-based electronics

The first two items were also raised in the earlier topic of Material and Production.

3.2.1 Electronics

Flexible electronics, electronic circuits on flexible, stretchable or conformable substrates, enable the realization of new, unconventional products like smart textiles, interactive skin patches and lightweight large-area electronics. The main challenges related to this area are:

- To ensure the exploitation of GRM developments in the realization of new flexible electronics products by transferring the scope of the work from material testing and component development to the development of integrated systems and demonstrating the upscaling of the manufacturing processes.
- To evaluate the true potential of GRM based flexible electronics in the context of sustainable development goals. Printing, the key unit operation in the production of flexible electronics is considered a green manufacturing technology due the typically low-emissions, low energy consumption and the possibility to avoid hazardous materials (e.g. solvents). When combined with abundant raw materials such as graphene and/or other 2D materials, the potential for sustainable solutions is huge. Sustainability can also be contributed through the development of new sensors for applications promoting good-health and well-being as well as the reduction of food waste.

The lack of satisfying flexible batteries is a bottleneck for the realization of a fully flexible solution for technologies like skin patches and intelligent packaging. Current solutions suffer from limited capacity, large footprints and high costs. This topic should be addressed to reach the challenges described above.

3.3 Health & Biomedical

Health and biomedical applications for GRM pose regulatory challenges not faced in other areas. The move from preclinical to clinical research and particularly human studies, for example, will require a very different type of support than what is currently offered by the standard instruments which do not fund these types of research programmes. Another challenge exists in the absence of standards for what would constitute “medical-grade” graphene, or guidelines for safety, dosage and toxicity. Regulatory and notified bodies need to take into consideration developments in GRM. The panel of experts in this area, therefore suggested the establishment of funding instruments to move from health and biomedical research in low-mid TRL, to consolidation of mature technologies, e.g. through pre-clinical trials.

Research programmes should focus on what GRM can do better than state-of-the-art technologies. GRM allow multifunctionality: combining biocompatibility, chemical stability, extreme sensing and actuating, and integration with flexible electronic technologies, in addition to versatile surface chemistry (for interface with biology). Research should take advantage of the combination of all these properties. All work on health and biomedical technologies should take a translational perspective, focusing on how the work will reach the clinic. Furthermore, multidisciplinary teams composed of engineers, material scientists, clinicians, patients, *and* ethics experts are essential.

The absence of an industrial ecosystem for the production of graphene for medical devices also needs to be addressed. A production system for medical grade graphene similar to the Experimental Pilot Line that will be launched to produce graphene devices for electronics, optoelectronics and sensors would help advance this area.

<u>Impacts of applications</u> should be directed to:

- Lowering cost and increasing efficacy
- Implementing personalized medicine
- Reducing hospitalization time (digital health & remote monitoring)
- Minimally invasive surgeries for improving quality of life (fewer surgeries)
- Increasing adoption & therapy adherence
- Increasing therapy outcomes
- Developing novel therapies for indications for which there is currently no solution

<u>Application fields</u>:

- Tissue engineering & bioengineering (muscle, organoid monitoring)
    - Soft electronics, biocompatible, resolvable electronics
    - Research (organoid monitoring and interaction with organoids),
    - Medical (biological membranes, artificial organs, etc)

- Sensors for digital health
    - Low cost, disposable sensors
    - Flexible electronics for wearables & implantable to allow continuous patient monitoring
    - Biodegradable electronics
    - Point of Care diagnostics

- Electronics for brain-computer interfaces, taking advantage of flexible devices
    - Medical (neural prosthetics for patient assistance: limb control, language, vision, brain disorders, etc)
    - Non-medical: broader use of BCIs beyond medical use (careful with ethical implications)

- Medical imaging (& monitoring: teraherz probes, quantum dots, etc)
    - Less invasive (safer), more accurate

- Energy storage & harvesting for implantable devices (heart, etc)
    - Miniaturized batteries with high performance
    - Nanomechanics, Flexible piezo electronics

- Graphene for drug & gene delivery

3.4 Energy Generation/Storage, Sustainable Technologies

Calls for GRM projects in energy generation and storage should focus on sectors were Europe can build a value chain that is competitive with the one that currently exists in Asia. The market for small consumer batteries is strong in Asia, making alternative battery projects more interesting for Europe. In the area of sustainable technologies, on the other hand, many exciting avenues suggest themselves.

- Energy Storage should focus calls on:

    - **Large energy storage for electric power grids/solar farms/wind farms**
      GRM added value: **durability,** energy density, power density
    - **Structural batteries and structural supercapacitors**
      Develop energy storage devices integrated in structural parts of airplanes and cars to address the demand of distributed sensors and electronics
      GRM added value: better integration in plastic and CF composites
      TRL: high

- Catalysis

- GRM based catalyst for replacement of critical raw materials (e.g. rare/expensive/polluting metals)
- Applications: e.g. electrolytic hydrogen generation
- GRM added value: high surface area, tunable catalytic properties using heteroatoms, cost advantage on standard catalysts
- TRL: medium
- Additional advantage: useful for other applications in EU chemical industry

- Direct CO_2 capture
  - There is currently no efficient technology for direct CO_2 capture from air
  - Demonstration plants have already been established at the pilot plant level (power plant outlets) but, EU has lost competitiveness vs. China for CO_2 capture
  - GRM added value: selective adsorption/transport of specific gases demonstrated
  - TRL: low
  - Additional advantage: Could be possible to use captured CO_2 to make graphene

- Water purification
  - Urgent need worldwide, but also in EU to increase trust in tap water
  - GRM added value: Efficient capture of ions/molecules, possible antibacterial properties
  - Promising results already demonstrated with advantage vs. activated carbon
  - TRL: medium

4. Workshop: Maximising the Impact of GRM Technologies

The second part of the discussions addressed various concerns regarding how the impact of GRM technologies on European industry and society can be maximized.

4.1 Developing the European Graphene Industry: Material production wafer scale integration and other capacities

Developing the graphene production industry in Europe is a transversal theme affecting all manufacturing routes: both top down and bottom-up pathways. While the two classes of manufacturing work under very different constraints, current market conditions are straining for both.

Europe has a good number of GRM manufacturers, mostly SME developers such as Graphenea and Antolin, as well as a much larger set of industries that could use GRM to create high value products, creating positive impact on European industry and society.

However, for jobs to remain in Europe and for European producers to stay competitive against non-European graphene developers (China, US/Canada, Australia…) that are better capitalised or possibly receive distortive state aids, GRM value chains must be expanded or in many cases created. Ensuring a level playing-field is an essential step to securing the growth of the incipient European GRM industry.

Just as silicon is a material with limited intrinsic market value but has enabled the foundation of huge value-creating industries, GRM need to be manufactured and processed into industrially valuable and societally beneficial products and services for the benefit of European citizens and as a global export base.

This group raised again the need for internationally recognised manufacturing and processing value chains that can provide:

- Consistent reliable quality
- Reproducible product properties
- Scalable to volumes of market-making size

For Europe's (potential) GRM-processing and value-adding industries, there is a need to remove a still-common industry perception that GRM is still far away from reaching the higher TRL levels needed for industrial take-up. The Experimental Pilot Line project is a useful step that will help to change this perception.

For "top-down" manufacturing:

- The competition with Chinese and other non-European companies concerns in particular top-down manufacturing
- Scaling acutely needs more European-based operational value chains
- European and global buyers and processors of GRM-enabled products need to be more confident regarding the market opportunities based on valuable product advantages.

- Potential European GRM-using industries, some very large, need to connect with European GRM manufacturers who are mostly small and in the process of scaling up.

For “bottom up” approach and wafer scale integration:

- European industry enjoys a relatively good competitiveness
- GRM can add value to some silicon products because they will provide additional functionalities, without needing to “break into” existing value chains controlled by non-European players.

Also, in this case the group argued there is a need for:

- Reproducibility of processes
- Yield increases for manufacturing
- Quality control methods
- Direct involvement of tool manufacturers, specifically for bottom-up synthesis

These subjects could be addressed by a CSA type project focused on supporting European graphene industry and creating value chains.

4.2 Developing European services for GRM: Material database, validation and standardisation

The Graphene Flagship currently provides industrialisation services including a Samples and Materials Database, validation and standardization. The Samples and Materials Database is a tool which is used by consortium members to request graphene samples, report test results, and search for materials of suitable performance. The validation service, provided by authorised national measurement institutes and facilities, provides documentary evidence demonstrating that selected characteristics of a sample as requested by the client are met. The measurements adhere to available standards or established procedures. The Graphene Flagship’s standardisation service works towards establishing consensus-based international standards in the field of graphene and related materials that will help stimulate innovation and market penetration. The panel recommended the expansion of these services in the future.

Europe needs a delocalised, distributed, virtual standardisation infrastructure that will be sustainably transferred to a European authority. This includes the materials database. This would become an entry point for GRM and help maintain the materials’ competitive advantage. The service must become financially sustainable.

The materials database should be the link between this infrastructure and a future technical or standardisation committee. This database should take advantage of modern technologies such as block chain and artificial intelligence to address the issue of confidential versus publicly accessible intellectual property. Challenges include (1) establishing an incentive for producers to submit their samples and make characteristics known and (2) the characterisation and reproducibility of graphene production methods. Solutions to these challenges could be found by looking at similar best practices in other fields (ie. REACH, NIA, OECD and Biotech).

4.3 GRM related regulations, toxicity and safety at the European level

The lack of knowledge in the industry, and in some cases society, are propagating misunderstandings concerning the toxicity level of nanomaterials (even comparing them to Asbestos). It is important that current and future GRM projects address these societal and industry concerns, making health and safety information more readily available.

Current work on health and safety issues concerning GRM (such as that of the Graphene Flagship's Health and Environment work package) should be made widely available to better inform decisions about their adoption or handling. Moreover, this work should continue so that clear recommendations and characterisations can indicate toxicity windows and best practices for safe handling of GRM.

Researchers and industry also need a set of best practices for the safe use and handling for GRM. What safety equipment (if any) should be used when handling different forms of graphene and other GRM, how should they be stored and/or disposed of, what other concerns should be addressed?

Links with regulatory, manufacturing bodies and other stakeholders (European Chemical Agency, Notified bodies, etc…) to make them aware of these best practices and toxicity parameters may be necessary. Once defined, compliance with these regulatory guidelines should be mandatory for European project partners.

5. Horizontal Services: Coordinating GRM R&I in Horizon Europe

The experts argued that the most effective and efficient way to reach Europe's ambitious targets for GRM research and innovation and create new GRM-based disruptive technologies is through a coherent, well-coordinated continuation of the Graphene Flagship's activities. As witnessed by the success of the Graphene Flagship thus far, a single coherent initiative facilitated the creation of a European GRM supply and value chain, linking together several industrial branches and providing advantages of scale.

Investment will be needed to maintain and expand this industrial ecosystem and to realize the expected benefits to society. Thus, the experts advocate a continued support from the EC and the Member States during Horizon Europe so that the EU can maintain and extend its strong position in GRM science and technology and capitalize upon the investments made during Horizon 2020.

The framework for funding in Horizon Europe is different from that in Horizon 2020, During the consultation, the experts were asked to consider alternatives to the current Graphene Flagship implementation model that would allow horizontal services like those provided by the administration, dissemination, innovation and industrialisation work packages within the Graphene Flagship to function as an umbrella, coordinating and serving multiple, individual--but connected--projects working on advancing GRM technologies.

There is a risk that synergies would be lost and duplication of efforts across the individual projects would start to occur. It was suggested that contractual obligations could be put in place to ensure the individual projects will collaborate with, and answer to, the project providing horizontal services. The risk being that without a means to enforce this collaboration, the horizontal services would not be able to function effectively or efficiently.

Furthermore, there is a clear need to address the challenge of shifting from graphene research and innovation to work on new materials, of which there are thousands to choose from for future research.

Annex 1: List of Participants

Last Name	First Name	Affiliation
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Goldberg	Anne	University of Mons
Hanssen	Jan Erik	1-TECH
Kinaret	Jari	Chalmers Technical University
Lemme	Max	AMO
Loiseau	Annick	Onera
Losurdo	Maria	CNR
Martí	Ferran	Aimplas
Neouze	Marie-Alexandra	ANR, coordinator of FLAG-ERA project
Smolander	Maria	VTT
Templ	Wolfgang	Nokia-Bell-Labs
Van Tendeloo	Gustaaf	University of Antwerp
Waters	Rebecca	Chalmers Technical University
Zurutuza	Amaia	Gaphenea

Annex 2: Agenda of the meeting

Agenda

Introduction

Presentation of the Graphene Flagship's Horizon Europe vision paper

Workshop: Four tables identifying challenges and impacts in:

- Material and production
- Electronics / optoelectronics / photonics
- Health & biomedical
- Energy generation/storage, sustainable technologies

Discussion of outcomes

Workshop: Three tables discussing ways to maximise the impact of GRM technologies

- Developing Graphene European Industry: Material production, wafer scale integration and other capacities
- Developing European services for GRM: Material database, validation and standardisation
- GRM related regulations, toxicity and safety at the European level

Discussion of outcomes

Plenary discussion about horizontal services and ways to coordinate different projects

Annex 3: Flagship Vision Statement

When the GF was launched, fewer than five layered materials were known, and most of the research was focused on graphene. Since then, over 2,000 such materials have been identified, but only a few tens have been studied experimentally thus far. These new GRMs have a wide range of properties: some are insulating or semiconducting, others metallic, some are superconducting and some magnetic. Many will gain substantial technological importance, both individually and as heterostructures comprising several layers with different relative orientations. Their possible combinations, and relative stacking result in an almost unlimited number of opportunities. A new holistic approach based on a combination of machine learning, artificial intelligence (AI), neural networks and advanced materials theory needs to be developed to navigate the phase space and select the most promising paths for experiments. Both the design of structures with desired properties and their fabrication can only be rationally managed using AI-based tools and techniques, combined with scalable synthesis of the individual materials and their combinations.

In applied research, many areas will reach industrial maturity with a long-term research support. One such area is the biomedical field, where GRM-based technologies show great promise. For example, neural interfaces to monitor brain activity and to stimulate the brain electrically. This paves the way to applications such as retinal implants that allow blind patients to recover vision, techniques to reduce symptoms caused by Parkinson's disease or epilepsy, and guide complicated surgical treatment of aggressive brain cancer (glioblastoma). These new biomedical devices will address increasingly important medical needs in the context of an aging society, bringing science and biomedical innovation to the homes of Europeans. On the longer scale, GRMs can be used as platforms for bioelectronics and drug delivery to treat cardiovascular diseases and cancer. The societal impact of this research is substantial and requires long term support and commitment, to navigate the clinical trials and approval processes.

In (opto-)electronics, photonics and sensors, GRM-based systems have already demonstrated extraordinary performance, e.g. photonic switches 10,000 times faster than existing technologies, with reduced power consumption, or photodetectors with hyperspectral range for applications such as autonomous driving, where quasi-immediate data exchange is a critical requisite for safe operation. Applications of GRMs in light detection and ranging, security, ultrasensitive physical and chemical sensors for industrial, environmental and medical technologies are beginning to emerge and offer great promise. These technologies must be developed to achieve full industrial impact as key enablers in 5G and 6G communications, as well as ubiquitous sensor networks. Mass manufacturability needs to be achieved.

Information and Communication Technology (ICT) systems are the fastest growing consumers of electricity worldwide, with >15% of the total carbon footprint generated by data centres (expected to double by 2050). Due to current limitation set by current CMOS technology, energy efficiency reaches fundamental limits. To counter this, GRMs will enable low-power semiconductor electronics through band gap engineering; in addition, GRMs can be used to create novel memory devices such as memristors for neuromorphic computing, which present another, architectural route to reducing energy consumption of ICT. These future, disruptive, GRM-enabled technologies represent an

outstanding opportunity for EU industries to boost their market share and secure the independence of the EU's communications infrastructure from other countries.
Composites are some of the most versatile and mature applications for GRMs. Multifunctional composites exploiting the unique properties of GRMs can be utilized in structures, not just lighter and stronger than current solutions, but at the same time electrically and thermally conducting. This enables new functionalities, such as self-monitoring and self-healing (concrete, components for automotive and aerospace, batteries), allowing replacement of metals in many applications and yielding up to 70% weight reduction. Graphene sponges can be used to filter air and treat oil spills, and we expect that they will find several more uses, thanks to their large surface area in combination with unique thermal properties.

Applications where GRM coatings provide chemical or mechanical protection have great industrial potential, ranging from anticorrosion to non-toxic prevention of biofouling and biofilm formation. Despite their ultimate thinness, GRMs can be made completely impermeable. This forms the basis for a number of applications, such as cleaning wastewater and purifying drinking water, as well as filtering and gas separation. GRMs will reduce the EU's reliance on raw (rare) materials and allow for the development of environmentally friendly solutions. GRMs also offer improved processability in material production, promoting new design solutions for components and products.

GRM-based products contribute to sustainable technologies, such as electromobility, by enabling more effective energy storage in advanced batteries (e.g., lithium-sulphur, lithium/sodium-air) and fuel cells. A combination of these energy-focused devices with power-focused supercapacitors will impact short- and medium-range logistics in buildings (elevators), warehouses (trucks), and cities.

All these applications require thorough understanding of health and environmental (H&E) aspects, as well as sustainability and the life cycle of GRMs. While some H&E issues, such as exposure routes, are application dependent, much of the underlying science of toxicology and life cycle analysis is the same. In Horizon Europe, the GF plans to continue to critically examine GRM H&E issues, ranging from general toxicology, to occupational health and environmental impact. Much of this work has thus far focused on graphene toxicology but needs to be broadened as other GRMs gain wider use. The training of experts in biological safety of GRM development and production, will make GRMs 'safe-by-design', as well as create the new generation of engineers with expertise in GRMs use, highly sought after by industry.

More generally, new jobs will be created, due to high-tech spin-offs and by securing and extending the market share of the EU's SMEs and large companies. The GF contributes to this not only by delivering the science and technology, but also by educating and training people working in these new jobs.

In order to reach their full impact, all GF activities are supported by centralized and interlinked actions on dissemination, innovation, standardization, validation, project administration and management. Dissemination targets new industrial and scientific communities, educating engineers in branches where GRMs are making an entry, and informing EU decision makers and the general public on the activities they fund. Innovation identifies new opportunities and provides guidance and support on how to capitalize upon them. Standardization and validation are key elements in establishing mature and robust value chains, as a basis for the sustained economic impact of the scientific and technological activities. Central administration guarantees all activities to be conducted efficiently, avoiding duplications and exploiting synergies.

The Graphene Flagship has identified four concrete recommendations for continued GRM research and innovation in Horizon Europe:

- Maintain and build upon the demonstrated strengths of the flagship concept
- Keep both fundamental and applied research, and consider their strategic importance to key European industries
- Identify a few specific topics that may be included in concrete call texts
- Underline the importance of broad cross-cutting measures to maximize impact and reduce costs

Within the framework of Horizon Europe, the Graphene Flagship sees most of its activities falling within Pillar 2, cluster 4 (digital, industry and space), although it could also make significant contributions to clusters 1, 5 and 6.