



GRAPHENE
FOR HEALTHCARE

SPECIAL
EDITION

HEALING WOUNDS WITH GRAPHENE

Grapheal's smart dressing uses graphene to monitor wounds and stimulate healing

Read on to learn about medical technologies brought to life by the Graphene Flagship

GRAPHENE HEARS YOUR BRAIN WHISPER

INBRAIN Neuroelectronics receives
€1M to develop graphene-based implants



Funded by
the European Union

CONTENTS

- 3 The road to next-generation healthcare
- 4 Healing wounds with graphene
- 6 Graphene electrodes on the brain

8 HUMAN OF THE FUTURE

- 10 Graphene Flagship launches COVID-19 task force
- 12 Real-time tissue imaging with graphene
- 14 Health and safety of graphene and layered materials



THE ROAD TO NEXT-GENERATION HEALTHCARE

By: Tom Foley



The possibilities are broad: from wearable sensors to optimise athletes' performance to implants that can provide artificial retinal vision

G

Graphene and layered materials are paving the way to new technologies in biomedicine, and this is all thanks to the unique properties they have to offer. For example, their exceptionally high surface area makes graphene and many similar layered materials excellent platforms for drug delivery. On top of this, their high conductivity and often tuneable electrical

properties mean they can be used to make highly sensitive and selective biosensors for medical applications.

The possibilities are broad: from wearable sensors to optimise athletes' performance to implants that can provide artificial retinal vision, graphene and layered materials could provide solutions in many different fields of biomedicine and healthcare.

To this end, several partners of the Graphene Flagship, along with some of our industry-led Spearhead Projects and spin-off companies, are working on exciting developments that could bring new graphene-based medical devices to the market.

One example is the Graphene Flagship's [CHEMSens](#) Spear-head Project, an initiative to develop a graphene-based plaster sensor for human skin. In this device, graphene enables the quick detection and analysis of key biological constants, like the levels of sodium, potassium, lactic acid and glucose in the sweat.

The plaster measures biophysical stress and transfers the information to electronic devices, and could help athletes to fully optimise their training. The sensor features four independent devices that can operate separately, and utilises paper-based fluidics to improve sweat flow into the sensor, enabling smooth and swift detection – while ensuring operation is safe for the user.

In this mini-magazine, we will look at several more key developments from Graphene Flagship scientists over the past year, and



investigate how they might shape the future of healthcare. To learn more about the new medical technologies brought to life by graphene and layered materials, please read on.

HEALING WOUNDS WITH GRAPHENE

By: SINC

C

Chronic or hard-to-heal wounds, those that do not heal after six weeks, place a significant economic burden on health systems around the world, costing around \$30 billion annually. They lead to half-a-million amputations per year globally. In the United States alone, more than 6.5 million people suffer from such wounds.

The costs and prevalence of chronic wounds are both increasing due to the growing number of older people in the population, among whom pressure ulcers and leg ulcers are more common – in addition to the increase in patients with diabetes, who are more prone to foot ulcers.

Faced with this problem and considering that the proper assessment of these wounds is not within the reach of caregivers with the relevant expertise, Graphene Flagship scientists in France have developed a new graphene patch that allows them to be monitored remotely. Furthermore, pre-clinical studies have even shown that they promote healing.

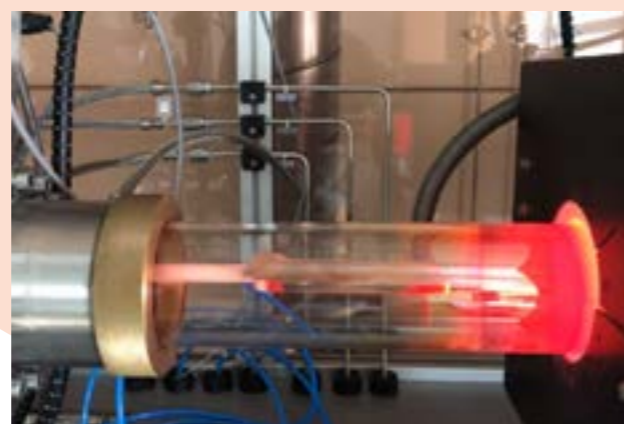
“The conductivity of the graphene electrode varies according to the physicochemical changes in the wound, so we produced films of this material on a polymer, a plastic, and integrated them into a bandage to record biological parameters in direct contact with the wound bed,” explains Vincent Bouchiat, CEO of Graphene Flagship Associate Member [Grapheal](#), a spin-off from France’s National Centre for Scientific Research (CNRS). Grapheal is based at Néel Institute, in Grenoble, where this technology was developed.

Graphene forms an ultrathin and robust conductive layer. Grapheal’s patented method of integration produces soft and



The conductivity of the graphene electrode varies according to the physicochemical changes in the wound, so we produced films of this material on a polymer, a plastic, and integrated them into a bandage to record biological parameters in direct

Vincent Bouchiat
CEO of Grapheal



Graphene Flagship Associate Member Grapheal produced a graphene patch that records the condition of chronic wounds, such as ulcers suffered by the elderly or those with diabetes, at any time. Credit: Grapheal



Medical and nursing staff can remotely monitor how wounds are healing with this system, receiving alerts for any infection that may arise

A SMART, CONNECTED DRESSING

The graphene dressing is ultra-flexible, adapts easily to any part of the body, and has tiny wireless electronics (with lightweight, fully flexible electrodes) that transfer the data to a mobile application. Then, using a telemedicine software and medical technologies in the cloud, the information can reach the hospital to be monitored and evaluated by a specialist.

Medical and nursing staff can remotely monitor how wounds are healing with this system, receiving alerts for any infection that may arise, which helps to prevent complications.

“This can improve and individualize the treatment of chronic wounds that require long-term care,” says Bouchiat, who emphasises: “in particular, it enables the early detection of infections, allowing a hospital solution at home.”

STIMULATING HEALING

The incorporation of graphene into skin patches of these types not only does not interfere with wound healing, but in fact can actually promote it, actively stimulating the process – as demonstrated by pre-clinical studies that have already been conducted.

The first human trials are about to begin. The medical device has been classified as class II-b, the same class as insulin pens, and requires the European mark of conformity. Its launch is planned for 2023.

The creators of the patch had intended to present it in February, along with other projects of the major European initiative known as the Graphene Flagship, at Mobile World Congress in Barcelona, which was cancelled to prevent the spread of the coronavirus.

In this context, the researchers point out that the new graphene device will be able to help monitor the chronic wounds of people in isolation due to the ongoing pandemic.



The data can be sent from the home to the hospital using a mobile phone app, meaning doctors can respond quickly if

GRAPHENE ELECTRODES ON THE BRAIN

SPIN-OFF COMPANY INBRAIN RECEIVES €1M TO DEVELOP GRAPHENE-BASED DIAGNOSTIC IMPLANTS FOR BRAIN DISORDERS

By: ICN2

€1M

Four new investors boosted Graphene Flagship spin-off INBRAIN with a total €1 million investment

Graphene Flagship spin-off [INBRAIN Neuroelectronics](#) received a €1 million investment from Sabadell Asabys, Alta Life Sciences, ICF and Finaves. This spin-off was born from Graphene Flagship partners the Catalan Institute of Nanoscience and Nanotechnology (ICN2) and ICREA to speed up the development of

novel graphene-based implants to optimise the treatment of brain disorders, such as Parkinson's and epilepsy.

According to a [2010 study](#) commissioned by the European Brain Council, the cost of brain disorders in Europe alone reaches approximately 800 billion euros a year, with more than one-third of the population affected. The high incidence of brain-related diseases worldwide and their huge social cost call for greater investments in basic research in this field, with the aim of developing new and more efficient therapeutic and diagnostic tools.

INBRAIN Neuroelectronics, now a Graphene Flagship Associate Member, was established in 2019 with the mission to develop brain-implants based on graphene technology for application in patients with epilepsy, Parkinson's and other neuronal diseases. These smart devices, built around an innovative graphene electrode, will decode with high fidelity neural signals from the brain and produce a therapeutic response adapted to the clinical condition of the specific patient.

Four new investors have recently boosted this spin-off with a total of €1 million. These include Asabys and Alta Life Sciences, collaborating through the Sabadell-Asabys funds, as well as the

Institut Català de Finances (ICF) and Finaves, a venture fund promoted and managed by IESE Business School. The new investment will allow INBRAIN to accelerate the development of these novel intracranial implants for patients affected by brain disorders.

INBRAIN designs the least invasive and smartest neural interface on the market that, powered by artificial intelligence and the use of Big Data, will have the ability to read and modulate brain activity, detect specific biomarkers and trigger adaptive responses to deliver optimal results in personalised neurological therapies. ICN2 and the University of Manchester validated the technology using *in vitro* and *in vivo* biocompatibility and toxicity tests, with the aim of ensuring the devices are safe and superior to current solutions based on metals like platinum and iridium. INBRAIN are currently testing the technology in large animals, and human trials will be led by The University of Manchester.

INBRAIN was founded, among others, by Jose Garrido and Kostas Kostarellos, from Graphene Flagship partner ICN2 and Anton Guimerà, IMB-CNM, an institute within Graphene Flagship partner CSIC.



INBRAIN Neuroelectronics, a spin-off company from Graphene Flagship partners ICN2 and ICREA, will use the investment to speed up the development of novel



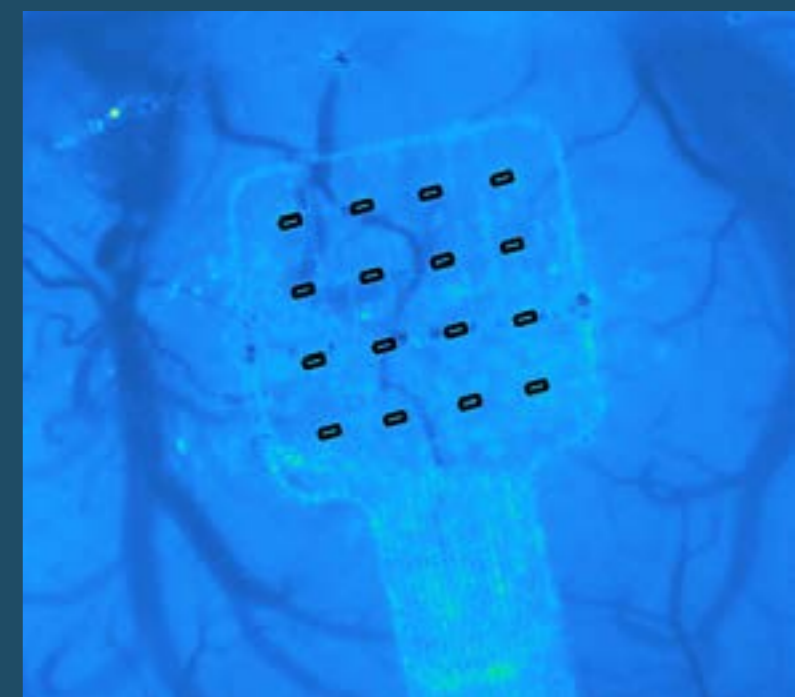
Minimally invasive electronic therapies represent a revolutionary alternative with less potential cost for health systems. In our case, the application of new 2D materials such as graphene represents a real opportunity to understand how the brain works to optimise and

Carolina Aguilar
CEO of INBRAIN Neuroelectronics

"Within the framework of the EU-funded Graphene Flagship, we were able to develop this novel graphene-based technology that will allow measuring and stimulating neuronal activity in the brain with a resolution much higher than that of current commercial technologies," explains Garrido. During 2019, the incorporation of INBRAIN was a priority project for the ICN2 Business and Innovation Department, which coordinated the technology transfer process and successfully orchestrated the licensing of this high-potential technology.

INBRAIN CEO Carolina Aguilar explains: "Minimally invasive electronic therapies represent a revolutionary alternative with less potential cost for health systems. In our case, the application of new 2D materials such as graphene represents a real opportunity to understand how the brain works to optimise and personalise the treatment."

Graphene Flagship Head of Innovation, Kari Hjelt, adds: "It is great to witness the development of INBRAIN bringing graphene from laboratories to market. Graphene offers unique capabilities to enhance multiple product attributes concurrently. Innovation at INBRAIN showcases the power of graphene in biomedical applications where its biocompatibility, electrical properties and flexibility make it as superior choice over many conventional materials."

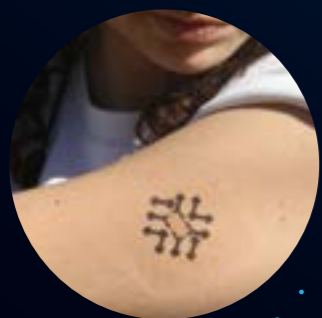


The sensor records brain activity at extremely low frequencies and could lead to new treatments for brain disorders like Parkinson's and epilepsy. Credit: ICFO

HUMAN OF THE FUTURE

Graphene-enabled technology expands the realm of possibility within the biomedical and

By: Melanie Lawson



Wearable health monitoring

ICFO FITNESS MONITORING SKIN PATCH

Graphene-enabled wearable health trackers conform to any surface and deliver accurate measurements of vital signs including heart rate and temperature.

BLOOD SUGAR MONITORING PATCH

A noninvasive graphene-based patch can detect and control glucose levels in sweat by delivering the necessary dose of medication through the skin.

UV SENSOR SKIN PATCH

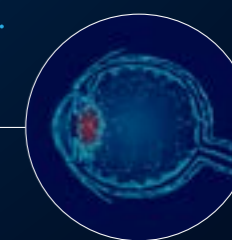
Graphene delivers a versatile light detection platform enabling the integration of sensors that monitor our exposure to UV light in real-time.

GRAPHEAL BAND-AID BIOSENSOR

A wearable and disposable electronic wound patch with a graphene-enabled "bio-electronics" platform capable of sensing and digitising biochemical signals in real-time.

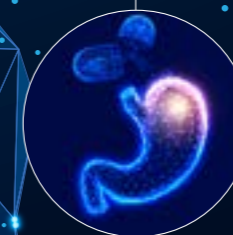
BRAIN-MACHINE INTERFACES

Flexible graphene can be used in neural implants which record and stimulate signals on the surface of the brain improving the understanding, treatment, and detection of neural diseases.



VISION RESTORATION

Next-generational retinal prostheses use graphene-based electrodes to provide artificial vision to patients blinded by retinal degeneration.



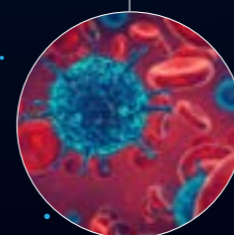
TARGETED DRUG DELIVERY

Drug delivery systems based on graphene and graphene oxide are ultra-efficient, taking advantage of graphene's extremely large surface area.



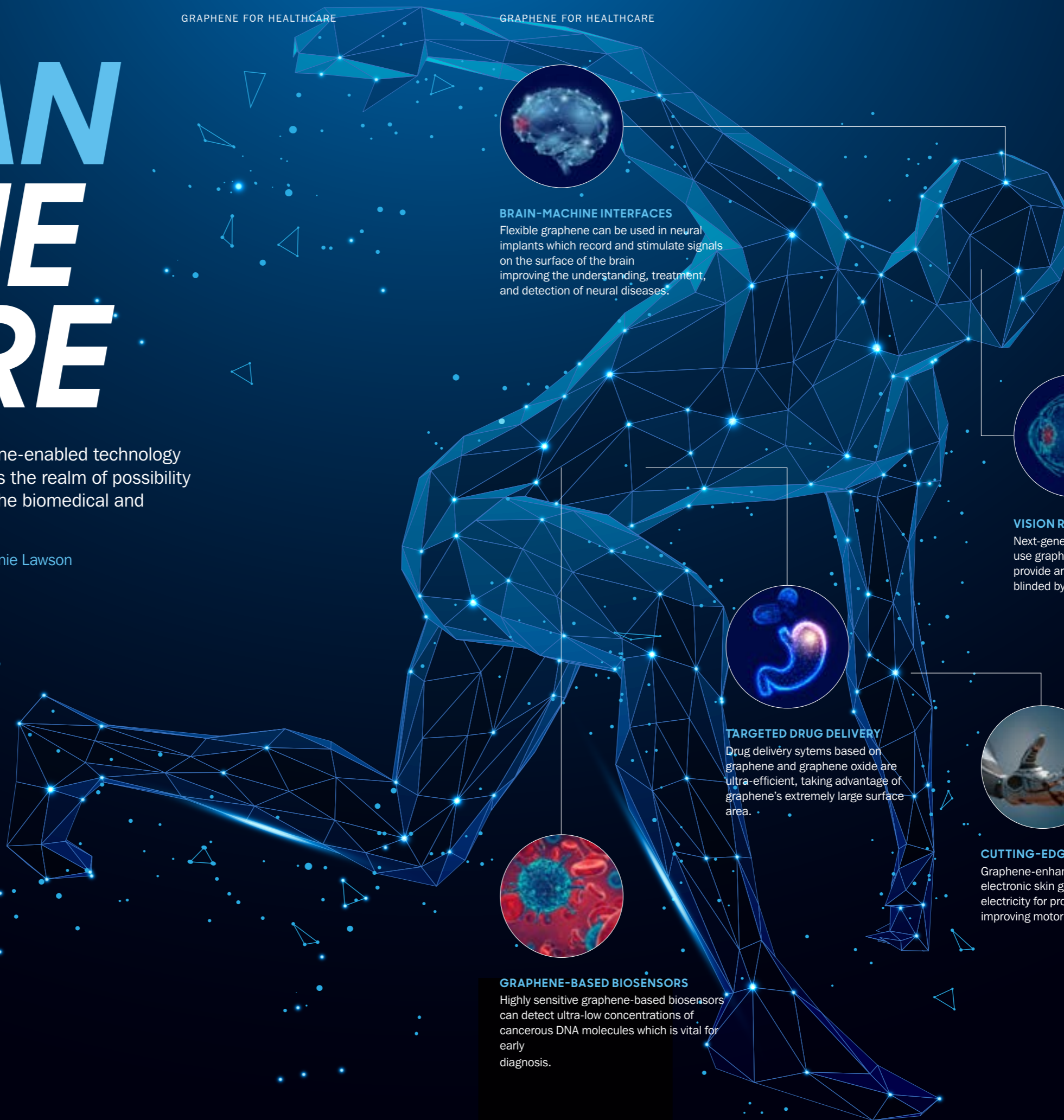
CUTTING-EDGE PROSTHETICS

Graphene-enhanced pressure-sensitive electronic skin generates and stores electricity for prosthetic devices, improving motor function.



GRAPHENE-BASED BIOSENSORS

Highly sensitive graphene-based biosensors can detect ultra-low concentrations of cancerous DNA molecules which is vital for early diagnosis.



GRAPHENE FLAGSHIP LAUNCHES COVID-19 TASK FORCE

By: Tom Foley

The current pandemic caused by COVID-19 brought to light an urgent need to devise new technologies to protect the human body from its immediate environment. Graphene and related materials are promising candidates for the design of a novel generation of surfaces to help deal with the daily challenges posed by COVID-19, as well as similar future diseases.

The Graphene Flagship Management Panel recognised that it is vital for the Graphene Flagship, as one of the largest Europe Science and Technology projects, to make use of all its collective and accumulated knowledge of graphene and related materials to fight the current pandemic – and those that may come in the future. To this end, it has assembled a targeted and multidisciplinary Working Group, comprising companies and researchers from across the consortium. The group's ultimate objective is to fully exploit the potential of graphene and related materials in order to contribute to the global front against this unprecedented societal challenge.

The Working Group aims to establish new connections between researchers, propose relevant topics for future funding calls, and initiate discussions with funders and stakeholders, with the ultimate ambition of making the best use of graphene and related materials in fields such as virology, biosensing and many others.

The group is led by Alberto Bianco, Graphene Flagship Work Package Deputy for Health and Environment, with deputy leader Paolo Samorì, Graphene Flagship Work Package Deputy for Functional Foams and Coatings, and includes a number of experts in fields such as material/virus interaction and biochemical sensing. For the full list of members, please visit the web page.

The Working Group has a 360-degree approach, covering fundamental to applied solutions. The group will investigate:

- The inhibition of the virus by graphene and related materials dispersed in solutions
- Whether graphene and related materials have the same capacity as antivirals as already demonstrated against bacteria
- How to modify graphene and related materials with antiviral agents
- How to design chemically tailored materials to either promote viruses' adhesion and inhibit their biological activity once adsorbed, or repel viruses
- How to design coated surfaces better able to withstand repeated cleaning cycles
- How to formulate disinfectant solutions and detergents containing graphene and related materials to clean surfaces
- How to design disposable masks, aprons and wearable tissues, with higher impermeability to viruses
- How to develop personal protective equipment technologies able to act as a barrier between the environment and human body
- How to create smart tissue, embedding by design not only anti-viral characteristics, but also with other functions
- How to design new chemical, electrochemical and optical sensors with high specificity for early diagnostics, and for portable point-of-care devices
- The wider challenges posed by global pandemics, such as how graphene and related materials can improve remote working: for example, by improving telecoms and datacoms, or through the development of more efficient batteries for a new green society.

"We are exploring the use of graphene to inhibit the infectivity of viral particles, as well as designing multifunctional graphene conjugates for conductive surface coatings," explains Alberto Bianco, Leader of the Graphene Flagship's Coronavirus Working Group. The surface coatings could be effective against the virus in two ways: either by directly repelling the virus, or by promoting its adhesion and destroying it once adsorbed.

Amaia Zurutuza, Member of the Graphene Flagship's Coronavirus Work Group and Scientific Director of Graphene Flagship industrial partner Graphenea, emphasises the importance of the group's collaboration with leading EU companies. "Graphenea is supplying graphene for diagnostics and treatment, and we are working on a number of virus-related projects," she explains.

"Graphene and related materials are promising candidates to develop the next generation of surfaces, to help with the daily challenges posed by the virus. The Graphene Flagship cannot and will not disregard such a major societal challenge," comments Paolo Samorì, Deputy Leader of the Working Group.

Prof. Andrea C. Ferrari, Science and Technology Officer of the Graphene Flagship and Chair of its Management Panel, adds: "In such a difficult and unusual time, it has never been more important to work together.

"The Graphene Flagship has a proven track record of delivering its promises. Many of our partners and associated members, both industrial and academic, are already working to develop new technologies based on graphene and related materials to help with the fight against COVID-19 and future pandemics.

"This Working Group will create many opportunities for collaborations both within and externally to the Graphene Flagship. We are convinced graphene and related materials have a role to play to help society tackle this challenging problem, and our Working Group will spearhead the Flagship's joint efforts in this area."



Graphene and related materials are promising candidates to develop the next generation of surfaces to help with the daily challenges posed by the virus. The Graphene Flagship cannot and will not disregard such a

Paolo Samorì
Deputy Leader of the Working Group

Graphene Flagship experts have united to tackle the effects of present and future pandemics with technologies based on graphene and related materials. Credit:



CORONAVIRUS WORKING GROUP

REAL-TIME TISSUE IMAGING WITH GRAPHENE

SPIN-OFF COMPANY CAMBRIDGE RAMAN IMAGING LTD TO DEVELOP NEW MICROSCOPE FOR CANCER TREATMENT

By: Graphene Flagship

G

Graphene Flagship spin-off [Cambridge Raman Imaging Ltd](#) has received an investment of €75,000 to support the development of graphene-based ultrafast lasers. These devices will be used in a new medical microscope to diagnose and track tumours, among other applications.

The graphene-enabled microscope will generate real-time digital images of tissue samples using Raman spectroscopy to differentiate between healthy and diseased tissue, and show the extent of tumours, their response to drug treatments, and allow surgeons to determine whether a cancer has been completely removed. Graphene and layered materials enable two fibre-based pico-second lasers to be synchronised in time. Furthermore, this architecture is much lower in cost than conventional solid-state systems.

Cambridge Raman Imaging was recognised as an official spin-off from Graphene Flagship partner Politecnico di Milano, Italy, and provided office space and state-of-the-art laboratories. This will also allow Cambridge Raman Imaging to be supported by PoliHub, one of the best university start-up incubators in Europe.

Paul Mantle, Director of Cambridge Raman Imaging, explains: "The announcements – the collaboration, the investment, the appointment of Dr Negro as the Chief Technology Officer and the membership and the support from PoliHub – are all important steps for Cambridge Raman Imaging. We look forward to bringing its technology to the market, at pace."

Giulio Cerullo, from Graphene Flagship Partner Politecnico di Milano and co-founder of Cambridge Raman Imaging, says: "It is exciting to see how basic research into the optoelectronic properties of graphene can be translated into a commercial product with potential impact on healthcare, enabling improvements to the accuracy of diagnostics and therapy for a variety of diseases."

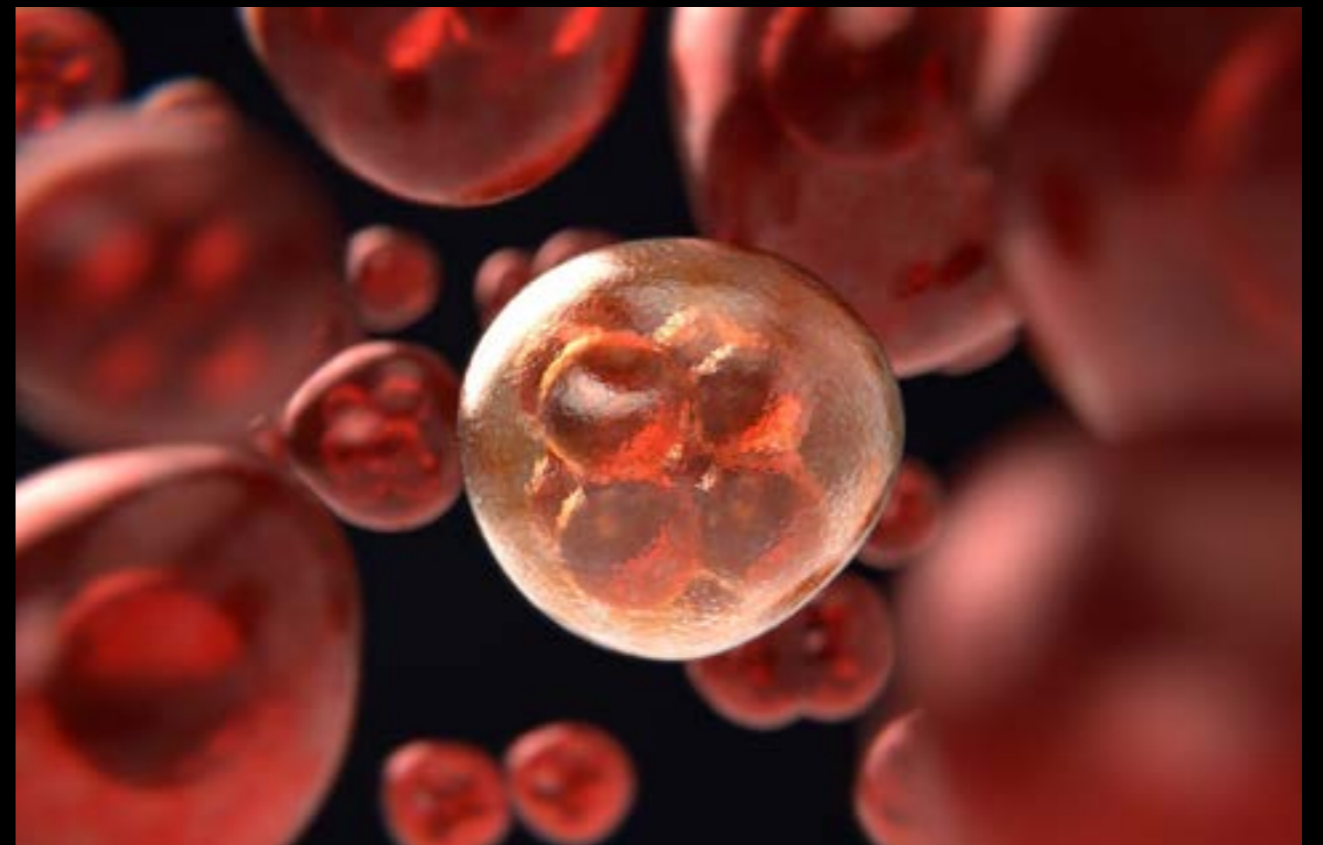
Marco Romagnoli, Leader of the Graphene Flagship Electronics and Photonics Integration Division, comments: "It is noteworthy how graphene can implement the accurate synchronization of two independent ultrashort pulse laser sources, operating at two different wavelengths. And all of this happens without any electronic controls."

Kari Hjelt, Head of Innovation of the Graphene Flagship, adds: "This innovation showcase the power of graphene in optoelectrical applications and highlights the progress made in bringing graphene from laboratories to the factory floor. This investment is yet another sign that investors are appreciating graphene's poten-

Open



Graphene Flagship spin-off Cambridge Raman Imaging Ltd (CRIL) will develop an innovative graphene-enabled scanning Raman microscope for cancer diagnostics, therapy



Graphene-based ultra-fast lasers will be used in a new Raman microscope to diagnose and track tumors, and more.

HEALTH AND SAFETY OF GRAPHENE AND LAYERED MATERIALS

By: Sian Fogden

A

As the drive to commercialise graphene continues, it is important to thoroughly research and understand all factors that could influence its safety. The Graphene Flagship project has a [dedicated Work Package](#) to study the impact of graphene and layered materials on human health, as well as their impact on the environment.

Because of this, **safety by design** is a core part of Graphene Flagship innovation.

The most crucial factor for assessing the toxicology of a material is to fully characterise it with safety in mind. To this end, the Graphene Flagship published a [detailed safety assessment](#) of graphene and layered materials and its effects on human health and the environment. The study investigates various methods of production and characterisation, and considers a number of different materials whose biological effects depend on their inherent properties.

“One of the key messages is that this family of materials has varying properties, and thus displays varying biological effects. It is important to emphasise the need not only for a systematic analysis of well-characterized graphene-based materials, but also the importance of using standardised in vitro or in vivo assays for safety assessment,” explains lead author Bengt Fadeel, Professor at the Karolinska Institute a Graphene Flagship partner in Sweden.

“This review correlates the physicochemical characteristics of graphene and layered materials to their biological effects. A classification based on the lateral dimensions, number of layers and carbon-to-oxygen ratio allows us to describe the parameters that can alter graphene’s toxicology. This can orient the future development and use of these materials,” explains Alberto Bianco, from Graphene Flagship partner CNRS, France, Deputy Leader of the Graphene Flagship Work Package on Health and



Understanding any potential health and environmental impacts of graphene and layered materials has been at the core of all Graphene Flagship

Andrea C. Ferrari
Graphene Flagship Science
and Technology Officer



The health and safety of graphene and layered materials is at the core of the Graphene Flagship’s ethos.



Environment.

The paper gives a comprehensive overview of all aspects of graphene’s impact on health and the environment, focusing on the potential interactions of graphene-based materials with key target organs including the immune system, skin, lungs, cardiovascular system, gastrointestinal system, central nervous system and reproductive system, as well as a wide range of other organisms including bacteria, algae, plants, invertebrates and vertebrates in various ecosystems.

“One cannot draw conclusions from previous work on other carbon-based materials, such as carbon nanotubes, and extrapolate this to graphene. Graphene-based materials are less cytotoxic when compared to carbon nanotubes and graphene oxide is readily degradable by cells of the immune system,” comments Fadeel.

Andrea C. Ferrari, Science and Technology Officer of the Graphene Flagship and Chair of its Management Panel, adds that “understanding any potential health and environmental impacts of graphene and layered materials has been at the core of all Graphene Flagship activities since day one. This review provides a solid guide for the safe use of these materials, a key step towards



Safety by design
is a core part of
Graphene Flagship

Sian Fogden

The Graphene Flagship is Research, Innovation and Collaboration

Funded by the European Commission, the Graphene Flagship aims to secure a major role for Europe in the ongoing technological revolution, helping to bring graphene innovation out of the lab and into commercial applications. The Graphene Flagship gathers nearly 170 academic and industrial partners from 22 countries, all exploring different aspects of graphene and layered materials.

Bringing diverse competencies together, the Graphene Flagship facilitates cooperation between its partners, accelerating the timeline for industry acceptance of graphene technologies. The European Commission's FET Flagships enable research projects on an unprecedented scale. With €1 billion budgets, the Graphene Flagship, Human Brain Project and Quantum Flagship serve as technology accelerators, helping Europe to compete with other global markets in research and innovation.



Funded by
the European Union

CONTACT US

General Queries:
info@graphene-flagship.eu

Administration:
admin@graphene-flagship.eu

Events:
event@graphene-flagship.eu

Innovation/Business Development:

FIND US



/GrapheneEU



graphene-flagship.eu