*Press Release*
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# The European roadmap for graphene science and technology at Leiden University

*Europe's Graphene Flagship lays out a science and technology roadmap, targeting research areas designed to take graphene and related 2d materials from academic laboratories into society.*

In October 2013, academia and industry came together to form the Graphene Flagship. Now with 142 partners in 23 countries, and a growing number of associate members, the Graphene Flagship was established following a call from the European Commission to address big science and technology challenges of the day through long-term, multidisciplinary R&D efforts.

In an open-access paper published today in the Royal Society of Chemistry journal *Nanoscale*, more than 60 academics and industrialists lay out a science and technology roadmap for graphene, related two-dimensional crystals, other 2d materials, and hybrid systems based on a combination of different 2d crystals and other nanomaterials. The roadmap covers the next 10 years and beyond, and its objective is to guide the research community and industry toward the development of products based on graphene and related materials.

*"We are very proud of the joint effort of the many authors who have produced this roadmap,"* says Jari Kinaret, director of the Graphene Flagship. *"The roadmap forms a solid foundation for the graphene community in Europe to plan its activities for the coming years. It is not a static document, but will evolve to reflect progress in the field, and new applications identified and pursued by industry."*

Graphene and related materials are expected to revolutionise the fields in which they are applied, and they have the potential to become the materials of the 21st century. They will supplement and at times replace existing substances in a range of applications. Two-dimensional materials shall in some cases be integrated into existing platforms in order to enhance them. For example, graphene could be integrated into silicon photonics, exploiting established technology for constructing integrated circuits.

The roadmap highlights three broad areas of activity. The first task is to identify new layered materials, assess their potential, and develop reliable, reproducible and safe

means of producing them on an industrial scale. Identification of new device concepts enabled by 2d materials is also called for, along with the development of component technologies. Our ultimate goal is to integrate components and structures based on 2d materials into systems capable of providing new functionalities and application areas.

Eleven science and technology themes are identified in the roadmap. These are: fundamental science, health and environment, production, electronic devices, spintronics, photonics and optoelectronics, sensors, flexible electronics, energy conversion and storage, composite materials, and biomedical devices. The roadmap addresses each of these areas in turn, with timelines.

Research areas outlined in the roadmap correspond broadly with current flagship work packages, with the addition of a work package devoted to the growing area of biomedical applications, to be included in the next phase of the flagship. We are learning here from experience, and also feedback from expert reviews of our work. A recent independent assessment has confirmed that the Graphene Flagship is firmly on course. With hundreds of research papers, numerous patents and marketable products to its name, the flagship is providing excellent value for money.

Roadmap timelines predict that, before the end of the 10-year period of the flagship, products will be close to market in the areas of flexible electronics, composites, and energy. We also hope to see advanced prototypes of silicon-integrated photonic devices, sensors, high-speed electronics, and biomedical devices.

*"This publication concludes a four-year effort to collect and coordinate state-of-the-art science and technology of graphene and related materials,"* says Andrea Ferrari, director of the Cambridge Graphene Centre, and chairman of the Executive Board of the Graphene Flagship, who with Italian Institute of Technology physicist Francesco Bonaccorso led the roadmap effort. Professor Ferrari adds: *"We hope that this open-access roadmap will serve as the starting point for academia and industry in their efforts to take layered materials and composites from laboratory to market."*

**Research efforts at Leiden University:**

More than 60 academics and industries have set out their roadmap for the application of graphene in marketed products. Leiden chemist Grégory F. Schneider believes that graphene and other layered materials can – one day – be used for DNA sequencing applications.

*Graphene applications.* Graphene, an extremely thin and flexible material, made up of a single layer of carbon atoms, is one of the world's strongest materials. Graphene and

related layered materials are expected to revolutionize the research fields in which they are employed. These materials have numerous potential applications, for example in biomedical devices, energy conversion and electronics.

*Roadmap from the laboratory to the market.* A large group of international authors are now publishing in *Nanoscale* a roadmap for graphene applications, related two-dimensional (2d) materials and hybrid systems. The roadmap covers the research and expected innovation for the coming ten years and beyond, with the objective to guide the research community and industry towards the development of products based on these remarkable materials.

*Graphene as a sensor.* One of the authors, Grégory F. Schneider, is a chemist and group leader at the Leiden Institute of Chemistry. His group conducts interdisciplinary research on graphene in the field of bionanotechnologies. He investigates the chemical properties of graphene in the perspective of using this material, for example, as a sensor. To these ends, graphene has three fantastic properties: it outstandingly conducts electricity, its edges are only a single carbon atom thin, and all the atoms located on the surface make graphene very sensitive to nearby environmental changes, commented Schneider.

*DNA sequencing.* One of the applications Schneider dreams of is DNA sequencing. 'In a proper device configuration, a graphene edge could scan a DNA molecule from head to tail, providing a linear read-out of the genomic sequence in real time' He anticipates that high-throughput sequencing could take up to twenty years, but look forward to a proof-of-concept much sooner. As Schneider describes in the roadmap, he pioneered this particular research field by demonstrating that graphene can be used for detecting single DNA strands.

More generally, eleven science and technology themes are identified in the roadmap, in the area of fundamental science, health and environment, production, electronic devices, spintronics, photonics and optoelectronics, sensors, flexible electronics, energy conversion and storage, composite materials and biomedical devices. The roadmap addresses each of these areas in turn, with timelines.
Schneider: 'This roadmap highlights and summarizes the most recent worldwide activities in graphene research and proposes new research directions. I do believe that this roadmap will yield, worldwide, interdisciplinary new research ideas at the boundary between chemistry, material science, nanotechnology and biochemistry and will be a trigger to innovate, both in academia and industry.'

*Affiliation.* Schneider's research group has been associated with the Graphene Flagship for the elaboration of this roadmap. This European collaboration was founded in 2013 under the auspices of the European Commission, to work towards a joint and

multidisciplinary approach to major technological challenges. The publication in *Nanoscale* is a product of this collaboration.
**Further reading:** Ferrari et al., Science and technology roadmap for graphene, related two-dimensional crystals, and hybrid systems, *Nanoscale* (2014).
http://xlink.rsc.org/?doi=C4NR01600A

**Notes to editors**

The Graphene Flagship is the EU's biggest ever research initiative. With a budget of €1 billion, it represents a new form of joint, coordinated research initiative on an unprecedented scale. Through a combined academic-industrial consortium, the research effort covers the entire value chain, from materials production to components and system integration, and targets a number of specific goals that exploit the unique properties of graphene.

The Graphene Flagship is tasked with bringing together academic and industrial researchers to take graphene from the realm of academic laboratories into European

society in the space of 10 years, thus generating economic growth, new jobs and new opportunities for Europeans as both investors and employees.

The first European Future and Emerging Technology (FET) flagship, the Graphene Flagship began life in October 2013.