GRAPHENE FLAGSHIP

“2D Materials Innovation for Biomedical Applications”

RIA PULSE: 4 HORIZON EUROPE PROJECTS IN ACTION

Funded by the European Union

Table of Contents

2D Materials Innovation for Biomedical Applications

Welcome to the world of two-dimensional (2D) materials-Materials so thin, , just a few atoms thick, which makes them both **exceptionally lightweight** and **highly versatile**. Some of these materials, such as graphene, are **incredible strong**, **flexible**, **excellent conductors of electricity**, and have a **large surface area**.

These qualities make 2D materials **incredibly useful in the field of biomedicine**, opening new ways to **detect**, **treat**, and **manage diseases**, in ways we couldn't imagine before. They can be used to increase the **selectivity** and **specificity** of biosensors, while being small enough for wearable devices. Plus, their **high biocompatibility** enables these materials to be used directly **on or inside the human body**, with the most recent exceptional example of the first patient receiving a graphene-based brain computer interface developed by INBRAIN Neuroelectronics.

With ongoing research, these groundbreaking materials are paving the way for **smarter, faster, and more efficient healthcare solutions**.

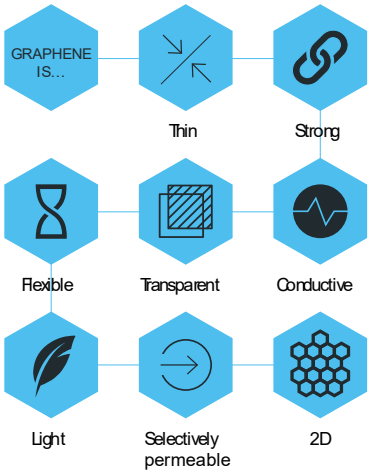

Figure 1: Graphene properties [Source: Graphene Flagship Initiative]

The Graphene Flagship Initiative

Biomedical applications of 2D-Materials are at the forefront of the Graphene Flagship Initiative (GFI). Launched by the European Commission in 2013, the GFI aims to mobilise researchers, academics, industry and national programmes to tackle major challenges in science and technology.

Over the past decade, the Graphene Flagship has delivered **outstanding results**[1], driven by **top experts in the field** and supported by **talented young researchers**, filing for **more than 80 patents**, and launching **over 100 products** onto the market, some of which through **20 spin-offs**.

The Graphene Flagship has entered a new era, currently providing support to 13 research and innovation projects. Check out below the current projects under the Graphene Flagship Initiative that offer unique solutions for significant healthcare challenges.

Funded by the European Union under GA no. 101120706 (2D-BioPAD), no. 101119473 (MUNASET), no. 101120832 (GRAPHERGIA), and no. 101135965 (SAFARI). Views and opinions expressed are however those of the authors only and do not necessarily reflect those of the European Union or CNECT. Neither the European Union nor the granting authority can be held responsible for them.

Funded by the European Union

[1] Read more about the Graphene Flagship 10-year assessment online: https://digital-strategy.ec.europa.eu/en/library/graphene-flagship-10-years-assessment

Supple Graphene Bio-Platform for Point-of-Care early detection and monitoring of Alzheimer's Disease

The 2D-BioPAD project aims to develop an innovative point-of-care (PoC) decision support device/tool for the **early detection of Alzheimer's Disease (AD)**. Using advanced graphene materials, the tool will enable a **fast, easy-to-use and minimally invasive test capable of measuring up to five AD biomarkers in real time**. Healthcare professional will have the opportunity to clinically validate 2D-BioPAD in Finland, Greece, and Germany, confirming its clinical added value.

Cutting-edge Technology

2D-BioPAD leverages the unique properties of 2D materials, such as graphene and its derivatives, combined with other cutting-edge technologies to deliver a graphene-based PoC IVD decision support tool for AD with improved biocompatibility, stability, as well as high sensitivity and specificity.

Having identified the most relevant target AD biomarkers, 2D-BioPAD is pushing the state-of-the-art on the following technologies:

- **Aptamers for AD biomarkers**: Primarily designed to mimic antibodies, these 'chemical antibodies' offer an alternative recognition element with comparable affinities, lower cost, smaller molecular size, and high biocompatibility.
- **Magnetic nanoparticles to boost biosensing**: $AuFe_3O_4$-based MNPs help sample purification and avoid non-specific signals, while also help control the flow of the sample on a bioassay.
- **Graphene derivatives for improved surface functionalisation**: Following the chemistry of fluorographene, high density (i.e. high functionalization degree) and control of the type of surface functional groups can be achieved, making short linkers that promote a specific binding with the biorecognition units (i.e., aptamers/antibodies), enhancing the biosensing reading.
- **Lateral flow electrochemical biosensing**: a combination of precise immobilization of bioreceptors, advanced functionalization of nanomaterials, state-of-the-art inkjet printing, and innovative graphene laser scribing techniques introduce highly efficient biosensors with digital electrochemical readouts for multiple analytes (i.e., proteins).
- **Graphene Field-Effect Transistors** (GFET) **as biosensors**: exploiting a patented disruptive technology using monolayer graphene, new GFET prototypes with advanced microfluidics are developed with high selectivity and specificity for detecting and quantifying multiple AD biomarkers.
- **Artificial Intelligence for 2DM sciences**: state-of-the-art models for aptamer selection, binding site identification or structural properties and defects prediction of graphene, can significantly accelerate biomedical research for novel graphene-based biosensors.

Socio-economic Impact

Alzheimer's Disease (AD) is the most prevalent form of dementia[2]. It is expected to affect **roughly 18.8 million people by 2050 in Europe alone**[3], with enormous financial burden for healthcare, long-term care, and hospice at a global scale.

Early detection of AD is crucial as it allows for timely interventions, helping to **slow down the disease's progression, and improve quality of life**. It also gives families and caregivers a chance to **seek support** and **plan ahead, reducing emotional and financial burdens**. With new medication now available, affordable and accessible screening is essential to catch the disease early, so people can **take advantage of treatments** and **make informed decisions** about their future care.

In this landscape, the 2D-BioPAD decision support tool, can be a significant asset to healthcare professionals to early diagnose AD, promising tremendous social and economic benefits if achieved.

Consortium

2D-BioPAD is formed by a consortium of 11 research and industrial partners from 8 European countries, coordinated by the Czech Advanced Technology and Research Institute of the Palacký University Olomouc.

CATRIN Czech Advanced Technology and Research Institute	**Czech Advanced Technology and Research Institute of Palacký University Olomouc** Czechia
Q-PLAN INTERNATIONAL	**Q-PLAN International Advisors PC** Greece
ICN2 Institut Català de Nanociència i Nanotecnologia	**Institut Català de Nanociència i Nanotecnologia** Spain
Grapheal	**Grapheal** France
	Aristotle University of Thessaloniki Greece

[2] https://www.alz.org/media/documents/alzheimers-facts-and-figures.pdf
[3] https://www.alzheimer-europe.org/dementia/prevalence-dementia-europe

	**NOVAPTECH** France
	**University of Eastern Finland** Finland
	**Greek Association of Alzheimer's Disease and Related Disorders** Greece
	**Evnia ApS** Denmark
	**Central Institute of Mental Health** Germany
	**University College Dublin, National University of Ireland** Ireland

Multiparametric nanoelectronic biosensors for therapy response testing

The aim of the MUNASET project is to develop graphene-based devices to help doctors **monitor the therapy response of patients suffering from major depressive disorders** (MDD). The envisioned test is **fast, easy-to-use, only requires blood samples and can be used at the Point of Care (PoC) to monitor and develop personalized therapies**. Therefore, the MUNASET platform has the potential to greatly improve the treatment outcomes for MDDs.

Cutting-edge Technology

MUNASET's goal is to develop a **next-generation biosensor device** that combines several existing technologies into a unique biosensor device that can potentially revolutionize the way how biochemical reactions and physiological interactions are studied. If successful, the resulting technology is expected to **significantly advance biomedical research** and enable the **development of novel PoC diagnostics and drug screening tools** that can provide a competitive advantage for the EU healthcare and wellbeing sector. By using 2D graphene, MUNASET plans to demonstrate the following advantages compared to conventional tools:

- **Improved biosensing performance**; including low detection limits, low drift, high chemical stability and biocompatibility to allow sensitive and selective biomarker detection in real time.
- **Versatile surface chemistry** via pi stacking of linker molecules on graphene to attach capture peptides for different analytes.
- **Novel field-effect sensing mechanism** based on specific charge removal by proteases to ensure high signal-to-noise ratios and reproducible signals.
- **Integrated CMOS** (Complementary Metal-Oxide Semiconductor) **readout** to enable robust multi-analyte measurements with built-in calibration, averaging, and integrated data analysis.

Socio-economic Impact

This graphene-based biosensor device is poised to advance the field of **protease diagnostics**, with a particular focus on addressing the unmet needs in MDDs and other chronic diseases. By enabling real-time, sensitive detection of biomarkers like MMP-9, this technology offers **a transformative approach to understanding and managing complex disorders** such as MDD. The platform will be further developed to:

1. Detect multiple proteases simultaneously, expanding its utility for biomarker profiling in neurological and systemic diseases.
2. Adapt the technology for use in more complex biological media, such as serum or blood, to validate its clinical relevance.

Consortium

MUNASET is formed by a consortium of 6 research and industrial partners from 4 European countries, coordinated by the Kaiserslautern University of Applied Sciences.

	Kaiserslautern University of Applied Sciences Germany
	Graphenea Semiconductor SL Spain
	Johannes Gutenberg University Mainz Germany
	VTT Technical Research Centre of Finland Ltd Finland
	Mainz University Medical Center Germany
	ProActive ltd Belgium

Innovative Pilot Lines for Sustainable Graphene-based Flexible and Structural Energy Harvesting and Storage Devices

The GRAPHERGIA project seeks to transform energy solutions with sustainable and efficient power technologies with a particular focus on case studies that provide **energy support for healthcare wearables**. The project aspires to achieve one-step, laser-assisted synthesis, processing, functionalization and integration of **graphene-based materials into energy storage devices**, aiming to revolutionise **smart e-textiles and electrodes** for Lithium-ion batteries (LIB) cells.

One of the project's key directions is the development of **self-charging wearable systems specifically designed for gait monitoring in individuals undergoing rehabilitation**, enabling continuous real-time tracking of gait parameters and movement patterns. This approach will provide clinicians with accurate, data-driven insights to tailor rehabilitation protocols.

Cutting-edge Technology

Achieving GRAPHERGIA's ambitious objectives necessitates tackling key challenges in producing high-quality graphene and its effective integration into energy harvesting and storage devices. This involves addressing critical aspects of scalable graphene production and seamless incorporation into device components, which is vital for advancing the fields of energy harvesting and storage.

To this end, the project will develop a **sustainable, laser-assisted process for depositing high-quality graphene electrodes directly onto textile surfaces**, ensuring a uniform, conductive layer while preserving the textile's flexibility. This method is coupled with a **novel power management system** that efficiently harvests biomechanical energy from daily movements. Together, these innovations will enable the creation of self-powered wearable devices with enhanced durability and performance, tailored for applications in healthcare and smart textiles.

Wearable electronics hold great promise for **continuous monitoring of personal health**, and the respective market is rapidly growing. GRAPHERGIA's "batteryless technology for wearables" can provide new prospects in healthcare monitoring, as it can enable the inclusion of additional biometric sensing functions without the power concern. One of the project's use-cases will be to integrate electronic systems (triboelectric nanogenerators - TENGs) on a **belt for on-line gait monitoring**, which may be proven essential for **early diagnosis of gait problems** and hence provide information for health evaluation, especially for the **elderly and patients with orthopedic injuries/surgeries** in the rehabilitation stage.

Socio-economic Impact

GRAPHERGIA's innovations will **improve** people's (particularly the elderly) **quality of life** by offering them a new generation of improved **eco-designed, low-cost, easy-to-use, batteryless, and smart wearables** with numerous applications in various IoT-related sectors, such as personalized healthcare. This will be first showcased with the **online monitoring of**

gait patterns; gait patterns can be affected by injuries and medical conditions affecting the brain, spinal cord, and legs, and GRAPHERGIA's prototype **can ultimately benefit people with chronic pain, Parkinson's disease, cerebral palsy, multiple sclerosis, spinal stenosis, hernia, muscular dystrophy,** etc. In the long term, early diagnosis of people's health problems will be saving resources and lowering health care costs.

Consortium

GRAPHERGIA is formed by a consortium of 11 research and industrial partners from 6 European countries, coordinated by the Foundation for Research and Technology Hellas.

FORTH INSTITUTE OF CHEMICAL ENGINEERING SCIENCES	**Foundation For Research and Technology Hellas (FORTH)** Greece
PLEIONE ENERGY	**Pleione Energy GmbH (PLE)** Germany
ADAMANT COMPOSITES	**Adamant Composites Ltd. (ADA)** Greece
Université Gustave Eiffel	**University Gustave Eiffel / ESYCOM lab (UGE)** France
born KNITTING ENGINEERS	**Born - Knitting Engineers (Born GmbH)** Germany
SAPIENZA UNIVERSITÀ DI ROMA	**University "Sapienza" Rome (URM)** Italy
COM SENSUS	**ComSensus (ComS)** Slovenia
DLR Deutsches Zentrum für Luft- und Raumfahrt	**Deutsches Zentrum für Luft- und Raumfahrt e.V. (DLR e.V.)** Germany
NEXT TECHNOLOGY TECNOTESSILE SOCIETA' NAZIONALE DI RICERCA R. L.	**Next Technology Tecnotessile (NTT)** Italy
AUSTRALO	**AUSTRALO Marketing Lab (AUSTRALO)** Spain
EUglottia IP	**EUGLOTTIA (EUGL)** Greece

Safe and Sustainable by Design Graphene/MXenes Hybrids

The SAFARI project´s primary objective is to integrate **safety and sustainability aspects** into the **development** and **utilization** of the 2D material **MXenes**, as well as a hybrid formulation of 2D materials, specifically **MXene-Graphene**.

MXenes, as a family of 2D materials with exotic and superior properties, consist of transition metal carbides, carbonitriles, and nitrides that have quickly captured the attention of researchers worldwide. MXenes and their hybrid formulation with graphene will be tested for usage in several applications, including **biosensors for bioanalytes** such as **glucose**, **lactate**, or **uric acid** among others.

Cutting-edge Technology

The SAFARI project stands out for its innovative approach, covering the entire value chain—from material production to end-user application testing. A key objective of the project is to functionalize and develop hybrid formulations of MXenes with graphene. These materials exhibit **excellent electrical, electrochemical, and electromagnetic properties**, as well as a safer 2D material configuration for industrial applications due to their larger size (~1-2 µm), reducing potential risks.

SAFARI goes beyond the state-of-the-art by developing **sustainable production routes** for the preparation of high-quality and high purity MAX phases, the precursors compounds for MXenes, based on the combination of Spark Plasma Sintering (SPS) and HighEnergy Ball Milling (HEBM) pilot lines. The scale up production of MXenes phases is achieved via a High Frequency Acoustic Emission (HFAE) process, **a fast and environmentally friendly process**, without the use of toxic acids.

SAFARI is actively developing and testing these hybrid materials in electrochemical sensors, specifically for biomedical applications. The goal is to achieve **biosensors for glucose and lactate with high sensitivity**, reaching detection limits as low as 10 nM for glucose and 100 nM for lactate.

SAFARI is closely collaborating with end-users to define their requirements for the functionalization and hybridization of MXenes with graphene. By doing so, the project aims to **optimize these hybrid materials** to achieve **superior** electrical, electrochemical, and electromagnetic **performance**, ensuring their suitability for **advanced biosensing applications**.

Socio-economic Impact

The development of biosensors for glucose and lactate monitoring will have a significant socio-economic impact by directly influencing the **cost of healthcare devices**, the **sustainability of the devices being produced**, **improving patients' quality of life**, and also **enhancing public health** through the widespread adoption of monitoring tools.

The SAFARI project plays a key role in **advancing both the nanotechnology and medical technology industries** by fostering innovation in **biosensors** based on MXene-Graphene hybrids. More accurate and efficient biosensors can improve the diagnosis and treatment of various diseases, including **diabetes** and other **metabolic disorders at an early stage**. Additionally, the **sports industry** could benefit from the use of lactate biosensors to monitor athletes' physical performance and avoid overexertion.

Finally, SAFARI's sensors intend to **enhance environmental sustainability** as the methods proposed for the MXenes production are characterized by significant environmental benefits (i.e, elimination of toxic chemicals, low energy consumption), positioning Europe as a leader in sustainable technologies.

Consortium

SAFARI is formed by a consortium of 11 research and industrial partners from 7 European countries and Israel, coordinated by the Poznań Institute of Technology.

Łukasiewicz Poznań Institute of Technology	**Poznań Institute of Technology** Poland
creative nano	**Creative Nano PC** Greece
UNIVERSIDAD DE BURGOS | ICCRAM	**University of Burgos** Spain
RESEARCH CENTER ITENE	**ITENE Research Center** Italy
ISQ	**Instituto de Soldadura e Qualidade** Portugal
aimen TECHNOLOGY CENTRE	**Asociación de Investigación Metalúrgica del Noroeste** Greece

	**Danish Technological Institute** Denmark
	**Israel Aerospace Industries Ltd** Israel
	**ThinkWorks BV** The Netherlands
	**AXIA INNOVATION GmbH** Germany
	**Metrohm DropSens SL** Spain

Driving biomedical innovation through collaboration

Collaboration is the **catalyst for driving innovation and scientific excellence**. With four pioneering projects uniting under the Graphene Flagship, we create a powerful ecosystem where **expertise, resources, and visions converge to redefine biomedical advancements**. By fostering interdisciplinary synergies, this collaboration will fuel the development of transformative healthcare solutions. With seamless integration of diverse knowledge domains, these initiatives unlock new frontiers in early diagnostics, precision medicine, patient-centered care, and disease prevention, driving tangible impact for global health.

At the heart of this collaboration lies **a shared commitment to excellence, knowledge exchange, and sustainable innovation**. Through knowledge sharing, joint research initiatives, and cross-sector engagement, the Graphene Flagship projects that focus on biomedical applications have the potential to shape the future of healthcare. By leveraging collective intelligence and harnessing the power of emerging technologies, such as 2D materials, they create **scalable, reproducible solutions that benefit both medical professionals and patients worldwide**. This dynamic network exemplifies how strategic cooperation transforms **ambitious ideas into real-world applications**, proving that when visionaries work together, the impossible becomes achievable.

Through projects like 2D-BioPAD, MUNASET, GRAPHERGIA and SAFARI, the EU can take the lead of the global market in the field of biosensing, from PoC IVDs to e-textiles products for sports & fitness, medical & healthcare, wellness, etc. The respective EU companies will gain a significant share of the market and will see their revenues increased, which will be translated into more attractive job opportunities for EU citizens. The wide market uptake of results developed by R&I projects of the Graphene Flagship will have multidimensional impacts on science, economy and society.

Learn more about GF's biomed news here.

…together, we can do so much more!