SIO GRAFEN

# Graphene Innovation in Sweden presented by SIO Grafen

SIO Grafen -
Strategic Innovation Programme for Graphene

**Helena Theander**
Programme Director, SIO Grafen,
Strategic Innovation Programme
for Graphene

# SIO Grafen is promoting and strengthening graphene research and innovation in Sweden

SIO Grafen is a Swedish national innovation programme which finances innovation projects through open calls, enables the transfer of knowledge between all levels in the value chains, publishes roadmaps for certain graphene application areas and organizes workshops and conferences.

We are actively working to increase the technological maturity of graphene-related innovations, strengthen value chains, promote financing possibilities, provide a common view and stimulate the availability of Swedish graphene materials.

**We are taking graphene from the lab to industry**.

# SIO Grafen is supporting industrial graphene development in Sweden

The Strategic Innovation Programme for Graphene, SIO Grafen, has been running since 2014. The ambition is to strengthen collaboration between industry and research providers in graphene application areas, by identifying and bringing together key players in value chains towards applications. The programme is open for international collaboration.

The programme is supported by the Swedish government agencies Vinnova (Sweden's innovation Agency), the Swedish Energy Ageny, the Swedish Research Council Formas and members.

SIO Grafen is cooperating with the Graphene Flagship, FLAG-ERA (Flagship ERA-NET) and the Advocacy Platform for Graphene Technologies.

## Areas of strength

The areas of strength within SIO Grafen are areas with strong Swedish industrial interest and where graphene is expected to contribute to increased competitiveness.

- **Electronics:** printed electronics, optoelectronics, sensors and high frequency electronics
- **Composites:** thermally and electrically conductive, used in textiles, metals, concrete and polymers with or without fibres
- **Coatings:** coatings, barrier layers, membranes or filters
- **Manufacturing:** graphene flakes, graphene on silicon carbide and graphene film
- **Energy:** electrical conductivity, use for storage of energy, generation of energy, thermal conductivity can be used for cooling of electronics.
- **Biotechnology:** in medical technology (biocompability), for sensors, electrodes and implants, issues such as environmental and health aspects

## Results so far

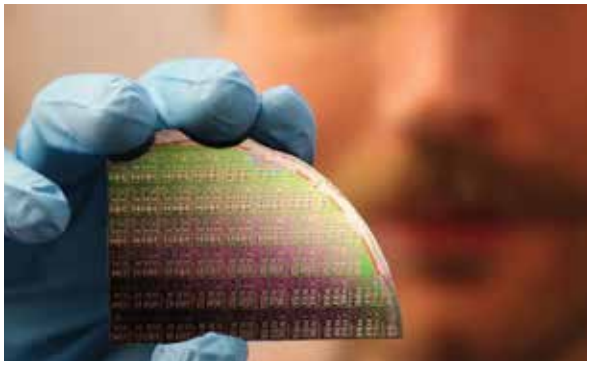
**70** projects funded

**90** organisations involved

**43** SMEs have participated

# Interest in international collaboration

Academia, research institutes and industry in Sweden are looking for international collaboration to support the establishment of global value chains.



KTH displayed the mobile infection monitoring at the Mobile World Congress in 2018.

## Instant identification of disease

**Blood samples contain vital information about a person's health. Conventional blood tests require laboratory equipment, which is not available in developing countries with-out specialized healthcare systems.**

In case of an epidemic outbreak, this lack results in a critical delay between sample collection and test result. There is a critical need for fast, low-cost biosensing in low-volume blood samples that gives immediate results. The sensing platform developed by KTH Royal Institute of Technology is based on silicon photonics with graphene photodetectors which identify the "molecular fingerprint" in the infrared spectrum of disease indicators in a single drop of blood from a prick in the fingertip.

Graphene provides the ability of low-cost, high-volume integration with established silicon photonics platforms - a unique combination competing technologies lack. The direct electrical readout enables the exchange of information over existing telecommunication infrastructure and supports the early identification of epidemic outbreaks and the coordination of humanitarian aid. KTH has implemented a similar project within SIO Grafen, *Waveguide-Integrated Graphene Based mid-Infrared Detectors for Optical Gas Sensor Chips*.

**Areas of interest for international collaboration:**
In the fields of graphene photonic devices, graphene based sensors, in particular gas sensors, graphene based mechanical devices, and high volume production of graphene sensor devices.

### Contact

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**KTH ROYAL INSTITUTE OF TECHNOLOGY**

KTH is Sweden's largest technical university, with 12 000 undergraduate students, over 2 000 research students, and 3 700 employees. KTH education and research covers a broad spectrum – from natural sciences to all branches of engineering. The department of Micro and Nanosystems (MST) employs 43 senior and graduate researchers with a research focus on Micro- and Nanoelectromechanical Systems (MEMS/NEMS). MST has five general fields of research: optical systems, telecom and remote-sensing THz technology, bio-micro-nanofluidics, 3D-MEMS integration and medical technology. Professor Frank Niklaus leads the work on Graphene MEMS, based on wafer-scale graphene-transfer technology. Assistant professor Kristinn B. Gylfason leads the work on waveguide integrated graphene-based photodetectors.

**www.kth.se/en**

# Inkjet printing

KTH has developed sophisticated inkjet printing techniques for graphene as well as other 2D materials (e.g., $MoS_2$), which enable directly writing arbitrary graphene patterns on any substrates (silicon, glass, plastics and metals, etc.) at the resolution around 50 microns. The printed graphene patterns are conductive and of large surface area, and hence have promising applications in printed electronics, energy storage and sensing. KTH has developed fully printed graphene-based micro-supercapacitors with areal capacitance around 1 $mF/cm^2$. Now they are aiming to develop more advanced printing techniques to directly pattern graphene on curved 3D surfaces and to explore industrial applications enabled or enhanced by their printed graphene structures.

In 2015-2016, KTH and XaarJet AB (Xaar) collaborated in the project *iEnergy - Industrialization of inkjet printing technology with graphene for energy storage applications,* financed by SIO Grafen. In this project, KTH was scaling up their fabrication technique for graphene inks and XaarJet was testing the inks' printability. The goal was to develop high-quality graphene inks to enable innovative applications and to strengthen Swedish industry in extensive fields.

The project verified the capability of industrial-scale inkjet printing of graphene. Motivated by this result, KTH spun off an ink company,


Aninkco AB, for further development and sales of high-quality graphene inks.

**Areas of interest for international collaboration:**
In the fields of 3D printing of graphene, advanced 2D materials beyond graphene for printed energy storage, and industrial applications of printed graphene coatings (e.g., heat conduction and water purification).

**Contact**

**Jiantong Li,** Assistant Prof. Integrated devices and circuits
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# 2D fab - supplier of customized graphene and electrically conductive flexographic printing inks

2D fab produces graphene flakes, using graphite from the Woxna Graphite company. The premises holds a laboratory and process equipment. 2d fab is currently involved in seven projects within SIO Grafen (four have already been finalised):

- *GNOME 2.0 ACA*
- *Micrographene*
- *Graphene Energy*
- *Graphene composite materials (step 2)*
- *Graphene zink alloy coating on steel wire*
- *GNOME ACA*
- *Polymers with exposed graphene edges: new antibacterial materials for medical device applications*
- *Saintshield DX3-Bulletproof*
- *Multifunctional paint through the addition of oriented graphene flakes*
- *Novel methods to include graphene as a packaging barrier*
- *Swedish graphene*

**Areas of interest for international collaboration:**
Looking for partners willing to work with polymeric parts with very high impact strength, for example bumpers for the auto industry.

**Contact**

**Sven Forsberg,** Founder and CEO
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**2D fab**

2D fab's vision is to become one of the largest European producers of graphene. The business idea is based on a unique energy efficient manufacturing process, to develop and produce 2D materials, primarily graphene, as well as providing products and services containing 2D material. 2D fab was founded in 2013 by Sven Forsberg, engineer and Tech. Lic. from the Royal Institute of Technology in Stockholm. Today the organization consists of 10-ish people involved in different ways and degree. 2D fab today has collaboration and project agreements with several listed companies, but also a number of SME.

**www.2dfab.se/en/**

# Nano coal coating for industrial applications

**Low friction coatings are of great interest for applications where reduced friction will give advantages in terms of increased efficiency, increased life span and extended maintenance cycles.**

The project *Nano coal coating,* financed by SIO Grafen, has been conducted by Applied Nano Surfaces, Epiroc, Trelleborg and Dalarna University in 2016-2018. In tribological situations it is important to take into account the component, its motive and lubricant. The project has included multiple component materials and coatings on the component as well as several different sealing materials in a comprehensive evaluation. Tests carried out have shown that treated components including seals receive a radically reduced start and motion friction, compared to standard performance. The friction is at a stable level and the leakage of oil is non-existent.


The coating can be used in applications for improving tribological properties of various parts (e.g. guide bars, rails, slideways) in those cases where the use of Triboconditioning® is not feasible.

**What was the most important knowledge in the project?**
– We have learned that there are large variations in properties as well as price, depending on the material source and manufacturing method and that the graphene has improved tribological properties and mechanical strength significantly in the coating, says Lena Killander, Implementation Manager at Applied Nano Surfaces.

**What has happened after the project ended?**
– The project was finalised in the spring of 2018. Since then we have commercialised the results. We have launched Tricolit®-GO, a graphene-fortified low-friction coating, that features low friction and high abrasion resistance, says Lena Killander.

Tricolit-GO can be supplied in bulk for professional use and in easy-to-use spray cans for DIY enthusiasts. It is applied to the surface like a regular paint and heat-cured afterwards. The resulting coating comprises a balanced set of friction modifiers, such as WS2, BN, PTFE, and graphite, embedded in a cross-linked organic polymer matrix.

**What are the tribological effects?**
– Friction and wear reduction, stick-slip reduction, seizure prevention, micropitting reduction and corrosion protection.

**Contact**

**Christian Kolar,** CEO,
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**APPLIED NANO SURFACES AB**

Applied Nano Surfaces (ANS) offers innovative solutions for friction and wear reduction. ANS Triboconditioning® is a mechanochemical surface treatment method process that is used to reduce frictional losses and wear on various steel and cast iron surfaces. ANS Tricolit® is a sprayable solution that is heat cured into a hard coating, resulting in reduced frictional losses and wear on various surfaces. It is a versatile product that can be used alone or in combination with other coatings in order to optimize the characteristics of the material.

**www.appliednanosurfaces.com**

# Electronics to be cooled down with graphene-based compressors

**Small, reliable and low cost cryogenic cooling systems that can cool down sensors or components are required within IR and magnetic detection, cardiology, geophysics and radio systems for satellite market stations and have a great potential to be used in mobile radio systems and magnetic field detectors.**

The project *Miniaturized cryo cooling based on graphene*, funded by SIO Grafen, is a continuation of a previous project collaboration between APR Technologies, SHT Smart High-Tech and Chalmers. The goal is to develop a small vibration-free graphene-based compressor without moving parts, powered by thermal energy. The project ends in 2019.

**What are the benefits of a graphene-based compressor?**
– In a future vibration-free cryo cooling system, the compressor is a critical component. Today's cryo system is drawn with high costs, low reliability, extensive maintenance and vibration from the compressors. It limits or even excludes usage in a variety of applications. A low-reliability compressor that has a long service life can be used in advanced instruments and communication systems, says Peter Nilsson, CEO of APR Technologies.

**How is the cryo coooling compressor built up?**
– The compressor is made up of graphene-based films with superior conductivity developed by SHT and subsequently verified by Chalmers. The knudsen membrane and insulation membranes in the compressor are powered by thermal energy, according to APR's invention. Gravity material also allows you to adapt gas permeability, and eventually mass-produce the parts at a reasonable cost.

**What effects and results do you expect?**
– The project will demonstrate and characterize functionalities of the graphical compressor together with other system components. The properties of the graphene material are further developed against higher thermal conductivity and improved gas permeability. This is done by adjusting the combination of heat conductivty and permeability through microperforated graphene based films. We are developing a more stable semiautomatic manufacturing process of the compressor and we will develop more components for the system.

Manufacturing and integration methods need further development, not least from a system perspective because all parts of the system must be adapted to each other, concludes Peter Nilsson.

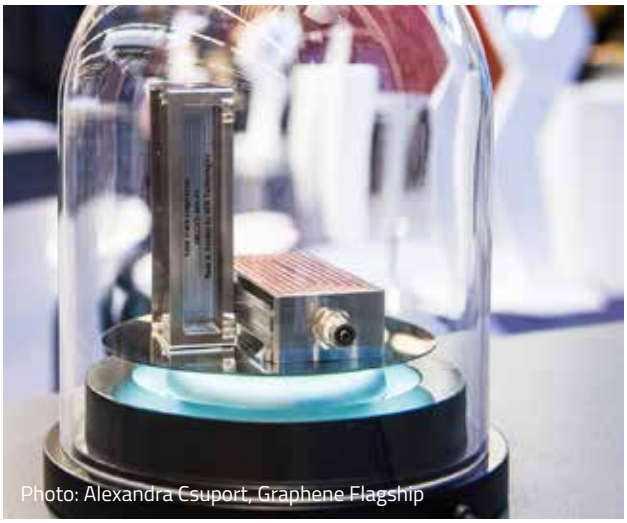
Photo: Alexandra Csuport, Graphene Flagship

Functional prototypes of cryo cooling compressors shown at MWB 2018. By using graphene in a small and compact cooling pump without moving parts, electronic systems should be able to cool down to ultra low temperatures.

**Contact**

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**APR TECHNOLOGIES AB**

APR Technologies is a high-tech hardware engineering company developing and selling products for thermal management in demanding applications, such as satellites and Li-battery cooling. One of APRs product platforms is liquid cooling based on own-developed pumps without moving parts. Typical clients are found in Space, Electric Vehicles, Medtech, Electronics, Big Science and other industries. APRtec has modern facilities, including cleanrooms, varous labs such as chemistry, electronics, laser, micro welding, and well-equipped mechanical workshop. Presently we are qualifying our first products and production lines. Our unique products and technology deliver unmatched performance for high quality thermal management applications in spacecraft, airplane, military and automotive environments.

**www.aprtec.com**

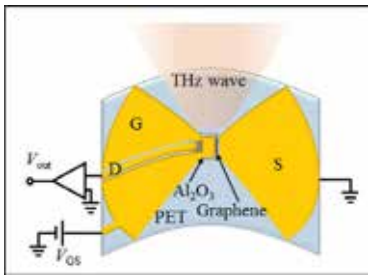
# Terahertz sensors: Flexible graphene Terahertz detectors

The first flexible Terahertz sensor brings high frequency electronics to flexible devices. Graphene combines flexibility and high frequency response for new powerful electronics systems.

Terahertz sensors open up new possibilities in wireless sensor networks, unique imaging characteristics (night vision, for seeng through rain, snow, and fog), wearable devices and smart clothing.

With the help of the two-dimensional material graphene, the first flexible terahertz detector has been developed by researchers at Chalmers.

*Photo: Boid – Product Design Studio*

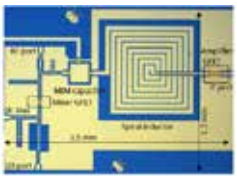



The opportunities are great within health (potential medical applications are for seeing through bandages and for the detecting of skin cancer), Internet of Things, and for new types of sensors. Watch the video *Flexible Terahertz Detector* on YouTube.

**Researchers**: Xinxin Yang, Andrei Vorobiev, Andrey Generalov, Michael A. Andersson and Jan Stake.

## Millimeter-wave receiver: 200 GHz graphene mixer + IF amplifier

By utilizing millimeter waves in electronics, future data traffic can get a big boost forward. This requires development of novel transistors with high charge carrier velocity. Graphene is a promising candidate here, since it reveals carrier mobility and saturation velocity higher than that in most semiconductors used today. This work is a first demonstrator of concept of the mm-wave receivers composed by 200 GHz frequency mixer and 1 GHz amplifier based on graphene field-effect transistors and integrated on a silicon substrate chip. The research has been funded by the EU Graphene Flagship, the Swedish Foundation for Strategic Research (SSF), and the Knut and Alice Wallenberg Foundation (KAW). Read the article in the journal Applied Physics Letters: *A flexible graphene terahertz detector*.



By utilizing mm-waves in electronics, future data traffic can get a big boost forward. This requires development of novel transistors with high charge carrier velocity. Graphene is a promising candidate here, since it reveals carrier mobility and saturation velocity higher than that in most semiconductors used today. This our work is a first demonstrator of concept of the mm-wave receivers composed by 200 GHz frequency mixer and 1 GHz amplifier based on graphene field-effect transistors and integrated on a silicon substrate chip.

**Areas of interest for international collaboration:**
From R&D to commercialization, in the areas of the millimeter-wave and terahertz communication and sensing.

**Contact**

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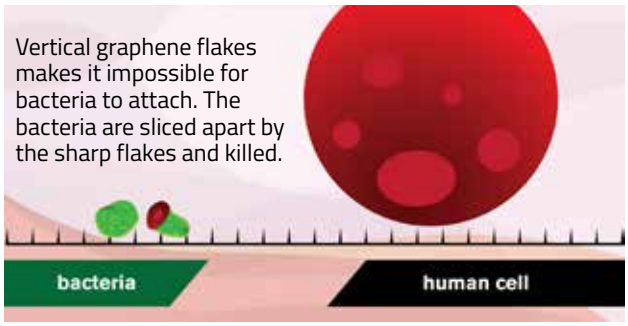
**CHALMERS UNIVERSITY OF TECHNOLOGY**

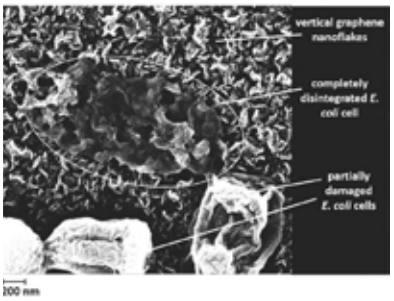
**Chalmers** conducts research and offers education in technology, science, shipping and architecture with a sustainable future as its global vision. Chalmers is well-known for providing an effective environment for innovation and has eight priority areas of international significance – Built Environment, Energy, Information and Communication Technology, Life Science Engineering, Materials Science, Nanoscience and Nanotechnology, Production, and Transport. Graphene Flagship, an FET Flagship initiative by the European Commission, is coordinated by Chalmers. Situated in Gothenburg, Sweden, Chalmers has 10,300 full-time students and 3,100 employees.

**www.chalmers.se/en**

# Spikes of graphene can kill bacteria on implants

**A tiny layer of graphene flakes becomes a deadly weapon and kills bacteria, stopping infections during procedures such as implant surgery.**




SEM image of E. coli cells on a surface coated with vertical graphene flakes, showing a completely disintegrated cell, and several partially damaged cells.

Chalmers and Dentsply IH AB (Wellspect Healthcare), have carried through the project *Graphene layers to prevent catheter related urinary infection,* financed by SIO Grafen. Operations for surgical implants, such as joint replacements or dental implants, have increased. However, there is always a risk of bacterial infection. Bacteria travel in fluids, such as blood, looking for a surface to cling on to.

Once in place, they start to grow and propagate, forming a protective layer, known as a biofilm. The project has given in-depth knowledge of why certain forms of graphene are antibacterial, while graphene in other forms do not affect bacteria (or other cells) whatsoever. In order to commercialize the patented results, a cost-effective manufacturing method is required.

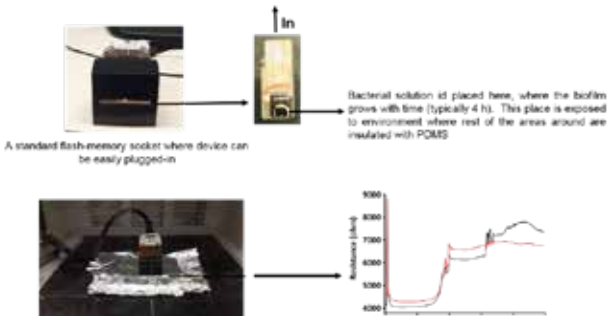
This work continues in the project *Polymers with exposed graphene edges: New antibacterial materials for medical device applications,* together with Dentsply IH/Astra Tech, Chalmers and 2D fab. A layer of vertical graphene flakes forms a protective surface that makes it impossible for bacteria to attach. Instead, bacteria are sliced apart by the sharp graphene flakes and killed. Coating implants with a layer of graphene flakes can therefore help protect the patient against infection, eliminate the need for antibiotic treatment, and reduce the risk of implant rejection.

– The key parameter is to orient the graphene vertically, says Ivan Mijakovic. The sharp flakes do not damage human cells. Chalmers is the first to use graphene in this way. The research team will test the graphene flakes further, by coating implant surfaces and studying the effect on animal cells.

The results are published in Advanced Materials Interfaces: *Vertically Aligned Graphene Coating is Bactericidal and Prevents the Formation of Bacterial Biofilms.* A video is available on on Youtube: "Graphene spikes that kill bacteria".

## Graphene for sensing

By contrast, a film where the flakes are deposited horizontally exhibits biocompatibility, does not harm the (bacterial) cell and can also be used as a sensor for the bacterial attachment and biofilm formation.




Biosensor system for detection of bacteria. Device holder is shown in the top left pane. Working devices (top right), are inserted in the holder and dipped in 6-well plates containing the sample (in this case a bacterial culture or a control empty medium). The whole working set up, with the device holder and chips dipped in the 6-well plate is shown in the bottom left panel. Output of the graphene-based bacterial sensor. The graph is showing changes in resistant value with the time of bacterial growth and biofilm formation.

### Areas of interest for international collaboration:

- Bio-sensing of virus particles, using graphene
- Antimicrobial coatings of 2D materials to 3D implant materials and in vivo testing
- Use of 2D materials in biotechnology, especially for biofuel extraction

### Contact

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# Projects funded by SIO Grafen

All projects presented below are financed by the Innovation Programme SIO Grafen. At least 50 percent of the total eligible project costs are funded by the participating actors.

## ELECTRONICS

- **Aros Graphene based thermal interface materials** – Nolato Silikonteknik, Ericsson, Graphmatech
- **Large area CVD graphene-based sensors/IR-photodetectors** – Senseair, RISE Acreo, Swedish Nat. Forensic Centre, Pamitus, KTH Royal Institute of Technology
- **From coal tar to graphene** - production methods and future areas of use –Swerea MEFOS, SSAB EMEA
- **Functionalized graphene as structural fortifier for polymers and coatings** – Applied Nano Surfaces, SHT Smart High-Tech, Chalmers University of Technology, Flexlink
- **GNOME 2.0 ACA** – ScandiDos, Akzo Nobel, Mycronic, 2DFab, RISE Acreo
- **Graphene in floorball blades** – Renew Group Sweden, Polykemi, Götene Plast, Chalmers Industriteknik
- **Graphene-based surface layers with improved conductivity** – Provexa, Chalmers Industriteknik
- **Graphene Coatings for High-End textiles** – FOV Fabrics, Chalmers University of Technology, Chalmers Industriteknik
- **Graphene reinforced concrete fences** – Heda Skandinavien, SHT Smart High-Tech, Chalmers University of Technology
- **Graphene enhanced adhesives for spot welding** – Chalmers University of Technology, RISE, Chalmers Industriteknik, Volvo Cars, CEVT, Lamera AB, Dow Automotive, SIKA
- **Graphene Coated Optical Fiber** – Bitelecom, Chalmers University of Technology, KTH Optical Network Lab, RISE/Acreo Optical Lab
- **Graphene-reinforced TeXtreme materials** – Oxeon AB, Chalmers Industriteknik
- **Micrographene** – 2D fab AB, Pegil AB, SaltX Technolgies
- **Multifunctional paint through the addition of oriented graphene flakes** – Saab Aeronautics, Linköping University and Danubia NanoTech
- **Self-lubrication and self-cooling Polymer-Aros Graphene composites** – Graphmatech AB, Kongsberg Automotive AB and Uppsala University
- **Stable dispersions of graphene and nanocellulose for future composite materials** – RISE Innventia, RISE and BillerudKorsnäs
- **Heat conductive graphene film in thermal band and heat exchanger for use in radar and laser** – Saab, SHT Smart High-Tech (SHT) and Chalmers University of Technology
- **Heat-reducing textile HeatReTex** – SAAB Barracuda, Swerea IVF

## COMPOSITES

- **Graphene in floorball blades** – Renew Group Sweden, Polykemi, Götene Plast, Chalmers Industriteknik
- **Graphene reinforced concrete fences** – Heda Skandinavien, SHT Smart High-Tech, Chalmers University of Technology
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- **Stable dispersions of graphene and nanocellulose for future composite materials** – RISE Innventia, RISE, BillerudKorsnäs
- **Heat-reducing textile HeatReTex** – SAAB Barracuda, Swerea IVF
- **Graphene in textiles** – Inuheat Group, Smart Textiles at University of Borås, Swerea IV
- **Graphene composite materials, part 2** - Saintpro, 2D fab, Chalmers Industriteknik
- **Graphene based self-lubricating composites for hydropower bearings in extreme condition** – Vattenfall (Älvkarleby Laboratory), Luleå University of Technology
- **GNOME ACA** – ScandiDos, Akzo Nobel, 2DFab, Acreo Swedish ICT
- **Graphene enhanced cement for light weight fencing applications** – Heda Skandinavien, SHT Smart High Tech, Chalmers University of Technology
- **Polymers with exposed edges of graphene: new anti-bacterial materials for med.-tech. applications** – Dentsply IH/Astra Tech, Chalmers University of Technlogy, 2D fab
- **Graphene modified composites for long time and high temperature applications** – Swerea SICOMP, Nexam Chemical, GKN Aerospace Sweden, Woxna Graphite
- **Multifunctional composite comprising graphene** – Saab Aeronautics, Blackwing, Chalmers University of Technology, 2Dfab
- **Graphene mixed with polycarbonates for production of melt blended personal protective equipment** - Saintpro AB, 2D fab AB
- **Graphene strenghtened concrete piles - industrialization of functionalized graphene in concrete** – Centrum Påle AB, Aarsleff Grundläggnings AB, SHT Smart High Tech AB, Chalmers Univrsity of Technology
- **Graphene** – a new lubricant in industrial applications – ABB AB, Uppsala University
- **Swedish graphene** - 2D fab AB, Woxna Graphite AB
- **Infrared-Chameleon** – Acreo Swedish ICT AB, Linköping University, Saab

## COATINGS

- **Functionalized graphene as structural fortifier for polymers and coatings** – Applied Nano Surfaces, SHT Smart High-Tech, Chalmers University of Technology, Flexlink
- **GNOME 2.0** – ACA, ScandiDos, Akzo Nobel, Mycronic, 2DFab, RISE Acreo
- **Graphene-based surface layers with improved conductivity** – Provexa, Chalmers Industriteknik
- **Graphene Coatings for High-End textiles** – FOV Fabrics, Chalmers University of Technology, Chalmers Industriteknik
- **Graphene Coated Optical Fiber** – Bitelecom, Chalmers University of technology, KTH Royal Institute of Technology, RISE Acreo
- **Graphene in textiles** – Inuheat Group, Smart Textiles at at University of Borås, Swerea IVF
- **Graphene zinc alloy coating on steel wire** – Swedwire, Chalmers Industriteknik, 2D fab
- **Graphene Enhanced Cement Based Coating** – Lanark, SHT Smart High Tech, RISE CBI, Chalmers, Chalmersfastigheter/Akademiska Hus
- **Graphene in loudspeaker membranes** – Transient Design Sweden, Chalmers Industriteknik, Chalmers University of Technology
- **Graphene on ship hulls for reduced corrosion and fouling** – SHT Smart High-Tech

- **Nano coal coating** – Applied Nano Surfaces Sweden, Epiroc, Trelleborg, Dalarna University
- **Graphene Barrier Coating for Paper Packaging** – BillerudKorsnäs, SP
- **Graphene-based Anti-fouling and Protective Coatings for Heat Exchangers** – **Alfa Laval Lund AB, SP,** KTH Royal Institute of Technology
- **Novel methods to include graphene as a packaging barrier** – Stora Enso Pulp and Paper Asia, 2D fab, Battenfeld Sverige, Perstorp, Polykemi, RISE Bioscience, Saving Spaces, Tetra Pak Packing Solutions, Chalmers University of Technology
- **Graphene layers to prevent catheter related urinary infection** – Dentsply IH AB (Wellspect Healthcare), Chalmers
- **Graphene - a new lubricant in industrial applications** – ABB AB, Uppsala University
- **Hybrid materials of graphene oxide and silica nanoparticles for water purification and other membrane applications** – Chalmers University of Technology, ENWA Water Technology, Akzo Nobel PPC, Biolin Scientific, Insplorion
- **Heat Pump Demonstrator with Graphene-Coated Ceramic Matrix for Increased Power Density** – Climatewell AB, Chalmers Industriteknik, Chalmers University of Technology
- **Graphene as barrier in packaging materials** – SP Food and Bioscience, Stora Enso, Chalmers University of Technology
- **Graphene-based coatings for heat exchangers** – SP Sveriges Tekniska Forskningsinstitut AB (AlfaLaval Lund AB, KTH Royal Institute of Technology)

## MANUFACTURING

- **From coal tar to graphene - production methods and future areas of use** – Swerea MEFOS, SSAB EMEA
- **Micro graphene** – 2D fab AB, Pegil AB, SaltX Technolgies
- **Graphene Energy** – 2D fab, VestaSi, Woxna Graphite, Uppsala University, Mid Sweden University
- **Simulation and modelling of GRM in CAE environment** – ÅF Industry, Chalmers University of Technology
- **Production of graphene on SiC for sensor applications** – Graphensic AB, Lindmark Innovation AB, Linköping University
- **Swedish graphene** – 2D fab AB, Woxna Graphite AB

## ENERGY

- **Heat conductive graphene film in thermal band and heat exchanger for use in radar and laser** – Saab, SHT Smart High-Tech (SHT), Chalmers University of Technology
- **Heat-reducing textile HeatReTex** – SAAB Barracuda, Swerea IVF
- **Graphene Energy** – 2D fab, VestaSi, Woxna Graphite, Uppsala University, Mid Sweden University
- **Graphene based self-lubricating composites for hydropower bearings in extreme condition** – Vattenfall (Älvkarleby Laboratory), Luleå University of Technology
- **Miniaturized cryo cooling based on graphene** – APR Technologies, Chalmers University of Technology, SHT Smart High-Tech
- **Heatspreader and heatconducting elements with graphene based films for radar and laser** – Saab, SHT Smart High Tech, Chalmers University of Technology
- **Graphene Enhanced Heat Spreaders for Electronics** – KTH Royal Institute of Technology, Huawei Technologies Sweden, Aninkco
- **Development, verification and validation of a graphene matrix for a solar and heat energy driven heat pump** – SaltX Technology Holding AB (ClimateWell) (publ), Chalmers Industriteknik
- **Graphene** - a new lubricant in industrial applications ABB AB, Uppsala University
- **Energy - Industrialization of inkjet printing technology with graphene for energy storage applications** – KTH Royal Institute of Technology, XaarJet AB (Xaar)
- **Miniaturized cryo-cooler based on graphene** – APR Technologies AB, Chalmers University of Technology, SHT Smart High-Tech AB
- **RF energy harvesting for M2M Communication** – Ericsson AB, Chalmers University of Technology
- **Printed graphene electrodes in high voltage products** – ABB AB, Acreo
- **Heatpump demonstrator with graphene coated ceramic matrix for increased power density** – Climatewell AB, Chalmers Industriteknik, Chalmers University of Technology
- **Preliminary study of miniaturized cryocooler based on graphene** – APR Techn. AB, Chalmers Bionano Systems Lab., SHT Smart High-Tech

## BIO TECHNOLOGY

- **Graphene-based flexible and recyclable light sources for life science applications** – LunaLEC, Umeå University
- **Polymers with exposed graphene edges: new anti bacterial materials for medical applications** – Dentsply IH/Astra Tech, Chalmers University of Technology, 2D fab
- **Graphene in radiation measurement** – ScandiDos, Acreo Swedish ICT


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