GRAPHENE
MAGAZINE

2020
EDITION

GRAPHENE GOES GREEN

Learn how graphene and layered materials could help make clean water and energy accessible to all

CHAMPIONS OF GRAPHENE REPORTING FOR DUTY

Two in-depth interviews with our recently appointed champions: Space Champion Carlo Iorio and Aeronautics Champion Elmar Bonnacurso

DIVERSITY IN GRAPHENE

Read about the Graphene Flagship's efforts to ensure diversity and equality in our scientific community and beyond

MEET THE HUMAN OF THE FUTURE

Funded by
the European Union

TABLE OF CONTENTS

Note: Graphene Flagship consortium members are displayed in bold throughout the text. Learn more about the consortium on our website.

FROM THE EDITOR

Dear reader,

Welcome to the 2020 edition of Graphene Magazine, the annual magazine brought to you by the Graphene Flagship.

Since our founding in 2013, the EU-funded Graphene Flagship has devoted itself to connecting research and industry in the field of graphene and layered materials. To this end, we have worked tirelessly over the past seven years to get graphene products out of the lab and into the market. Moreover, in the process, we introduced new jobs to Europe, fostered a unique and innovative ecosystem and bolstered the European economy.

Now, although 2020 has been a tumultuous year for many, our heads are high, and we are delighted to report excellent progress on several fronts.

We soared into a new phase of the Graphene Flagship project in April, kicking off with the injection of an additional €150 million into our budget. Following this, we introduced 11 new Spearhead Projects with defined, application-oriented objectives, seeking to develop products to fill gaps in the market, and warmly welcomed 16 new FLAG-ERA Partnering Projects into our ever-growing consortium, focusing on both fundamental and applied research.

We also oversaw the creation of a number of spin-off companies based on Graphene Flagship research. For instance, INBRAIN Neuroelectronics are working on graphene-based implants to record brain activity for the treatment of brain disorders like Parkinson's and epilepsy, and Cambridge Raman Imaging Ltd will develop graphene-based imaging devices to diagnose and track tumour growth in cancer patients.

On top of this, we set up a new EU-funded initiative to develop the necessary tools to integrate graphene and layered materials into established semiconductor fabrication lines for electronics, photonics and sensors – the Experimental Pilot Line. To find out more about this exciting project, please turn to page 44.

Lastly, our move to digital conferencing and networking was an enormous success. We hosted our annual Women in Graphene event entirely in a 3D world for the first time, which was hugely well-received, and we are set to continue this trend with our Graphene Hub initiative for digital events (see page 31). COVID or not, the wind is in the Graphene Flagship's sails, and you can see it in our shiny new logo and branding.

It is an exciting time to be part of such a vibrant and diverse scientific community, and we are glad to have you on board. Read on to take a deep dive and discover how the Graphene Flagship aims to shape the future of Europe.

Warm wishes,

Tom Foley

Top: Tom Foley. Image: Vesa Laitenen
Bottom: Dissemination Team, from left to right: Sofia Järbur, Rebecca Waters, Elena Novoselova, Luciana Löberg, Tom Foley and Fernando Gomollón-Bel. Not pictured: Melanie Lawson and Letizia Diamante. Image: Vesa Laitinen

GRAPHENE FLAGSHIP DISSEMINATION TEAM

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GRAPHENE: A NOBEL STORY

By: Fernando Gomollón-Bel

Since 2013, the Graphene Flagship has brought together academic and industrial researchers to push graphene and layered materials to the forefront of European scientific research. But when – and how – did everything begin? Join us on a journey back in time as we tell the tale of graphene's rich and iconic history.

Graphite is the most stable form of carbon, and it has been known since ancient times. In graphite, the carbon atoms arrange themselves into a series of layers, bound together by weak interactions. This unique structure makes it a great lubricant, a good conductor of heat and electricity, and the ideal ingredient for pencils: because the layers easily slide apart, they can be precisely transferred to a piece of paper, allowing us to write, draw, imagine and wonder.

Among these wonderers were scientists, who first dreamt of isolating single layers of graphite in the late 1940s. They predicted that such a material – the thinnest ever conceived – would have very unusual electronic properties, due to both quantum phenomena and relativistic effects, because the laws of physics can be very different at the nanoscale. But could they be really different enough to allow a single layer of graphite to exist? Many of the brightest minds thought it would be unstable, and some believed it to be utterly impossible – a theoretical utopia.

THE JOURNEY BEGINS

More than anything, scientists love to explore the unknown. They chase their dreams, sometimes fighting against all logical odds, in the ceaseless pursuit of knowledge and understanding. So it wasn't long before the hunt began for a single, pristine layer of graphite.

In 1962, they gave it a name: **graphene.** Because the layers of graphite peel off so easily, the keen investigators thought that would be the best way to obtain it. They attempted to 'exfoliate' single layers of graphene using different mechanical techniques, including 'the drawing method' – literally trying to draw the finest lines possible with an incredibly sharp graphite point. But alas, it seemed like an insurmountable quest. Their best results were graphite sheets 10 nanometres thick, 2000 times thinner than a human hair, but still 30 times thicker than a single layer of carbon atoms.

But after decades of intense theorycrafting and research, back in 2004, on an otherwise unremarkable Friday night in Manchester, the dream finally came true.

PIONEERS MAKE THEIR MARK

Every week, Andre Geim and Konstantin Novoselov would stay in the lab after work to discuss new ideas and try out unconventional experiments – some of which are just as whimsical as the concept of drawing atomically-thin strokes of graphite with a super-sharp pencil. Indeed, in a running theme, one of their experiments also involved playing with office supplies. They grabbed a roll of sticky Scotch tape, tore off a few pieces, and began to attach and detach them from a big chunk of graphite. Some fragments came off that looked extremely thin, almost invisible to the human eye and nearly indistinguishable from the tape itself.
Could this be graphene? Perhaps a microscope could determine

> There were many unsuccessful experiments, but eventually, one did work – and we produced graphene. We found that it was really interesting and
>
> Konstantin Novoselov

1962

One-atom-thin graphite is given a name:

2004

Geim and Novoselov isolate graphene for the first time using sticky tape.

the nature of these delicate carbon films.

Novoselov remembered that a few days earlier, he overheard some colleagues boasting about a new tunnelling microscope in their department. This device was capable of rendering sharp images of nanoscale objects and, at the same time, could measure their electrical properties. Right away, Novoselov knew that this device was the key to elucidating their material. And Eureka! The tunneling microscope killed two birds with one stone: it enabled them to observe, for the first time, individual layers of graphene – called graphene monolayers – and allowed them to demonstrate that the physical behaviour of graphene matched their theoretical predictions.

Was graphene about to enter the realm of modern electronics? The answer is history.

It quickly became clear that graphene would be sticking around. It was no longer merely a fantasy – graphene could now be isolated easily from graphite, and it was stable at room temperature and ambient pressure. Even further than this, measurements showed that graphene was a 'zero-gap semiconductor,' a rare type of material in which electrons can seamlessly jump to the conduction band, resulting in unique and unusual physical properties.

Zero-gap materials are extremely sensitive to small changes in their environment, such as pressure, magnetic field or the presence of molecules. In addition, further experiments showed that graphene conducts heat better than any known material, and that it conducts electricity even better than copper and silver. This rare combination of unusual properties makes graphene an ideal candidate for next-generation sensors, electronic devices, optical instruments and more.

A one-atom-thin layer of carbon may sound fragile, but graphene is flexible and 200 times stronger than steel. Once again, the

HISTORY, WRITTEN IN GRAPHENE

1560s
First pencil developed

1924
Graphite's layered structure identified

1947
Theoretical study into graphene's electrical properties

2004
Graphene first isolated by Geim and

2007
Freestanding graphene nanomembranes

2008
Graphene inks from liquid-phase exfoliation

2009
Transparent graphene electrodes for solar cells

Graphene-based quantum resistance

2010
Geim and Novoselov awarded Nobel Prize

Large-scale graphene fabrication and graphene-based touch screens

2012
Graphene photo-detectors demonstrated with high gain

Inkjet-printed graphene electronics

2013
Graphene Flagship launched

classical laws of physics break down at the nano-scale – the effects we see in graphene are unthinkable in metals, silicon and plastics. The isolation of graphene kicked off a whole new era in materials science.

Graphene is also the first two-dimensional material: "it expanded our toolbox to a whole new dimension," as Geim often says. And ultimately, it did. Scientists have gone on to discover that other materials can be exfoliated too, just like graphite, leading to a family of two-dimensional and layered materials with extraordinary properties. By combining them like ingredients in a sandwich, we can manufacture devices for all sorts of different applications that would've been unfathomable just a couple of decades ago.

NOBEL RECOGNITION FOR A NOBLE ACHIEVEMENT

Geim and Novoselov didn't expect this at all. They were purely driven by scientific curiosity, in pursuit of unfound knowledge and undiscovered possibilities. They were not looking for fame or fortune, so they decided not to file a patent on the new method to isolate graphene – much like how Marie Curie decided not to patent her discoveries for the greater good.

In October 2010, almost exactly six years after their original Science paper was published, the Royal Swedish Academy of Sciences gave them a call. Geim and Novoselov had been selected for the most prestigious award a scientist can get – and like Curie, they were presented with the Nobel Prize just a few years after their ground-breaking discovery.

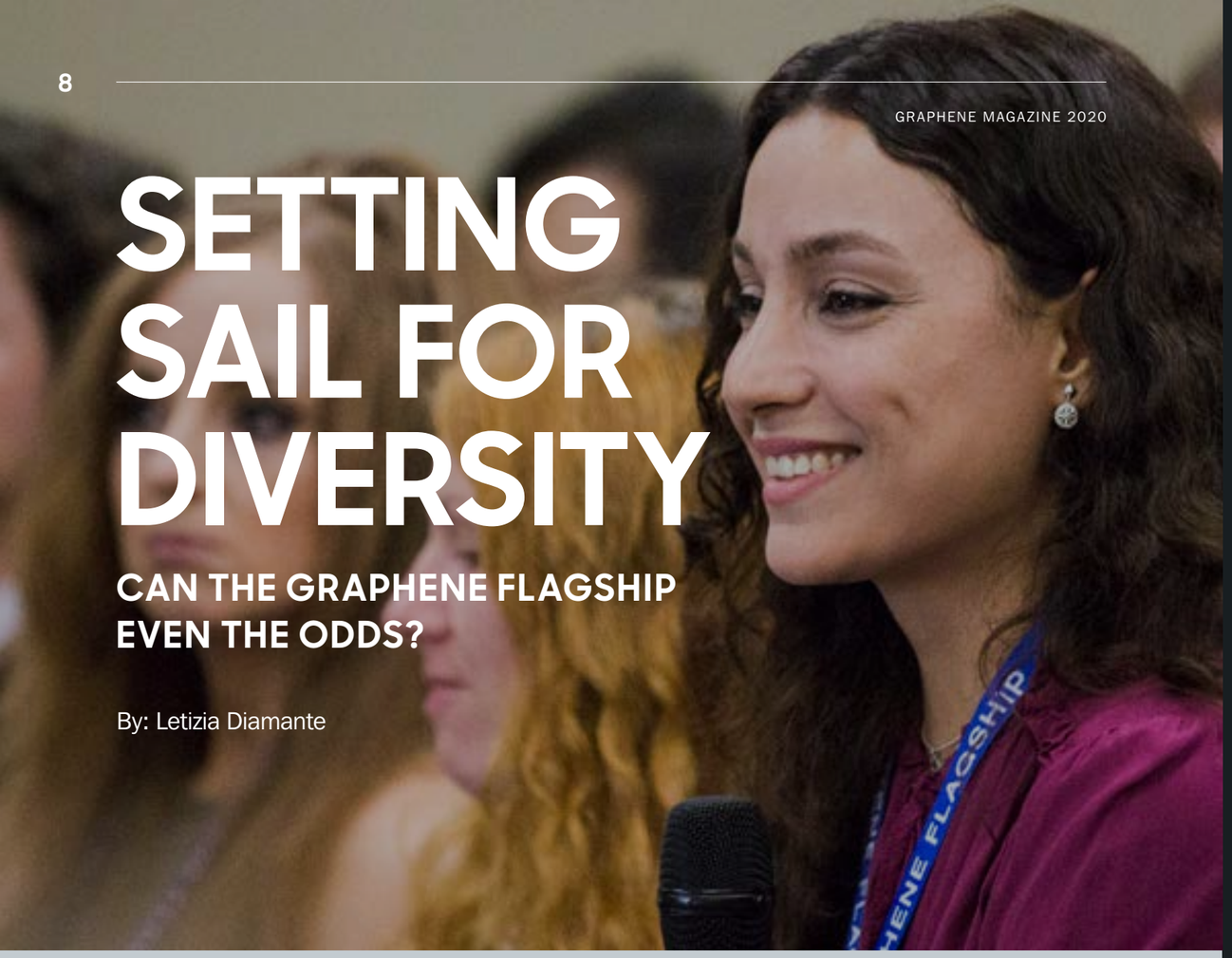
The Nobel committee highlighted the strength of graphene, famously stating that "an invisible hammock made from graphene could hold a cat without breaking" – as well as shining the spotlight on its superlative versatility, in that "it could give new twists to quantum physics, (…) speed up transistors and computers, and be suitable for producing transparent touch screens, light panels and solar cells."

Soon after, the European Commission decided to invest €1 billion in a one-of-a-kind multidisciplinary project, to boost research into graphene and layered materials, and to put the EU at the forefront of this new technological innovation.

They called it the Graphene Flagship – but that is a story for another day.

2010

Geim and Novoselov are awarded the Nobel Prize for their groundbreaking discovery.



SETTING SAIL FOR DIVERSITY

CAN THE GRAPHENE FLAGSHIP EVEN THE ODDS?

By: Letizia Diamante

The Graphene Flagship is fully committed to ensuring equality and diversity, both within our family and beyond. We are proud to report that women now make up 35% of the Graphene Flagship, better than the EU average of 32% for women employed in high-technology sectors: our efforts to promote equality in STEM never falter, and our percentage is ever on the rise. We actively contribute to the United Nations' Sustainable Development Goal 5: achieving gender equality and empowering all women and girls.

Our efforts began with the first Women in Graphene initiative organised during Graphene Week 2015. We launched Women in Graphene as an all-inclusive platform for our scientists and innovators, at all stages in their careers, to discuss gender and diversity issues in STEM – particularly within the community of graphene and layered materials. The pioneering initiative was a huge success, and set the precedent for the future of gender equality in the Graphene Flagship.

Since then, we have organised two Women in Graphene workshops every year, continuing our efforts to challenge gender bias in science, promoting gender diversity and providing a support network for professional growth. We even hosted our first ever online Women in Graphene conference in a fully 3D virtual world in March 2020, which was overwhelmingly well-received.

DID YOU KNOW?

Virtual conferences are sustainable and accessible, particularly for students and early career researchers.

WOMEN IN GRAPHENE GOES DIGITAL

Due to safety concerns at the beginning of the COVID-19 lockdown, the in-person meeting for our 2020 Women in Graphene career development workshop unfortunately had to be cancelled. But the virus could not stand in the way of the Graphene Flagship celebrating gender diversity: instead, we made the bold and experimental decision to host the conference in a virtual world, in a time when online events were uncommon and still in their infancy. The platform, provided by Virtway Events, was fully 3D and interactive. Delegates began by creating a character with their likeness, then jumped straight into the virtual world to begin networking with other attendees.

We were proud and honoured to be joined online by over 70 attendees, well in-line with our previous in-person Women in Graphene events. Furthermore, hosting the conference online allowed us to expand our reach far beyond our usual limits. Some delegates joined from far beyond the borders of the EU, and other students and early career researchers – who may have otherwise struggled to secure funding for travel and accommodation – were able to join for free from the comfort of their own home.

We were exceptionally grateful to receive overwhelmingly positive feedback from both our speakers and attendees. The event was greatly enjoyed by all who came, and we are very excited to see what the future holds for sustainable, accessible and affordable conferencing. To read more about the future of virtual events, both within the Graphene Flagship and beyond, please turn to page 31.

DID YOU KNOW?

Diverse companies are more likely to financially outperform their peers.

INTRODUCING DIVERSITY IN GRAPHENE

Now, we are expanding the initiative even further: Women in Graphene has now become Diversity in Graphene, and it will support all underrepresented groups in the graphene and layered materials community going forward.

In the times of Black Lives Matter, #MeToo and the COVID-19 crisis, it has never been more important to shine our spotlight towards discrimination and marginalisation in each and every part our lives. Sadly, diversity issues and bias – both conscious and not – certainly exist in science, academia and industry. People with disabilities, people of colour and the LGBT+ community are underrepresented in most scientific fields, and they commonly face exclusion, harassment, unfair pay and obstacles to their career progression.

> From 2020 onwards, Diversity in Graphene will represent all minority and marginalised communities, and it
>
> Letizia Diamante

Below: Women in Graphene, the Graphene Flagship's pioneering diversity initiative was a huge success, and set the stage for discussion about inclusion in the project.

But science supports diversity. A recent study collected data from more than 1,000 large companies across 15 countries, and reported that companies in which women hold more than 30% of the executive positions are more likely to outperform their counterparts in profitability. Additionally, companies in the top quartile for ethnic and cultural diversity achieve 36% higher profits compared to those in the bottom quartile. However, the same report also showed that in the last five years, progress towards inclusion and female leadership slowed down – so it is vital for the Graphene Flagship to keep pace by introducing new ideas and initiatives.

DID YOU KNOW?

Over 70% of Fortune 500 companies offer a mentorship programme.

COMMITTING TO CHANGE

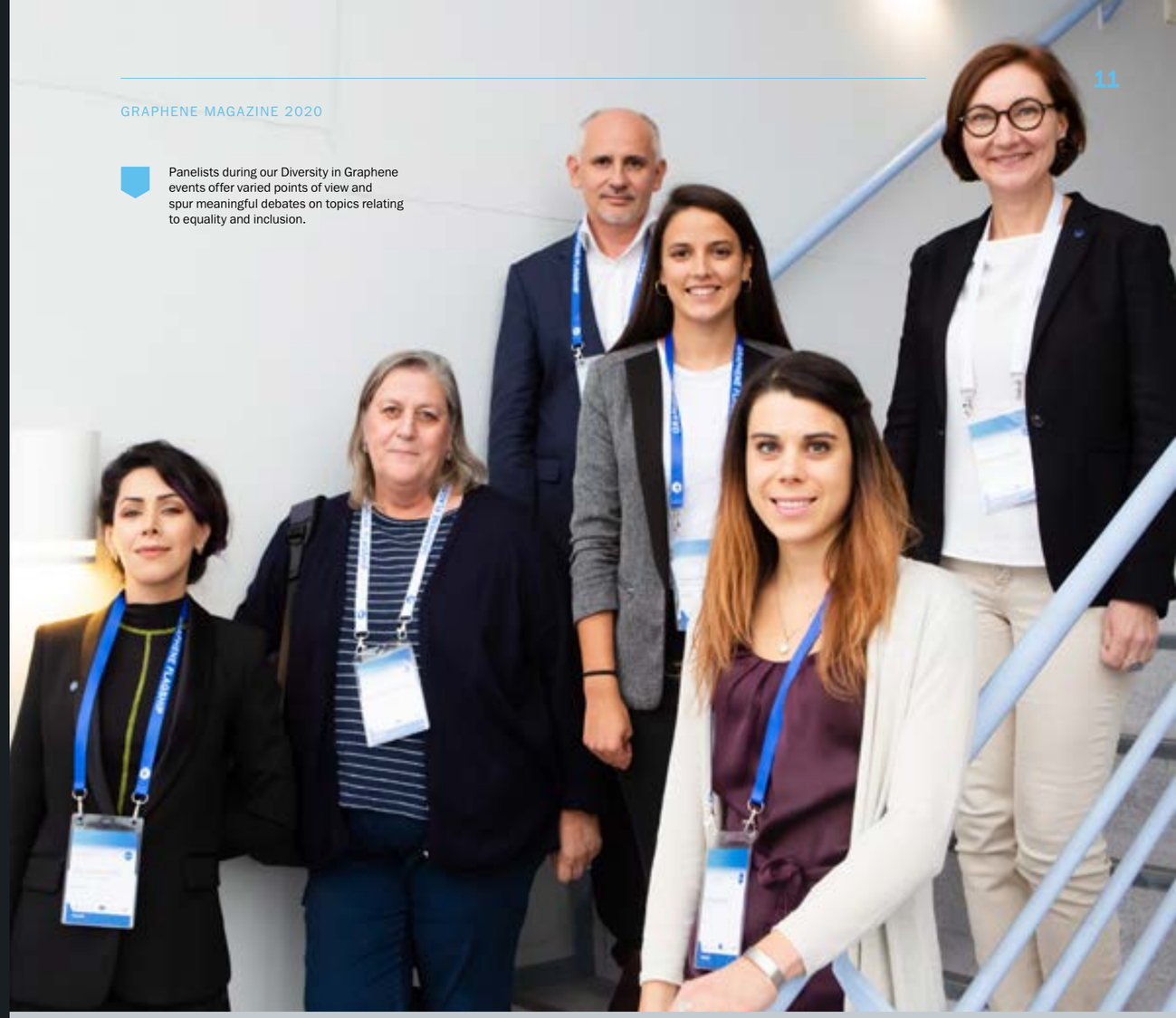
Given the success of Women in Graphene, and our position and influence as one of Europe's largest scientific projects, we strongly believe that we have a duty to expand our platform to be fully inclusive. So, from 2020 onwards, Diversity in Graphene will represent all minority and marginalised communities, and it will bring new initiatives, too. The first edition of Diversity in Graphene will take place on 24 September 2020 during our Graphene For Research, Innovation, Collaboration online event.

36%

Companies in the top quartile for ethnic and cultural diversity achieve 36% higher profits compared to those in the bottom quartile.

Networking and skills development are just two of the benefits offered by our Diversity in Graphene events.

Panelists during our Diversity in Graphene events offer varied points of view and spur meaningful debates on topics relating to equality and inclusion.



Due to popular demand, as part of Diversity in Graphene, we will set up a pioneering mentorship programme within the Graphene Flagship to support professional growth in underrepresented groups. Following a brief training session, early career researchers and students will be connected with more experienced scientists, to act as their mentors. This programme will facilitate networking inside the Graphene Flagship and provide a mutually beneficial learning experience for both mentors and mentees. Anyone involved with the Graphene Flagship will be able to register online to be matched with a mentor or mentee, according to career goals and availability.

Connect with us on social media! You can engage with us on Twitter and Instagram at @MyGraphene, or join the Women in Graphene Facebook Group.

> We will set up a pioneering mentorship programme within the Graphene Flagship to support professional growth
>
> Letizia Diamante

SCIENCE BEYOND THE LAB

CAREERS IN STEM OUTSIDE OF ACADEMIA

By: Fernando Gomollón-Bel

There is a whole host of careers in science, technology, engineering and mathematics (STEM) outside of the traditional academic pathway, and young scientists are often surprised to learn that they have more options than they originally thought. Here, four experts from the Graphene Flagship explore the alternative career paths they chose away from the lab.

CAREERS IN GRAPHENE

In a 2019 survey by Nature of more than 6,000 PhD students, 56% of respondents said that academia was their first choice for a career. For most young scientists, then, academia is seen as the gold standard in STEM careers, from a PhD all the way to professorship. But this path will not suit every science graduate, however – and fortunately, a scientific education opens many doors.

With our position as one of Europe's largest research projects, the Graphene Flagship has a unique insight into alternative career pathways in science and technology. Our core consortium consists of over 150 academic and industrial research groups, and together, we aim to bring graphene out of laboratories and into European society. Four women working with us to achieve that goal are Ana Helman, Patricia Huijbers, Sinead Savage and Cinzia Spinato.

My role gives me a much broader view, and I get to see graphene's impact across many areas of science."

Ana Helman
European Science Foundation

Helman is a science officer at the **European Science Foundation**, working for the Graphene Flagship. She manages several programmes for large-scale collaborative research, working to align all the projects and partners that make up the Flagship.

I knew I wanted to work in project management, and the Graphene Flagship gave me the opportunity

Patricia Huijbers
Chalmers University of Technology

Huijbers is based at **Chalmers University of Technology** in Sweden, and works as a project manager for the Graphene Flagship. She focuses on technical reporting, covering all of the Work Packages that make up the Flagship. Her responsibilities are to collect information from our partners for internal and external evaluation, to support researchers, and to analyse project output.

Savage is a project manager, too, but she works solely within the Graphene Flagship's Biomedical Technologies Work Package. She also manages the nanomedicine lab at the **University of Manchester**, UK. Her job is to ensure researchers submit deliverables and reports promptly, as well as working on funding applications and liaising with the team at Chalmers.

Finally, Spinato works within the business and innovation team at **ICN2**, Spain, dealing with the protection and commercialisation of intellectual property produced by the research centre. She also negotiates contracts, collaborates with industry and works on the creation of spin-offs, all as part of her work as a knowledge and technology transfer (KTT) specialist and a Business Developer.

As a researcher, you quickly learn how to be patient – and as a PhD student, you learn to be very

Sinead Savage
University of Manchester

THE ONLY PATH?

For both Savage and Huijbers, there was a time when they couldn't have imagined leaving academia. "While studying, I felt academia was the only route. I come from a family of academic scientists, and knew I wanted work in science too," comments Savage.

Huijbers had a similar experience but credits a lack of role models for feeling like academia was her only choice. "Many young scientists, including me at one time, feel like academia is the only path available to them," she suggests. "The examples they have are people already on that track – their supervisors and professors. It can be difficult to imagine what else is out there."

Spinato, however, hopes an influx of new roles will encourage other women to pursue careers outside of academia. "Five years ago, when I finished my PhD, there were very few roles working in KTT available," explains Spinato. "Since then, there has been a huge shift in Europe, with many more opportunities available.

TAKING THE LEAP

It was Huijbers' skills-oriented approach to her career that led to her leaving academia. "After my post-doc, I realised I needed a change. I wanted to work within the realm of science but felt my skillset would better suit something other than research," she says. "I knew I wanted to work in project management, and the Graphene Flagship gave me the opportunity to do something new."

Savage, on the other hand, experienced a more gradual transition. She hadn't enjoyed her PhD, but "PhDs are renowned for being stressful, so I wasn't sure whether my problems were with the PhD or with the research itself. So I decided to do a postdoc and worked in the lab I'm in today."

"After a few years, I concluded that research wasn't the career for me," Savage continues. "I started to split my time between my post-doc and managing the lab, then moved away from research altogether."

None of the four women left academia because they loved science any less. In fact, it was because they felt that something else was missing – whether they were looking for a new challenge, or a chance to use the skills that they otherwise wouldn't in a career in research.

THE SKILLS TO SUCCEED

One challenge is translating your skills into a new environment. But scientists may already have the skills they need to succeed in roles outside of academia.

"The skills you develop in academia are still applicable to the outside world. Think outside the box in terms of the roles you could fill and be prepared to convince others too," Huijbers says.

Savage's experiences confirm this idea. "As a researcher, you quickly learn how to be patient. This comes in handy as a project manager as I have to look at deadlines on a broader scale, and wait for things to come to fruition," she explains.
"As a PhD student, you learn to be very organised. Mislabelling or not keeping track of timing can be disastrous when collecting data, so I already had the most essential skill for project management.

Don't be afraid to leave academia. There's a world of opportunities out there beyond the lab."

Cinzia Spinato
ICN2

A FRESH PERSPECTIVE

Embarking on a career outside of academia can still be daunting. Having spent years in the lab, it can be difficult to adjust your sense of self, as Savage found. "My identity was built on being a scientist; I had to learn how to define myself without a research project. As time has passed, I've realised that I'm still a scientist, even if what I'm working on has changed," she remarks.

But there are many benefits to this switch in career trajectories, including new challenges and experiences. Helman, Savage, and Spinato all agree that their positions outside of academia gave them a different perspective on scientific research.

"While I'm not directly involved in the research being produced in the laboratories, my role gives me a much broader view, and I get to see graphene's impact across many areas of science," Helman explains. "Rather than just seeing one piece of the puzzle, I work across all the different work packages that form the Graphene Flagship."

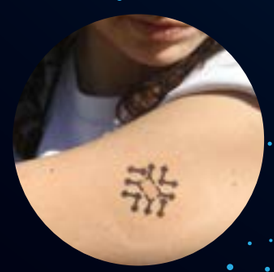
While project managers, science officers, and business development managers may not be the first STEM careers that come to mind, it does not make their contribution to science any less valid. There are countless fulfilling STEM career options outside of academia if you look for them.

For young scientists thinking about leaving the traditional academic track, Spinato has some final advice to offer: "Don't be afraid to leave academia. There's a world of opportunities out there beyond the lab."

HUMAN OF THE FUTURE

Graphene-enabled technology expands the realm of possibility within the biomedical and wearable electronics sectors.

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

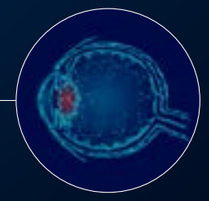
Graphene delivers a versatile light detection platform enabling the integration of sensors that monitor our exposure to UV light in real-time.

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.

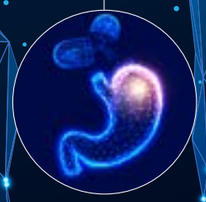
BRAIN-MACHINE INTERFACES

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.



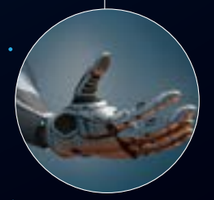
VISION RESTORATION

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



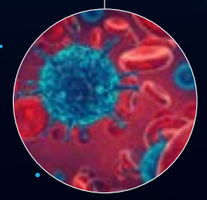
TARGETED DRUG DELIVERY

Drug delivery sytems 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.

MEDICAL GRAPHENE

HEALTHCARE AND BIOMEDICINE ENHANCED BY GRAPHENE

By: Tom Foley

Could graphene transform the future of healthcare? From graphene-based wearable monitors to optimise athletes' performance or track wound healing to implants that can record brain activity or provide artificial retinal vision, graphene and layered materials have great potential for a number of next-generation biomedical technologies.

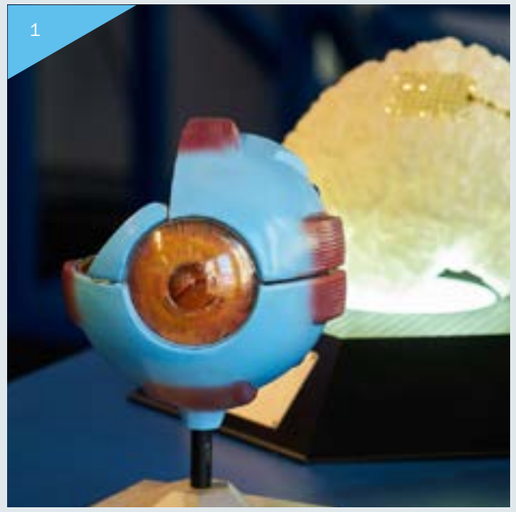
> Graphene has great potential for implants and therapeutic elements that target specific clinical outcomes in neurology,
>
> Tom Foley

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. Here, we highlight six of these promising initiatives.

One is CHEMsens, an initiative to develop a graphene-based plaster sensor for human skin. 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 can measures biophysical stress and transfer 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.

Also in the ever-expanding realm of wearables, Grapheal have developed a pioneering wearable patch to remotely monitor chronic wounds. The flexible and transparent graphene-based biosensor continuously records and stores biometric wound data, which is then communicated to the cloud thanks to a smartphone app. Using this technology, doctors and nurses can remotely monitor wound healing in their patients, with prompt alerts if any infections or medical complications arise. Grapheal are also currently developing a graphene-enabled diagnostic test based on saliva sampling to rapidly screen for the COVID-19 infection.

New spin-off company INBRAIN Neuroelectronics was born with a pioneering spirit in mind. Originating from ICN2 and ICREA, Spain, INBRAIN scientists are working on graphene-based implants to record brain activity for the treatment of brain disorders like Parkinson's and epilepsy. The smart devices are built around an innovative graphene electrode to decode neural signals with high fidelity, enabling a personalised therapeutic response. The spin-off already attracted a €1 million investment from four investment firms earlier in 2020 to accelerate their development.



In the same vein, a newly developed graphene-based brain implant detects electrical brain activity at extremely low frequencies and over large areas, unlocking previously undetectable information. Indeed, brain activity at such low frequencies – below a tenth of a hertz – carries critical information about the onset and progression of epilepsy and strokes, and the mapping of these was unprecedented. The technology, developed by Graphene Flagship scientists at ICN2, IDB-CNM, IDIPABS and ICFO, Spain, has already been adapted for brain recording, and could change the way neurologists visualise brain activity.

In the field of biomedical imaging and diagnostics, Graphene Flagship spin-off company Cambridge Raman Imaging Limited (UK and Italy) are developing graphene-based ultrafast laser devices to diagnose and track tumour growth in cancer patients. Their devices will be used in a new kind of medical microscope that takes advantage of Raman spectroscopy to generate digital images of tissue samples in real-time. The technology could differentiate between healthy and diseased tissue, show the extent of tumours and measure their response to drug treatment, potentially allowing surgeons to verify whether a cancer has been completely removed after operation.

With a bold vision, Jose Garrido and other Graphene Flagship scientists are working on graphene-based retinal implants to provide artificial vision to patients with retinal degeneration. They have developed electrodes that mimic the way stimulation works in natural photoreceptors: images are captured by an external camera and sent wirelessly to the graphene-enabled electrodes, which transform these signals into electrical impulses that can travel into the brain. Using this device, patients blinded by retinal degeneration may be able to see again. So far, images are still pixelated, but the team were recently awarded a €1 million grant by the la Caixa Foundation to further develop their prototypes. Now, they plan to embark on an ambitious three-year project to design the next generation of retinal prostheses using graphene.

The future is bright for graphene in healthcare, and the Graphene Flagship looks forward to seeing the first fruits of these promising initiatives come forth over the decade ahead.

1. Graphene-based retinal implants to provide artificial vision to patients with retinal degeneration. Graphene Flagship researchers have developed electrodes that mimic the way stimulation works in natural photoreceptors. Image: Graphene Flagship

2. An adhesive human skin sensor can detect and analyse key biological constants, like the levels of sodium, potassium, lactic acid and glucose in the sweat.

3. INBRAIN scientists are working on graphene-based implants to record brain activity for the treatment of brain disorders like Parkinson's and epilepsy. Image: ICN2/INBRAIN

4. A newly developed brain implant detects electrical brain activity and could change the way neurologists visualise brain activity. Image: ICN2

GRAPHENE WEARABLES

EXPLORING THE FUTURE OF GRAPHENE-BASED WEARABLE DEVICES

By: Melanie Lawson and Tom Foley

Over time, scientists and manufacturers are integrating more and more technology into wearable accessories like wristbands, watches, glasses and clothing. Owing to its astounding physical properties, such as its strength, conductivity and thinness, graphene could play an integral role in the wearable technology of the future, and the Graphene Flagship are working hard to make this happen.

"It's the thinnest material, making it an excellent choice for new sensing devices. It's also a more sustainable solution, as graphene-based circuits can be printed without requiring rare or precious metals," comments Maria Smolander, leader of the Graphene Flagship's Flexible Electronics Work Package at VTT, Finland. Its thinness and durability are also extremely valuable: "One of the best things about graphene is that you can use it to make stretchable structures that are also really strong, with great electronic properties. This gives it fantastic potential for wearables," Smolander continues.

But can the Graphene Flagship thread the needle? Our scientists have developed a number of new wearable technologies that could help to shape the future of personal and flexible electronics. Read more to find out about a few of them.

The next generation of retinal prostheses, developed by ICN2, ICFO and IFAE, use graphene-based electrodes to provide artificial vision to patients blinded by retinal degeneration.

The outstanding flexibility and durability of graphene allow it to easily be integrated into flexible substrates to provide bidirectional communication, which is essential to establishing a proper interface with the nervous system.

IIT developed graphene-based nerve sensors that control motion and force in artificial robotic limbs.

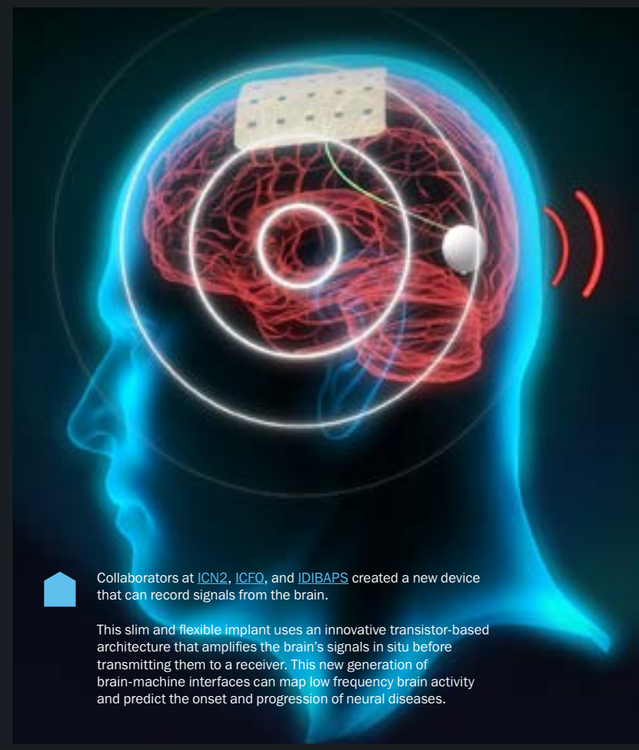
The fast response of graphene ensures natural movement and grip with biocompatible, non-invasive sensors. This allows for

Grapheal developed a pioneering wearable patch for the remote monitoring of chronic wounds.

The flexible and transparent graphene-based biosensor enables hyper-responsive treatment of chronic wounds with early detection of complications in the healing process. Their patented graphene-on-polymer formula is non-invasive and actively reacts

Atomic Mechanics developed a transparent, force-sensitive film, made from graphene and plastic, which allows for accurate pressure detection. The laminate film is so thin that it can be applied to 3D surfaces and integrated into flexible devices.

The film can even be used as an electronic skin, enabling any surface to become highly responsive to its environment. This could see applications in healthcare, robotics, and industrial automation.



Collaborators at ICN2, ICFO, and IDIBAPS created a new device that can record signals from the brain.

This slim and flexible implant uses an innovative transistor-based architecture that amplifies the brain's signals in situ before transmitting them to a receiver. This new generation of brain-machine interfaces can map low frequency brain activity and predict the onset and progression of neural diseases.

ICFO designed a flexible, transparent and disposable skin patch containing a UV sensor that allows users to monitor their exposure to sunlight.

The patch connects to a mobile device and alerts the user via an app once a defined threshold of sun exposure has been reached.

ICFO's fitness bands monitor multiple vital signs during exercise, including heart rate, hydration, blood oxygen saturation, breathing rate and temperature.

This data, relayed to the wearer via an app, could help the user to optimise their exercise conditions and routine, and could

SPEARHEADS TAKE AIM FOR INNOVATION

By: Rebecca Waters

Of all of the Graphene Flagship's initiatives, it's possible that the Spearhead Projects are the most effective tool for advancing our goal to bring graphene out of the lab and onto the market. The Spearhead Projects are company-led initiatives with well-defined, application-oriented objectives, aiming to produce industrial prototypes using graphene and layered materials within two years.

In fact, the Spearhead Projects' objectives are so important to the Graphene Flagship that roughly 30% of the budget allocated to the current phase of the project is assigned to them. "This is a bold move that shows our firm commitment to maximising the impact of the Graphene Flagship," says Graphene Flagship Director Jari Kinaret.

Here, we take a look at three Spearhead Projects that are driving graphene-based technology forward on the road to a better world.

> 30% of the budget allocated to the current phase of the Graphene Flagship is assigned to the Spearhead
>
> Jari Kinaret

GRAPHENE COLLISION AVOIDANCE SYSTEMS FOR AUTONOMOUS VEHICLES

Autonomous driving is the future – but is it safe? With current technology, driving in darkness or adverse weather conditions such as rain, fog and snow could be dangerous. The AUTOVISION Spearhead Project is developing a new high-resolution image sensor for autonomous vehicles, which can detect obstacles and road curvature even in extreme and difficult driving conditions.

Currently, self-driving cars use visible cameras, but in dense fog, these cameras are insufficient. Autonomous cars will also use LIDAR sensors, relying on pulsed laser to measure distances and constantly scan the area around them. However, this is a relatively slow-processing technology in comparison with the potential of next-generation imaging systems.

The AUTOVISION project, led by ICFO in Barcelona, benefits from collaboration with industrial partners such as Aixtron in the UK and Veoneer in Sweden. The project will help to make safe the deployment of autonomous vehicles possible. Afterall, the success of autonomous driving will largely depend on how split-second moments of imminent danger are handled.

Over the course of three years, AUTOVISION will produce complementary metal-oxide semiconductor (CMOS) graphene quantum dot image sensors in prototype sensor systems, ready for uptake in the automotive sector. Across the duration of the project, the image sensor under development is set to take huge leaps in terms of sensitivity, operation speed and pixel size.

In the wider electronics industry, CMOSs are at the heart of technological revolution. They have enabled compact and low cost micro-electronic circuits and imaging systems, but the diversification of this technology in applications other than microcircuits and visible light cameras has seen limited progress. This is due to the difficulty of combining CMOSs with semiconductors other than silicon.

Recently, monolithic integration of graphene into a CMOS-integrated circuit was made possible, enabling high-resolution image sensing that detects UV, visible, infrared and even terahertz frequencies.

AUTOVISION is developing a high-resolution image sensor for autonomous vehicles that can detect obstacles and road curvature even in extreme and difficult driving conditions.

The sensor's ability to see in the infrared – effectively night vision – means that same graphene CMOS sensors can be used as part of a self-driving car's automatic brake system, specifically in bad weather. This collision avoidance system is set to be a crucial application for graphene, and one that will support the wider uptake of autonomous driving technology.

NEXT-GENERATION AEROSPACE FILTRATION

Developed in collaboration with Naturality Research & Development in Spain, and Lufthansa Technik, Phi-Stone and Sixonia Tech in Germany, the AEROGrAFT Spearhead Project is on a mission to develop prototype self-cleaning air filters that utilise aero-graphene foam.

Developed with graphene's homogenous heat distribution properties in mind, the graphene-enabled foam will ensure even heat throughout the air filter, to elicit a consistent cleaning across all air filter surfaces. What's more, the self-cleaning air filters can use the same graphene foam repeatedly, for recurrent cleaning cycles, without losing stability.

Not only will the self-cleaning filter need servicing, but it can also be cleaned quicker. The team believes they will have developed a prototype filter that will take less than 30 minutes to clean within 18 months. By the end of the project in 2023, this will be below the ten-minute mark.

Moreover, this project will explore the use of graphene-foam filters to remove contaminants from cabin air. Their unique qualities allow them to filter out germs that current HEPA filters are unable to eliminate. Imagine the benefits of filters that can materially reduce the chance you'll get sick when you fly!

GRAPHENE BROADBAND INFRARED IMAGER FOR CAMERA SYSTEMS

The graphene broadband infrared imager for camera systems (GBIRCAM) Spearhead Project is developing a camera that detects visible light (VIS), near-infrared (NIR), short-wavelength infrared (SWIR) and long-wavelength infrared (LWIR) in one single superpixel device, which will reduce the costs of broad spectrum imaging.

The lower costs make imaging technology more accessible to businesses, not only for sensor integration in products, but also from an end-user perspective. The broad-spectrum capabilities allow users to see beyond the capabilities of the human eye, to quickly analyse and determine the chemical composition of organic products such as food. This means vastly improved safety for the food, pharmaceutical and security sectors, among others.

This graphene broadband infrared imager for camera systems allows users to see beyond the capabilities of the human eye, to quickly analyse and determine the chemical composition of organic products such as food. Image: Emberion

Led by industrial partner Emberion, the main goal of the GBIRCAM project is to produce a broadband and high resolution single focal plane array infrared imager that covers all wavebands from 400 nm to 14 micrometres. The final product will be capable of simultaneously detecting light in all atmospheric transmission bands, enabling many commercial applications.

Detectors for the wavebands of interest, from VIS to LWIR, currently rely on very different material solutions. There is an inherent difficulty in combining these on the single substrate needed for a compact imager, which is why broadband focal plane arrays do not yet exist on the market. Suitably functionalised graphene offers the opportunity to combine the needed waveband sensitivities onto a single substrate, enabling a broadband-sensitive single focal plane array.

The final broadband camera product, using a single detector array, is set to perform in an operational environment at a pre-commercial scale by the end of the three-year project.

Learn more about Graphene Flagship Spearhead Projects that support a more sustainable future on

DIALING UP SMARTPHONE TECHNOLOGY

WITH GRAPHENE AND LAYERED MATERIALS

By: Kari Hjelt

A graphene-enhanced phone has the potential to use the full bandwidth of the 5G network, which is up to five times faster

Kari Hjelt

Innovations in graphene, thanks to its unique electronic and physical properties, are driving forward a new wave of exciting innovations in smartphone hardware. Kari Hjelt, Graphene Flagship Head of Innovation, explains how, thanks to graphene, phones could become faster and better-connected, with longer battery lives than ever before.

The dawn of the smartphone transformed the face of personal electronics. Since then, consumers worldwide have endlessly wondered what – and when – the next big innovation in smartphone technology will be.

In recent years, materials science has proven to be paramount in the development of next-generation phones. New types of high-tech glass, for instance, ushered in a wave of phones with curved and foldable screens. Similarly, ceramics-based materials like piezoceramics are now being used to make super-small phone speakers, and they have much better sound quality than the ones on the market just a couple of years ago.

Given that graphene is million times thinner than a human hair, harder than a diamond and more electrically conductive than copper, it is in an excellent position to be investigated and exploited by scientists developing new smartphone technologies. The time is ripe for graphene to enter the fray, and the Graphene Flagship aim to lead the charge.

CONNECTIVITY

Graphene could make the phones of the future even faster. Using graphene-based photonics, the Graphene Flagship's 5G Spearhead Project developed a method to transmit data at speeds of up to 56 gigabits per second – significantly faster than a wired Ethernet connection. This new data connection is faster, consumes less energy and results in fewer transmission errors than current 4G wireless connections. A graphene-enhanced phone has the potential to use the full bandwidth of the 5G network, which is up to five times faster than 4G.

Also in the realm of data transfer, the Graphene Flagship's radio frequency identification (RFID) Spearhead Project has created a platform to produce printed RFID sensors. RFID sensors are commonly used in shops, hospitals and educational institutions, and their main function is to sense light, humidity or physical strain and communicate this data to a reader or a phone via near-field communication (NFC). The printable graphene-based RFID sensors are poised to be low-cost and easy to use, although due to the limited quality and performance of today's printed components, these benefits have yet to be fully realised. But RFID sensors printed from graphene could be the solution, unlocking the potential for further innovations in wearable electronics.

HARDWARE

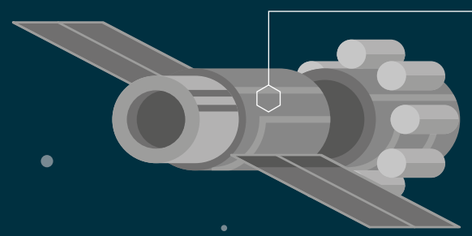
Consumer demand for more advanced smartphones is ever on the rise. But could graphene take phone technology to the next level? All signs point to graphene being a promising contender on many fronts.

Firstly, graphene's electronic properties make it ideal for faster, more reliable internal components. Graphene is strong and highly conductive, but also extremely thin – just one atom thick – so it could lead to smaller but faster microprocessors for smart objects and the Internet of Things. Furthermore, graphene and layered materials are flexible, meaning graphene could potentially be incorporated into foldable or curved screens. Graphene-based screens could even be pressure-sensitive, meaning smartphone screens could respond differently to hard and soft taps.

Graphene could also improve the capacity, efficiency and stability of phone batteries. For instance, the Graphene Flagship's lithium–oxygen-based rechargeable battery has energy densities up to ten times higher than conventional lithium-ion batteries with over 90% efficiency, and it can be recharged over 2,000 times. Graphene and layered materials could also enhance the properties of other energy storage solutions, like supercapacitors.

Graphene and layered materials are also a good candidate for next-generation headphones and speakers, and graphene-based earphones are already on the market. This is because graphene is flexible but strong, meaning a speaker made from a graphene-based membrane would experience fewer unwanted vibrations, resulting in less noise and clearer sound.

Finally, mixed with resins and plastics, or even just as a coating, graphene can already be used to make safer helmets, stronger and lighter aeroplane parts and more resistant construction materials. Incorporating graphene into phone casing could make it much more robust, so we may never need to worry about dropping our phones ever again!



GRAPHENE IN SPACE
Graphene's thermal properties improve the performance of loop heat pipes and thermal management systems used in aerospace and satellite applications.

CITY OF THE FUTURE

Progressive technologies and innovative devices from the Graphene Flagship promote sustainable smart cities.

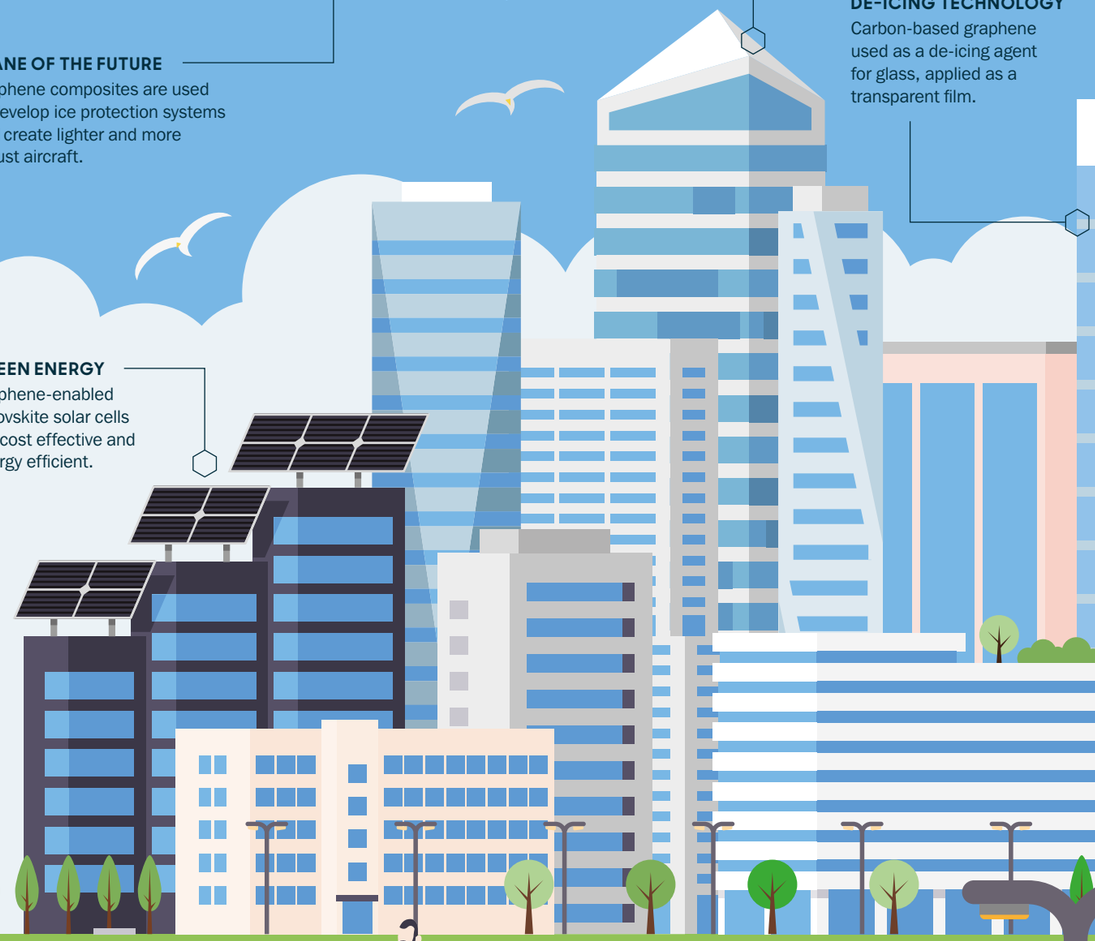
By: Melanie Lawson

PLANE OF THE FUTURE
Graphene composites are used to develop ice protection systems and create lighter and more robust aircraft.

SMOG REDUCING PAINT
Graphene composite coatings can be applied to concrete walls and pavements to remove air pollutants.

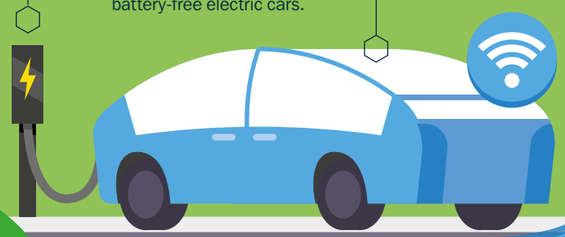
DE-ICING TECHNOLOGY
Carbon-based graphene used as a de-icing agent for glass, applied as a transparent film.

GREEN ENERGY
Graphene-enabled perovskite solar cells are cost effective and energy efficient.



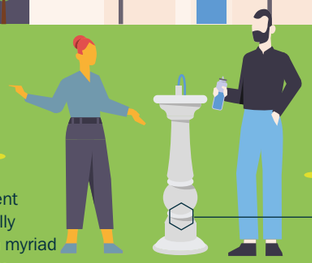
GRAPHENE SUPERCAPACITORS
Graphene supercapacitors are paving the way to ultra-fast charging and battery-free electric cars.

AUTONOMOUS DRIVING
High resolution hyper-spectral image sensors enable safe autonomous driving.



INTELLIGENT CAMERA SYSTEMS
A single super-pixel device will reduce the cost of broad-spectrum imaging.

CONDUCTIVE CONCRETE
Graphene makes cement thermally and electrically conductive, providing a myriad of new possibilities from underfloor heating to charging solutions for electric cars.



WATER FILTRATION
Graphene enables innovative water filtration systems for sustainable and efficient water purification.

POLLUTION SENSORS
Graphene-based gas sensors enable portable and highly sensitive environmental monitoring of nitrogen dioxide.

GOING GREEN WITH GRAPHENE

GREENER POSSIBILITIES FOR A SUSTAINABLE FUTURE

By: Letizia Diamante

The Graphene Flagship, hand-in-hand with many institutions, enterprises and governments around the world, have pledged to work towards the United Nations' 2030 Agenda for Sustainable Development and the EU Green Deal.

Our sustainable research across Europe is diverse in both discipline and scale, and aims to solve a broad range of important societal and environmental challenges – from the development of low-cost, handheld graphene-enabled water quality sensors, to the establishment of the world's first graphene-enabled solar farm in Greece. Overall, our projects contribute to 11 of the 15 UN Sustainable Development Goals (SDGs), and we believe that graphene and layered materials will play a key role in the green revolution.

But with less than ten years to go before 2030, the need for new technologies to ensure sustainable access to energy and water has never been greater. To this end, the Graphene Flagship is paying more attention to sustainability than ever, focusing many of our industry-led Spearhead Projects and a broad range of our research initiatives and commercial endeavours to develop innovative solutions for a greener, more sustainable future. Among them, several concentrate on SDGs 6 and 7: clean water and sanitation and affordable and clean energy.

WATER

In line with SDG 6, which aims to ensure availability and sustainable management of water and sanitation for all, Graphene Flagship researchers are investigating various applications of graphene to improve water filtration and contaminant detection technology. Furthermore, graphene-based membranes could potentially purify sea and waste-water, making it suitable for consumption and agriculture.

Since many common water contaminants are resistant to conventional purification techniques, Graphene Flagship researchers are working on new graphene-enriched water filters. These filters could remove toxins and contaminants from European water, and they could also contribute to water conservation programmes in arid regions in the Global South.

AFFORDABLE, POINT-OF-USE WATER TREATMENT

Graphene-enriched water filters favour the absorption of organic and inorganic contaminants, so they are a great candidate for next-generation water filtration technology. Scientists at **Medica SpA**, Italy, lead the recently established Spearhead Project GRAPHIL, which seeks to develop micro-filtration membranes that can be directly connected to a household sink. The commercial product should be ready for the market in 2023.

MEMBRANE FILTERS FROM INDUSTRIAL SCRAPS

Researchers at **CNR, Italy,** and **Chalmers University of Technology, Sweden**, envisioned a new technique to produce water filters from graphene oxide (GO) and a waste product from the industrial production of polysulfone membranes. The graphene-coated membrane combines the unique properties of both materials and works simultaneously as a filter and as an adsorbent.

"Our method can not only be applied to commercial membranes, which are already manufactured on large scales, but also to scraps derived from their fabrication," explains Vincenzo Palermo from Chalmers University of Technology, Vice Director of the Graphene Flagship. "This is a great advantage, and a step forward towards a circular economy."

CONTAMINANT SENSING FOR SAFE WATER

Low-cost graphene-based sensors developed by the Graphene Flagship can detect bacteria, viruses, proteins, oligonucleotides, toxins and metal ions. These easy-to-prepare sensors also show promising sensitivity.

"We are developing paper or plastic platforms with graphene-based electrodes. They can become cheap lateral flow devices, with structures similar to pregnancy tests or simple microfluidic devices," explains Arben Merkoçi from **the Catalan Institute of Nanoscience and Nanotechnology (ICN2).**

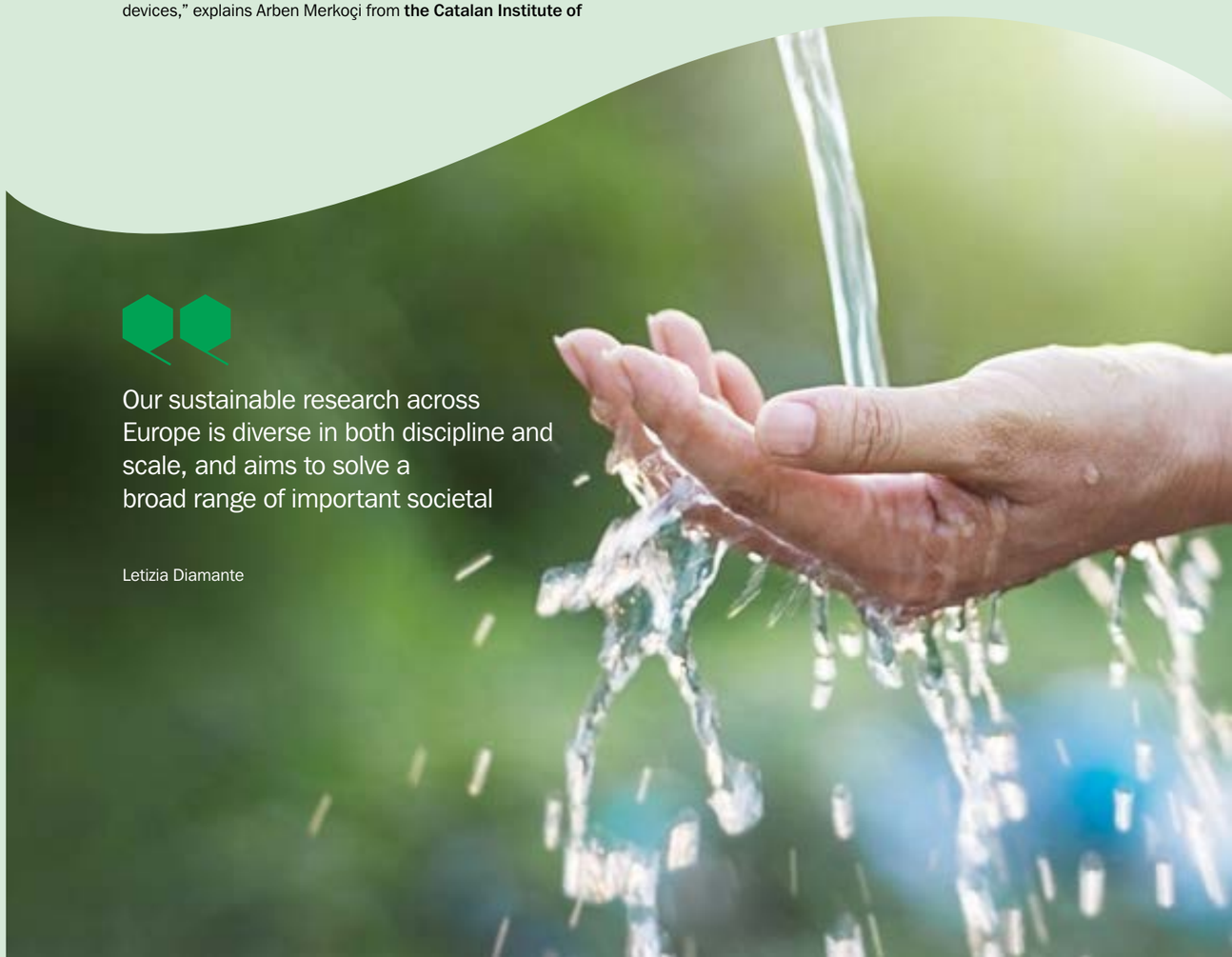
Recently, Merkoçi and colleagues in the Graphene Flagship's Sensors Work Package created a sensing platform, based on reduced GO, to detect harmful toxins originating from fungi that are frequently found in agricultural products like wheat and corn. Farmers could use these graphene-enabled sensing platforms to protect their crops and help their agricultural businesses to thrive.

TOXICITY TESTING FOR RESPONSIBLE RESEARCH

We recognise that it is vital for the Graphene Flagship to study the effects of graphene and layered materials on health and the environment, in addition to those of our research and the industrial and commercial processes we enable.

To this end, the Graphene Flagship's Health and Environment Work Package works tirelessly to conduct environmental toxicity tests – in line with the OECD Guidelines for Sustainability – and determine appropriate methods for the disposal, treatment and recycling of products containing graphene and related materials.

In addition, our SafeGraph Spearhead Project formulates strategies to help our other projects comply with all the relevant safety regulations and legislation, helping Graphene Flagship-



> Our sustainable research across Europe is diverse in both discipline and scale, and aims to solve a broad range of important societal
>
> Letizia Diamante

enabled products reach the market in a safe, cost efficient and timely manner.

ENERGY

To cope with the ever-increasing global demand for energy, Graphene Flagship researchers are searching for new renewable and sustainable options. Graphene-enabled batteries, supercapacitors, solar cells and other new energy-saving solutions could bolster the European Union's efforts to reduce our dependence on fossil fuels.

Two of our Work Packages, dedicated to Energy Generation and Energy Storage, and several of our Spearhead Projects address SDG 7 to ensure access to affordable, reliable, sustainable and modern energy for all.

CREATING THE WORLD'S FIRST GRAPHENE SOLAR FARM

The Graphene Flagship's Solar Farm Spearhead Project established the world's first graphene-enabled solar farm in Crete, Greece. In 2019, our Italian partners the **Italian Institute of Technology (IIT), the University of Rome Tor Vergata** and **spin-off BeDimensional** collaborated to produce large-area graphene-enriched perovskite solar cells, which achieved excellent power conversion efficiencies of 15.3%.

Now, our industry-led GRAPES Spearhead Project includes partner companies such as **Greatcell Solar and Siemens**, and aims to surpass this figure with new solar cell configurations. Beyond flexibility, transparency and low-light responses, graphene-enabled solar cells could reduce the cost of photovoltaic energy below €20/MWh – cheaper than fossil fuels.

SAVING WEIGHT, FUEL AND ENERGY IN CARS AND PLANES

Lightweight graphene-based composites can save significant amounts of energy in the automotive and aerospace industries. An industrial collaboration between partner companies **Avanzare, Spain, and Nanesa, Bioage SRL, SPAC SpA** and **Fiat-Chrysler Automobiles, Italy,** aims to replace the metal in conventional vehicle dashboards with graphene-based materials. The Spearhead Project G+BOARD will reduce the weight of vehicles, lowering their fuel consumption and CO_2 emissions.

In addition, our Spearhead Project GICE, which comprises several key partners in the aeronautics industry, including **Airbus and Sonaca**, is studying graphene-enabled systems to remove ice or prevent ice accumulation in helicopters and planes. Thanks to the outstanding properties of graphene, thermoelectric de-icing or anti-icing systems can be lighter and more fuel-efficient, saving up to 90% of the energy required for conventional hot air alternatives.

To learn more about the Graphene Flagship's contributions to the aeronautics industry – and to find out about our recently appointed Aeronautics Champion, **Airbus'** Elmar Bonnacurso, and his commitment to new and existing innovations in the field – please turn to page 34.

> When it comes to sustainability, be it in terms of green energy, clean water or beyond, the future of graphene and
>
> Letizia Diamante

GREENER TECHNOLOGIES FOR ENERGY STORAGE

Worldwide demand for battery-based energy storage will significantly increase by 2025, and graphene and layered materials could play a vital role in meeting this higher demand.

Due to its light weight and high surface area, electrical conductivity, chemical stability and mechanical flexibility, graphene can increase the energy capacity, charge rate and nourishing stability of lithium-ion batteries. In practice, this means graphene-enabled batteries for electric vehicles, mobile phones, laptops and more could have longer lifespans and faster charge times.

The Graphene Flagship Spearhead Projects Batteries and GreenBAT aim to provide innovative energy storage solutions to significantly increase the energy density of lithium-ion and post-lithium batteries – not only for portable and automotive applications, but also for the decentralised storage of renewable energy.

PAIRING SILICON AND GRAPHENE

In March 2020, Graphene Flagship researchers at **VARTA Micro Innovation GmbH**, Austria, and BeDimensional and **the Istituto Italiano di Tecnologia (IIT)**, Italy, announced a new prototype of graphene-enabled lithium-ion batteries with capacities more than 30% higher than any currently available alternative. With graphene, batteries can overcome some of the mechanical limitations of silicon. Christoph Stangl, from **VARTA Micro Innovation GmbH**, has a clear goal: "Now, we want to quickly push this exceptional battery technology towards commercialisation."

When it comes to sustainability, be it in terms of green energy, clean water or beyond, the future of graphene and layered materials is bright. Thanks to the Graphene Flagship's push for innovation, we are confident that graphene and layered materials will have a vital role to play in the move to a

Beyond flexibility, transparency and low-light responses, graphene-enabled solar cells could reduce the cost of photovoltaic energy below €20/MWh – cheaper than fossil fuels.

INTRODUCING GRAPHENE HUB

CONNECTING RESEARCH AND INDUSTRY ONLINE

By: Sofia Järbur and Luciana Löberg

The Graphene Flagship is, at its roots, a community. An international community of researchers and innovators that are working on common challenges, enabled and enhanced by close collaboration and communication.

Traditionally, many of the interactions that brought our community together came in the form of conferences, tradeshows and meetings, but now, the events landscape is evolving. Why limit our community to one or two opportunities to connect each year, when we can introduce new opportunities for knowledge transfer, collaboration and networking at regular intervals?

This is the idea behind the Graphene Flagship Dissemination Team's new Graphene Hub: a single portal for a variety of digital and hybrid events, in addition to providing community-building resources. Launched in 2020, the Graphene Hub offers the international graphene and layered materials community the latest technology for digital events with a modern interactive platform.

Say goodbye to standard Zoom meetings, webinars and slide-shows. The Graphene Hub will now allow attendees at Graphene Flagship digital events to join discussions about the presentation, submit and vote on audience questions, and chat one-on-one with fellow attendees and speakers. Do you miss mingling during coffee breaks and hallway chats at conferences? The Graphene Hub offers a variety of networking opportunities, from easy one-to-one chats and video calls with digital event attendees to speed networking and break-out room discussions.

PORTFOLIO OF EVENTS

By launching the Graphene Hub, the Graphene Flagship's Dissemination team aims to deliver the next generation in digital events.

GRAPHENE FOR...

Graphene For... is a free digital event series that provides insights on specific topic areas within graphene research and innovation. These events are open to the global graphene community making them a fantastic venue for networking and sharing your ideas.

INDUSTRY EVENTS

Digital exhibitions will provide the Graphene Flagship's industry partners with the possibility to showcase their work virtually and network with experts, collaborators and investors. A digital product gallery could keep your products in the spotlight 24/7.

HYBRID CONFERENCES

Meetings combining a "live" in-person event with a "virtual" online component are shaping the future Graphene Flagship international conferences, including Graphene Week 2021 (20–24 September) in France and Graphene Study 2021 (summer) in Sweden.

GRAPHENE WORKSHOPS

Our events portfolio will also include smaller, more interactive virtual workshops, providing attendees the opportunity for group discussions, breakout sessions delving into detailed applications and networking. Stay tuned for upcoming workshops.

WEBINARS

A series of innovation webinars are planned for the upcoming year. View past content on the Graphene Flagship Innovation Education and Training Platform. The platform includes webinar videos and presentations by our very own Graphene Flagship experts, in addition to a wealth of learning materials provided by

ADVANTAGES OF GOING DIGITAL

While in-person meetings are important and will never be replaced in our events portfolio, the advantages of virtual events are already impossible to ignore. It's clear that, even in combination with in-person conferences, the online world offers many benefits that could make the latest ideas in academia accessible and enlightening for

FROM THE ORGANISERS

This new portfolio of online event opportunities was developed thanks to the work of our dedicated events and marketing team. They work together to offer an incredible experience, whether you are attending one of our in-person research or innovation events, or logging into our online Graphene Hub from anywhere in the world.

If you have suggestions or questions regarding the Graphene Flagship's events portfolio, please don't hesitate to contact us at event@graphene-flagship.eu.

We adapt to new circumstances to keep our community connected. The growth and development of online meeting tools has accelerated incredibly quickly over the last six months or so, and the Graphene Flagship has undoubtably

Luciana Löberg
Graphene Flagship Event Manager

Digital events provide an unprecedented level of accessibility. Now, you can easily meet with buyers or collaborators from Europe, Asia, North America and beyond, all at the same time, all from the comfort of your own home. A truly international

Sofia Järbur
Graphene Flagship Marketing Coordinator

CALENDAR

October

Mo	Tu	We	Th	Fr	Sa	Su
			1	2	3	4
5	6	7	8	9	10	11
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15 October
Graphene for Healthcare

November

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3 November*
Workshop: Graphene from the Buyer's Perspective

12 November*
Innovation Day: Electronics

December

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10 December
Graphene For Space Exploration

GRAPHENE TAKES FLIGHT

WITH AERONAUTICS CHAMPION ELMAR BONACCURSO

By: Letizia Diamante

Elmar Bonaccurso is an expert in the science of innovative materials and new aircraft technologies. He works as a Senior Scientist at **Airbus** in Taufkirchen, Germany. Airbus is leading a Spearhead Project focused on the prevention and elimination of ice in aircraft: GICE.

We have now appointed Bonaccurso as our Aeronautics Champion, to act as a public-facing representative for the Graphene Flagship's efforts to develop next-generation technologies for aviation using graphene and layered materials.

He talks about his background and his new position as our Aeronautics Champion, and explains why graphene and ayered materials have the potential to make aviation cleaner and greener.

How did you get started in the field of aeronautics?

I grew up with a strong interest in aeronautics and aerospace, convinced that these fields need the most advanced materials possible to progress. After gaining a broad background in engineering, chemistry, physics and materials science, I started working for one of the biggest aeronautics players worldwide – Airbus.
Now, I get to do exactly what I love most: investigate advanced materials for aeronautical applications. I work in the Central Research and Technology department at Airbus, where innovations are born, and new projects take their very first steps.

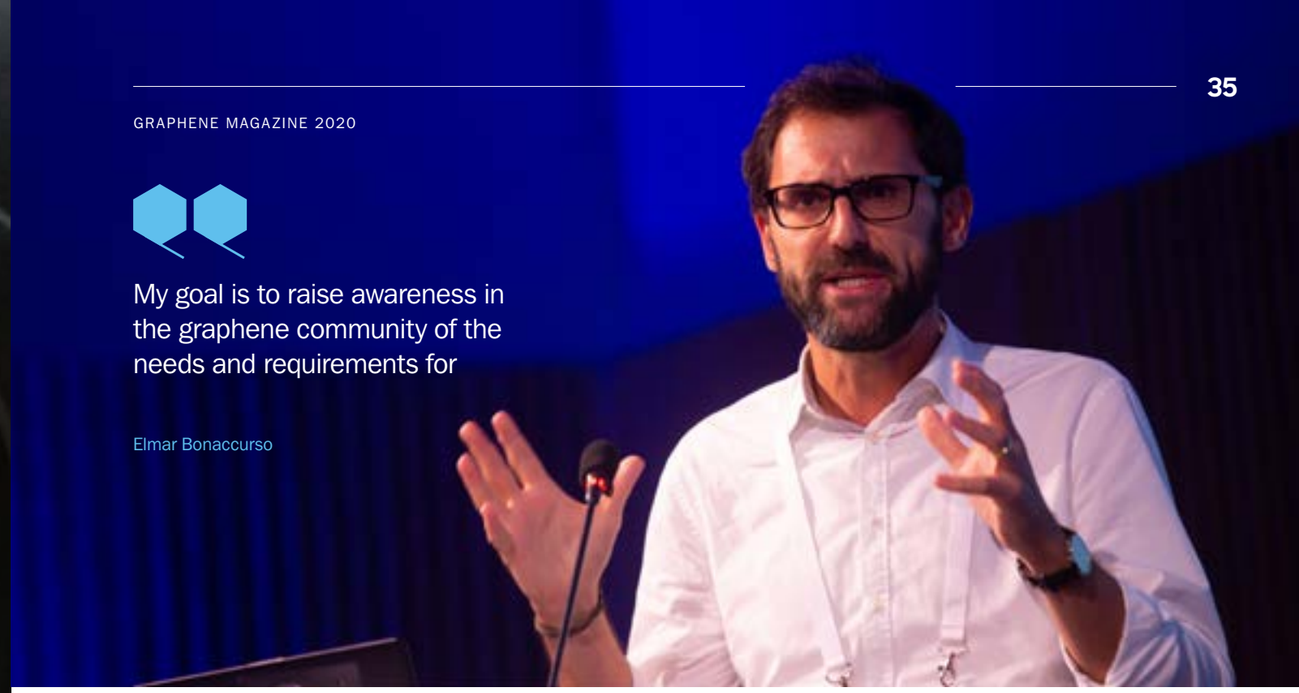
What kind of innovations are you currently working on?
Broadly speaking, my colleagues and I are working to make aviation greener and more sustainable. There's no readily available blueprint for this, which makes this multidisciplinary task extremely challenging… but it's exceptionally fascinating.

We are developing new materials with a variety of properties, always with sustainability in mind. For instance, we are looking into lighter components for aircraft that retain the high mechanical resistance of their heavier counterparts. We're investigating materials derived from renewable sources that are fully recyclable – and we're also trying to identify multifunctional materials with a combination of attractive properties.

Graphene and layered materials will certainly be able to meet a number of these requirements, which is another aspect that makes my work so exciting!

Have you worked with graphene before?

Although I had never worked with graphene before, I closely followed all the developments that occurred during the last decade. Personally, I am really interested to see if we can use graphene to improve the materials and technologies in aeronautics. Now, thanks to the Graphene Flagship Spearhead GICE, we can investigate whether the properties of graphene and



My goal is to raise awareness in the graphene community of the needs and requirements for

Elmar Bonaccurso

How can graphene help us to build better aeroplanes?

Graphene can play a role in several parts of the aircraft. It can make composite materials simultaneously strong, tough and lightweight. Reducing the weight of the aircraft brings considerable advantages: each kilogram spared saves approximately two tons of fuel, avoiding six tons of CO_2 emission, over the lifetime of an aircraft.

Graphene can also protect metals, composites or ceramic materials from environmental hazards, including sand, rainfall and strong UV radiation. Its high thermal and electrical conductivities can be used to add new functionalities to materials and increase their performance. It can be used for electrical motors, on-board systems, electrical sensors, thermal actuators and many more applications.

We have recently started looking into using graphene for some novel and sophisticated technologies, applicable to our field – however it is too early to say exactly which solutions graphene will bring to the aeronautics industry.

Can you tell us a bit about your role as the Graphene Flagship Aeronautics Champion?

My goal is to raise awareness in the graphene community of the needs and requirements for aeronautical innovation. Graphene is one of the most promising materials we are currently working with, and since I have a good overview of materials research in the aeronautics field, I hope to provide new input and drive innovation. This will be possible in cooperation with both my network at Airbus and with other aeronautical companies around the world.

What's next for the future, and for the GICE project?

Airbus has been Graphene Flagship partner from the very beginning, and this close collaboration further increased with the launch of the GICE Spearhead project. The project is coordinated by Airbus, but also involves other leading companies and universities in Europe. Together, we will incorporate graphene and layered materials into novel ice-protection systems for planes and helicopters.
The accumulation of ice and snow on the wings and other parts of aircraft mid-flight is dangerous, as it can disrupt the airflow and hinder the pilots' control of the vehicle. We want to test whether graphene is a flexible solution to replace the current electrical heating elements that prevent ice formation. Several of graphene's properties play a role here, in terms of weight saving and the scalability and flexibility of the manufacturing processes.

We've seen promising results so far. Now, we need to develop a

Graphene increases the mechanical properties of the leading edge of an airplane wing, enabling it to be thinner, decreasing its weight, while maintaining its functions. Image: Johan Bodell/Chalmers

Above: Elmar Bonaccurso
Image: Vesa Laitinen

PLANE OF THE FUTURE

The Graphene Flagship is using current research and disruptive technologies to solve enduring challenges within the aviation industry.

By: Melanie Lawson

DE-ICING

Graphene-based ice protection systems prevent the accumulation of ice on critical components of the aircraft. Improving the safety robustness and eliminating expensive chemical de-icing

THERMAL MANAGEMENT

Graphene can improve efficiency in heat transfer in loop heat pipes – cooling systems used in satellites and aerospace instruments. Loop heat pipes cool electronic devices by using the heat they generate to evaporate a fluid inside a wick. The wick can be coated in graphene to improve the heat transfer between the electronic

STRENGTH AND ROBUSTNESS

Graphene's high aspect ratio, flexibility and mechanical strength enable it to enhance the strength of weak points in currently used composites, such as at the interface between two different components.

DISPERSING LIGHTNING

The excellent conductive properties of graphene are harnessed to create an electrically conductive framework that improves resistance to electromagnetic interference and disperses the energy of lightning strikes on the surface of the fuselage and wings.

ECO-CONSCIOUS DESIGN

Integrating graphene and related materials into fibre-reinforced composites can greatly improve the strength and stiffness. This enables aeronautical engineers to design and deploy lighter components. The weight savings contribute to improvements in fuel efficiency and a major decrease in associated greenhouse gas emissions.

DAMPING VIBRATIONS

Graphene composite foams can dampen vibrations, reducing noise inside the cabin. The graphene also improves the mechanical properties and heat endurance of these structures.

FUEL REDUCTION

Aircrafts incorporating graphene composite skins could carry heavier payloads without using more fuel or fly for longer distances on a given amount of fuel.

SENSORS

Using graphene composites, many sensors such as fluid, pressure, and optical sensors could be made smaller and more sensitive, and therefore consume less power.

AIR FILTRATION

Heatable aero-graphene foams can reduce the cleaning time of aeromaterial filters, saving huge sums of maintenance costs, and could even remove impurities from the cabin air.

HYPERSPECTRAL CAMERAS

Graphene can be used in cameras that detect visible light, near-infrared (NIR), short-wavelength infrared (SWIR) and long-wavelength infrared (LWIR). This enables detection of elements beyond the capabilities of the human eye, even in extreme conditions.

GRAPHENE WILL REDUCE PLANE EMISSIONS AND MAKE AVIATION MORE SUSTAINABLE

A NEW HOPE FOR SPACE EXPLORATION

WITH SPACE CHAMPION CARLO IORIO

By: Tom Foley

Carlo Iorio is a Senior Researcher at the Microgravity Research Centre at Graphene Flagship partner Université Libre de Bruxelles in Belgium. His research interests focus on mankind's exploration of the final frontier: in particular, by developing new materials to enable stronger and more reliable vessels for space travel.

Iorio was recently appointed as the Graphene Flagship Space Champion: our spokesperson to represent our efforts to integrate graphene and layered materials into space science and technology.

We interviewed him about his research, his appointment as our Space Champion, and his views on humanity's foray into the dark beyond.

Can you tell me a bit about your role as the Graphene Flagship Space Champion?

My duty is to drive innovation in space-related research involving graphene and layered materials, and to coordinate new and existing projects that help bring technology enabled by graphene and layered materials to the forefront of space exploration.

What are you working on right now?

I'm collaborating with **Leonardo** and **CNR**, in Italy, and **the University of Cambridge**, in the UK, on a new cooling system using graphene-enhanced loop heat pipes. These are a low-energy, low-maintenance solution to thermal management onboard spacecraft, and the results so far are really encouraging!
Other than this, I'm currently using graphene to strengthen the mechanical properties of hydrogel-based building materials, so we can build lighter and stronger spacecraft. I'm also looking into the interactions of graphene with human cells. This is a hot topic, especially in the Graphene Flagship, thanks to the potential of graphene for biomedical applications.

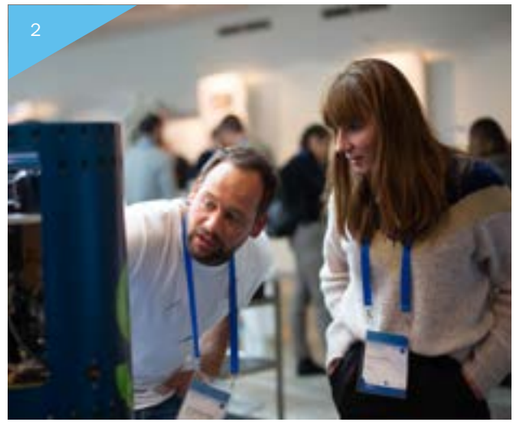
Where do you see humanity, in terms of space exploration, over the next few decades?

I think that in 10 to 15 years, we can establish a small colony on the Moon. I'm less confident on the timing for Mars, but I think a colony on Mars might be achievable in 30 to 50 years – although there are a lot of challenges that humans need to address beforehand.

We're at the beginning of a revolution in space exploration, and the word 'revolution' is certainly not a small term for what's happening. Just over 20 years have passed since the launch of the International Space Station (ISS), and for most of that time, there have been very few new developments. But over the last five or six years, there's been a really thrilling atmosphere among us space scientists. We have the European Space Agency, NASA, the Chinese Space Agency and the Russian Space Agency, all considering space as the new frontier again. Our target is to create a base on the moon, and then use this as a platform to go to Mars further down the line.

What are the main challenges for these space agencies, and for the Graphene Flagship?

Firstly, we need devices and systems to be extremely reliable. But in space, failure can be catastrophic, because the luxuries of external support and servicing are not available.
If we want to have people living and working on the moon, they'll need water. This means we need the technology to extract, refine and purify it. But to do this in an environment where the temperature can go from hundreds of degrees above zero to hundreds of degrees below, we need an intricate thermal



The Graphene Flagship is developing new technology that can address this: a system of loop pipes that could be used for thermal management in satellites, planes, and of course, space exploration.

But the main thing we will need to overcome, before we can get to Mars and beyond, is our lack of technology for radiation shielding. When we go to Mars, it will be a trip that could last from a few months to over a year. The astronauts will be subjected to very dangerous cosmic radiation, and right now, there is no shield that could protect them from this.

There are a few solutions being talked about: we could use graphene to develop better-protected spacecraft, which is what I'm working on at the moment, or we could reduce the risk by simply getting there faster – potentially by using graphene to make better engines.

How can graphene help us to build better spacecraft?

Current spacecraft are protected by materials like polyethylene, or materials that are water-rich. They are very good, but as with everything that gets taken to space, we have to pay the price of transporting extra weight. This is expensive, especially for materials containing water.

Now, we are testing porous materials that can be graphene-based, or alternatively, embedded with water-based materials like hydrogels. Some groups, like at the Microgravity Research Centre at **Université Libre de Bruxelles**, are even working on lightweight composites made from graphene-enhanced polyethylene particles.

However, we should not consider graphene as the solution to all problems. We've had many revolutions over the history of mankind, and science keeps advancing. 300 years ago, people weren't talking about gravity much – but now we're so much more advanced that we can even calculate the deflection of light through a black hole.

In the same way, graphene has the potential to enable very reliable composites that can be functionalised. We are at a relatively early stage right now, but graphene is one of the best candidates to help us solve these challenges.

1. Carlo Iorio was recently appointed as the Graphene Flagship Space Champion. Image: Vesa Laitinen

2. The MASER 14 rocket brought graphene to space! Here, a researcher from the Swedish Space Centre explains where the experiments were loaded - samples stayed in microgravity for almost six minutes. Image: Vesa Laitinen

3. The MASER 14 was launched from the European Space Centre in Esrange, Sweden, thanks to a collaboration between the ESA, SSC and three Graphene Flagship partners. Image: Christophe Minetti, ULB

What are the most important things to keep in mind if humans make it to the final frontier?

Space exploration is a moral issue as well. We have to consider what we are capable of, and what our goals are. There are long-lasting discussions about whether or not we should terraform Mars. We could introduce some bacteria to slowly lower the CO_2 content of the atmosphere, and gradually make Mars closer to the living conditions on Earth. But should we?

The problem is whether we want to take responsibility for this. Maybe terraforming would be okay, but at what cost? Would we also export our pollution, conflict and war to other planets?

One day, we might need to abandon Earth. How will humans deal with this? Will we have big vessels colonising planets, travelling around the universe? These are some of the most difficult questions that mankind as a whole will need to answer.

On May 2019, the Graphene Flagship embarked on a campaign of zero-gravity parabolic flights to test novel thermal management graphene devices for space applications. Researchers enjoyed zero-gravity during the tests.

LEARN MORE ABOUT GRAPHENE FOR SPACE APPLICATIONS ON OUR YOUTUBE CHANNEL

PRODUCT GALLERY

Graphene Flagship Partners and Associated Members have released a number of products containing graphene to the market. Here's a

By: Melanie Lawson

VIBORA KING COBRA 2019

Vibor-A presents the Vibora King Cobra 2019: a high-quality diamond-shaped padel racket designed for advanced and professional players. The graphene frame ensures maximum flexibility and durability, and the excellent heat conduction properties of graphene enable blades with high recovery capacity, greatly reducing vibrations.

Vibor-A
viborapadel.com

G-DISP: SURFACTANT-FREE FLG DISPERSIONS IN WATER, NMP AND OTHER SOLVENTS

Sixonia's G-DISP series is a range of dispersions of function-al¬ised large-flake, high-quality, few-layer graphenes in various solvents such as water and N-methyl-2-pyrrolidone (NMP). The functionalisation of E-graphene at the edges results in an easy-to-use product, providing high film conductivities directly after application without the need for surfactants, or chemical or thermal post-treatment. Custom dispersions can be produced depending on customer-specific requirements upon request.

Sixonia Tech GmbH
sixonia-tech.de

GXT-LUBRICANT

GXT-lubricant utilises graphene to produce a class of oils and dry-to-the-touch coatings which reduce the friction, heat and wear between mechanical components. Graphene can replace some of the toxic and hazardous components found in traditional oils.

GXT-INK

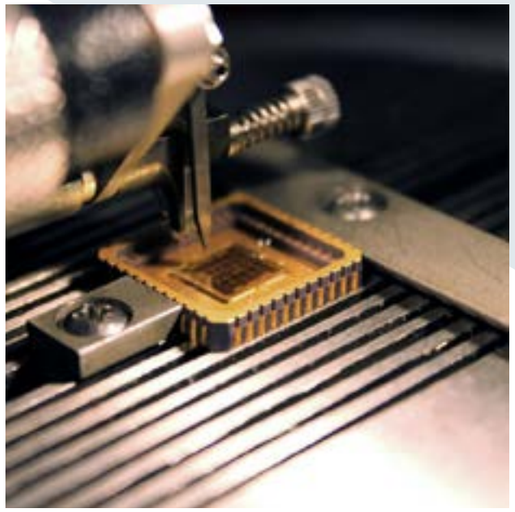
GXT-ink is suitable for printing geometric paths on different types of substrates and biopolymers like PLA with a sheet resistance as low as 4 ohm/sq/mil. The printed path can be laminated with common plastic films without damaging the electrical properties, and printed circuits on PET film remained stable under high stress conditions.

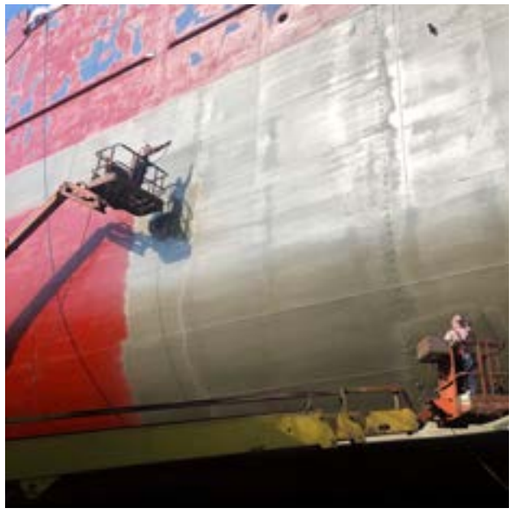
Graphene-XT
graphene-xt.com/en

GRAPHENE HALL SENSOR GHX-1

The Graphene Hall sensor, GHX-1, detects magnetic fields and outputs an analog signal proportional to the intensity of the field. Hall sensors made with epitaxial graphene show sensitivities to magnetic fields 10x greater than silicon-based Hall sensors, and record-low magnetic field detection limits when compared to other semiconductors and graphene-based Hall magnetometers. The performance persists up to temperatures of 150 °C.

Graphensic
graphensic.com





TALCOAT™

Talcoat™ is a range of formulated functionalised graphene (Talphene™) additives developed specifically for anticorrosion coating systems. The product utilises Talga-developed patent-pending functionalisation technologies and Talphene™ products targeting automotive and aerospace pre-treatment, zinc silicate and epoxy primers. The Talcoat™ product, currently undergoing commercial-scale trials, is designed to boost the performance of two-part epoxy based commercial primer coating systems for marine vessels.

Talga
talgagroup.com

MARIGI RIXON-003 RACING THERMAL COATING

The RIXON graphene-based coating improves the thermal dissipation performance of racing components such as brake calipers and radiators, and has been applied in official motorcycle world championship competitions (Superbike and MotoGP). With micrometric thickness, this coating can be applied to various metallic materials on non-friction surfaces, achieving improved thermal diffusion and resulting in 20–25% thermal dissipation reduction.

Marigi & Nanesa
marigi.eu

NEW PLANT TO MANUFACTURE GRAPHENE ELECTRONICS

EUROPEAN COMMISSION LAUNCHES ITS FIRST EXPERIMENTAL PILOT LINE FOR GRAPHENE AND LAYERED MATERIALS

By: Rebecca Waters

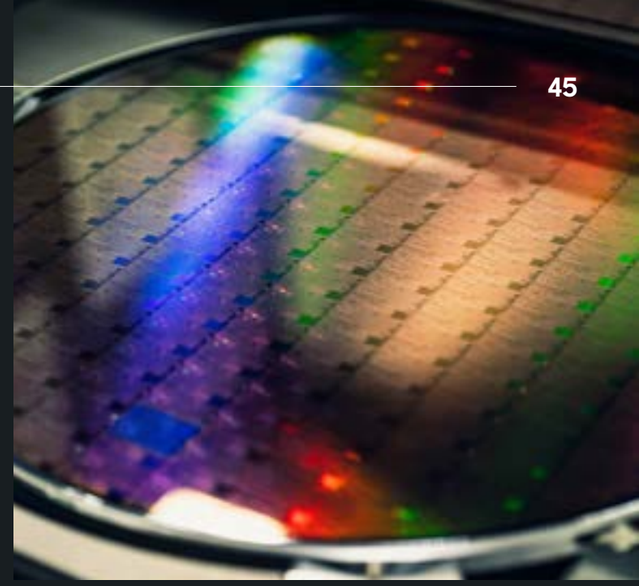
The European Commission will invest €20 million in the next generation of electronics and semiconductors. Graphene and related layered materials are ready to hit the market, maturing out of the lab for electronics and optoelectronics applications. The 2D Experimental Pilot Line (2D-EPL) will be the first graphene foundry to integrate graphene and layered materials into semiconductor platforms, keeping Europe at the forefront of this technological revolution – and scaling-up manufacturing is a critical step forward for the advancement of electronic components.

Born within the innovative ecosystem pioneered by the Graphene Flagship EU-funded project, the new 2D-EPL will cover the entire value chain, from tool producers and chemical and material providers to manufacturing lines. This collaborative project will integrate several Graphene Flagship members to pioneer the fabrication of new prototype electronics, photonic devices and sensors integrating graphene and layered materials. The 2D-EPL will offer comprehensive prototyping services to companies, research centres and academics, so they can develop and test their innovative technologies based on 2D materials.

"By developing a European pilot line for the processing of graphene and layered materials, we aim to bring these innovative materials from the academic laboratories to the semiconductor production lines, making them compatible with the standards in the industry. Moreover, we want to offer early access to experimental pilot line production to the innovative graphene community in Europe. The pilot line will allow them to scale up the production of their innovative devices based on graphene and layered materials," explains Cedric Huyghebaert, technical leader for the EU-funded 2D-EPL project, and programme manager for exploratory material and module integration at **imec**, Belgium.

Combining graphene and 2D materials with silicon could enhance the potential of electronic technologies, traditionally based on silicon. Nevertheless, integrating both materials at a large scale has been challenging, and up to now advances have progressed at a slow pace, due mostly to a lack of infrastructure. The 2D-EPL will address this challenge, allowing manufacturers to control the interfaces between silicon semiconductors and 2D materials on a large scale.

> We aim to bring 2D materials from the academic laboratories to the semiconductor production lines, making them compatible with the
>
> Cedric Huyghebaert



The 2D-EPL will produce wafers with embedded 2D materials like this one. Image: imec

TOOLS OF PRODUCTION

The 2D-EPL will develop the tools, chemistry and materials required for the integration of graphene and layered materials on established semiconductor platforms, which use silicon technologies. The ecosystem and procedures will be validated in state-of-the-art cleanroom environments all around Europe, such as **AMO** and iHP, Germany; **VTT**, Finland; and **imec**, Belgium.

In a later phase, the project will also develop modules to manufacture the basic building blocks for graphene and layered material-based technologies in the fields of optoelectronics, photonics and electronics. These modules will be publicly available for European users through multi-purpose wafers. This strategy will guarantee that these novel technologies are widely available and accessible at a reasonable cost.

The ultimate goal of the 2D-EPL is to build demonstrators and achieve low volume production of innovative graphene and layered material-based technologies integrated with traditional semiconductors, working closely together with leading Graphene Flagship partners across Europe, including SMEs, industrial companies, research institutions and academic partners.

"For many applications, the wafer scale integration of graphene and potentially other 2D materials is required for products to appear on the market," says Lilei Ye, the Business Developer for Electronics Applications at the Graphene Flagship. "The 2D-EPL will accelerate the manufacture of new prototypes for electronics, photonics and optoelectronics with integrated graphene and layered materials."

THE GRAPHENE FLAGSHIP MAKES AN IMPACT

"The 2D-EPL really highlights how the European Commission, through projects like the Graphene Flagship, can make an impact in European research, development and industry," says Graphene Flagship Director Jari Kinaret. "We identified a challenge – upscaling the production of graphene electronics – and the European Commission heard us, finding funding to address this challenge."

A large number of partners participating in the new adventure, the 2D-EPL, are also active members of the Graphene Flagship, one of the largest research initiatives ever funded by the European Commission. The 2D-EPL will work closely with the Graphene Core 3 project to understand the fundamentals of graphene and layered materials and establish a plan to bring these materials to the market. The 2D-EPL will be also deeply intertwined with the Graphene Flagship industry-led Spearhead Projects, leading to the production of graphene and layered material-enabled demonstrators, some of which are already being developed.

2D-EPL partners all have leading roles at the forefront of Graphene Flagship research groups. Moreover, 2D-EPL partners have also identified the need for new players to join the project to contribute expertise not yet established in the framework of the Graphene Flagship. All of these new collaborators will also join the Graphene Flagship consortium.

The collaboration between the 2D-EPL and the Graphene Flagship core projects will be paramount, as a large number of the potential applications supported by the Pilot Line are under development in the Graphene Flagship core. Nevertheless, the focus and organisation of the new 2D-EPL project is radically different – its objective is to build a long-term plan to overcome the 'window challenge' of publicly funded projects, and it will become a sustainable on-demand service for research and innovation in Europe and abroad.

The 2D-EPL will count on the expertise from **imec**, Belgium, which will lead the scientific and technological aspects of the project. The Graphene Flagship team at Chalmers University of Technology, Sweden, will also join the project – providing all its expertise in management and communication. Moreover, the pilot line will be supported by a core technical steering group consisting of principle investigators from the different partners of the project, and it will be overviewed by an Industrial Advisory Board, integrated by key players from the European semiconductor industry.

The board will be constantly informed about the progress and solutions developed by the 2D-EPL project and will also provide feedback on market analysis and early opportunities for the project.

THE WIND IN OUR SAILS

By: Tom Foley

Since the Graphene Flagship's inception in 2013, our talented and passionate scientists have worked tirelessly to take graphene out of the realm of the academic laboratory and into European society in the form of real, working products. Our concentrated, collaborative research efforts encompass the entire value chain, from the lab to the factory to the market, and our consortium, consisting of over 1200 people and nearly 170 partners across 21 countries, gets larger and more inclusive by the day.

Now, as 2020 draws to a close, it's the perfect time to take a look at the Graphene Flagship's progress over the last decade, and reflect on where we envisage ourselves – and the new technologies enabled by graphene and layered materials – in the coming years.

Read more to journey with the Graphene Flagship on a voyage into the future.

DID GRAPHENE MEET THE MARK?

Before we set sail, we need to ask ourselves an important question: did graphene and layered materials really meet the expectations we had in the months after its isolation by Andre Geim and Konstantin Novoselov in 2004?

At the time, a great many people in the scientific community predicted that graphene would revolutionise their fields and many others. For example, in the computing industry, scientists thought that graphene could replace silicon in microelectronics. But they quickly came to realise that graphene-based computing was unfeasible. In the simplest terms, this is because the materials used to make computer components need a band gap to store data, and, by definition, graphene does not have one.

Indeed, as with all early-stage technologies, scientists and the general public alike initially tended to underestimate the hurdles to overcome. In the 1940s, Thomas J. Watson, the president of IBM, famously said that he thought there was "a world market for about five computers." Of course, he turned out to be completely wrong – but who in the 1950s and 60s could have predicted that in 50 years, we'd be walking around with computers in our pockets millions of times more powerful than the ones aboard Apollo 11?

This shows more than anything that scientists' dreams never die. Indeed, researchers soon found that it was entirely possible to create derivatives of graphene that do have a band gap, along with a whole host of other layered materials with band gaps, with huge potential to enhance computer components like processors and random-access memory. So, perhaps things didn't play out exactly how people anticipated, but every good story has its twists and turns, and we know now that the future is still bright for graphene in computing – just not in the way we originally thought.

The same can be said for many of the fields in which graphene is emerging. For instance, of all the ways scientists thought that graphene would enter the world of healthcare and medicine, could they really have predicted graphene-based bioelectronic eye implants? All the signs point in one direction: that graphene and layered materials most certainly have the potential to make our vision come true, at least in part, and maybe in ways that we can't yet imagine.

> We are laying the foundations for things to come true in the near future that, 10 or 15 years ago, people

Henning Döscher

THE DAWN OF A NEW AGE

Just as silicon was discovered over 150 years before we entered the Information Age – the age of computers, technology and endless interconnectivity – perhaps we're just now setting the scenes for humanity to enter the Graphene Age a little further down the line?

Henning Döscher, Senior Researcher at the **Fraunhofer Institute for Systems and Innovation** Research ISI and coordinator of the Graphene Flagship's Technology and Innovation Roadmap endeavour, gives his thoughts.

"It's a question of perception. Are we in the Silicon Age today? Or should we call it the Plastic Age or the Concrete Age instead? There are several classes of materials that shape our modern society, and the technology for each of these keeps advancing over time. In the future, historians will classify the progress we're making – perhaps as the dawn of the Graphene Age, or maybe as one decisive step into the Nano Age."

Döscher remarks that the Graphene Flagship's efforts to expand the family of layered materials is a shining achievement that further cements our role at the forefront of European science. "There's now a huge portfolio of materials under investigation by the Graphene Flagship and our partners. We've made significant progress in our ability to manufacture them through a variety of different methods, from small-scale to large, sowing the seeds for industrial uptake in the years to come."

"We are laying the foundations for things to come true in the near future that, 10 or 15 years ago, people could only dream of," Döscher continues. "But progress takes time, and as is always the case, only a small fraction of our initial predictions will come true. We should start to see the first signs of our most successful projects coming to fruition over the course of this decade."

MAKING WAVES

Graphene is already in the spotlight in fields like sensing, flexible electronics and water filtration, but as time goes on, more and more industries are looking to graphene and layered materials to enhance their technologies. In particular, Döscher highlights two promising commercial industries in which he believes graphene will soon make its mark: the production

of battery electrodes and the manufacture of tyres.
Indeed, Graphene Flagship scientists are working hard to use graphene, and other layered materials, to increase the capacity and power density of batteries. In fact, graphene itself is looking to be a promising additive to electrodes in lithium ion batteries to improve their performance. Graphene may also find a new home in the manufacture of tyres: Döscher says that the results are promising, the technical hurdles for graphene to be incorporated into elastomers are low, and the main barriers to commercialisation are mass production and quality control – projects that are already underway. Indeed, Vittoria's graphene-based bike tyres are already on the market. "Furthermore, once we see an initial product line of graphene-enhanced car tyres on the market, this could get the ball rolling and kick off an industrial trend. And, once picked up by industry, graphene consumption could easily reach the kiloton scale," he adds.

Graphene is even emerging in the field of space science and exploration. The Graphene Flagship's Space Champion, Carlo Iorio, Senior Researcher at the **Microgravity Research Centre at the University of Brussels**, speaks about graphene's role in humanity's foray into the final frontier – read more in our exclusive feature on page 38. Iorio says that scientists are working on graphene-based solutions to thermal management, developing new lightweight composites for spacecraft based on graphene and more.

Furthermore, the Graphene Flagship has now begun the early stages of plotting the roadmap for graphene's role in space science. "But this is a very different market to the usual, as it isn't made up of private sectors – so it's more difficult to predict the nature or extent of graphene's involvement," Döscher says.

> We should start to see the first signs of our most successful projects coming to fruition over

Henning Döscher

"However, multiple private companies have entered the fray in recent years, so this very well might change," he continues.

SAILING FORWARDS

By 2030, the Graphene Flagship anticipates products based on graphene and layered materials for flexible solar cells and wearable electronic devices, water treatment and desalination, neural interfacing, high frequency electronics and many more. In the longer term, we hope to see graphene as part of the 6G revolution, part of the move to clean, green and sustainable fuel cells for transportation, and part of a new horizon of biomedical technologies to endow mankind with longer and healthier lives.

Any further than this is pure speculation, but scientists are dreamers, and collaboration is power. We fully expect that the Graphene Flagship, purely driven by the collective strength of our

ROADMAP FOR THE FUTURE

Graphene Flagship innovations pave the way to the market

GRAPHENE WEEK

Université de Strasbourg

SAVE THE DATE
GRAPHENE WEEK 2021

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