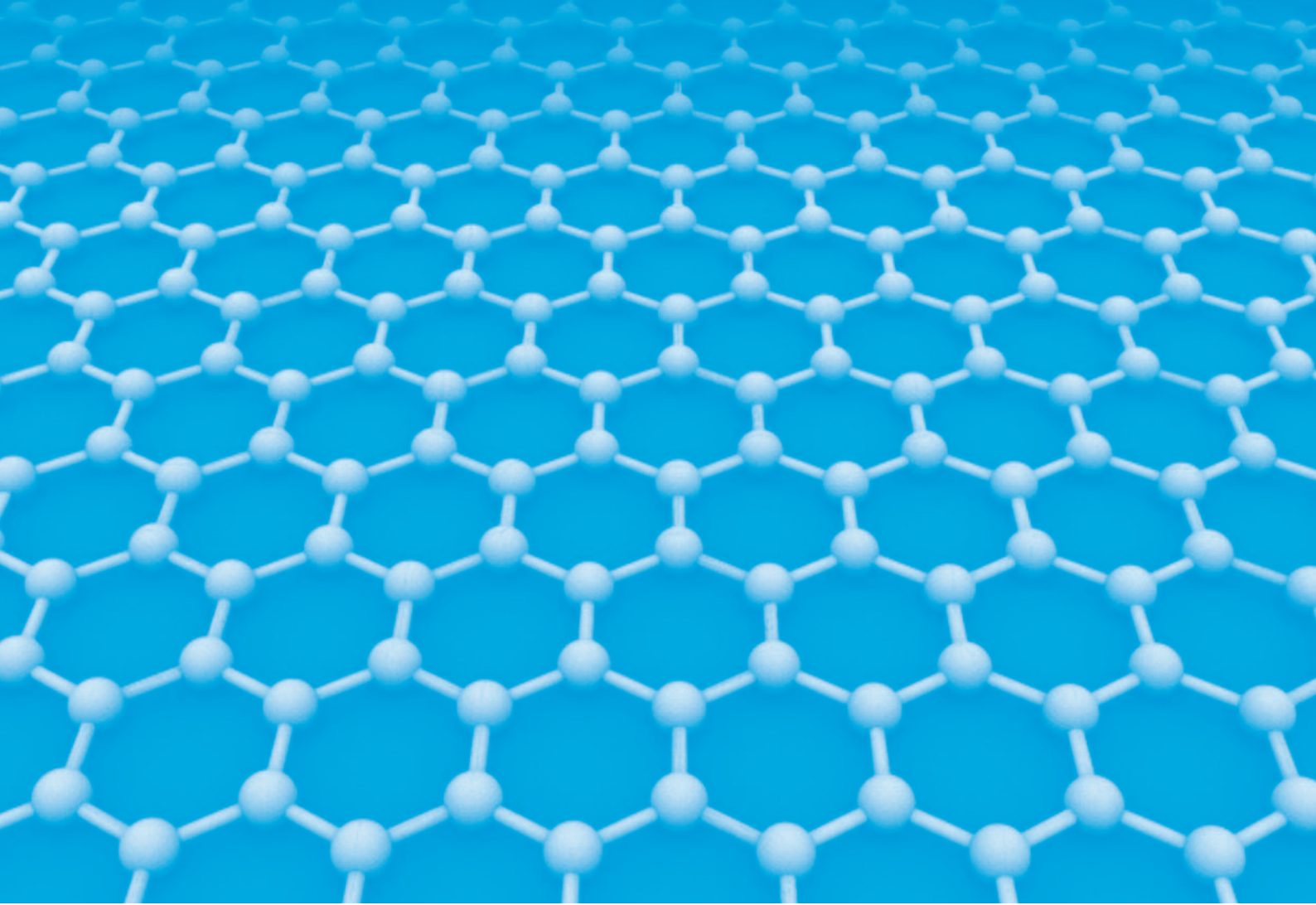
Innovation DB

GRAPHENE:

WONDER MATERIAL OF THE 21st CENTURY



INDEX

GRAPHENE: WONDER MATERIAL OF THE 21st CENTURY

EXECUTIVE SUMMARY

Graphene. First described and named in 1962 it took more than 40 years before it was rediscovered, isolated and characterised in 2004; but when will it be useable in the myriad applications that have generated enormous interest since?

Graphene is emerging as a hugely promising material in a wide variety of applications because of its combination of extreme properties; however, before we can exploit these we need Graphene in forms that overcome numerous practical problems. If Graphene is to be put to good use in applications, we need to be able to use various combinations of its properties and to be able to exploit these simultaneously.

One of the greatest challenges to be overcome before Graphene can move from a research curiosity to applications is manufacturing at scale. Along with the manufacturing capabilities and capacity is the need for Graphene metrology ('if you can't measure it, you can't make it') and standards and development of appropriate regulations to manufacture high quality material, on a large scale at low cost, sustainably and in a reproducible manner.

Graphene also needs to be manufactured at a quality fit for application: defects, impurities, grain boundaries, multiple domains, structural disorders, wrinkles and so on in the Graphene can considerably affect its properties from mechanical through to optical and electronic.

For use in electronic and electrical applications the requirement of large areas of uniformly very high quality Graphene are required, which is currently possible only when Chemical Vapour Deposition processes are used. Chemical Vapour Deposition is usually referred to as 'CVD' and is a chemical process used to produce high quality, high-performance, solid materials. The process is often used in the semiconductor industry to produce thin films. In typical CVD, a substrate - in the case for Graphene production Copper is usually used - is exposed to carbon-containing volatile precursors such as Methane, which decomposes on the substrate surface to produce a Graphene layer. It is difficult to produce high quality, single crystalline Graphene thin films with very high electrical and thermal conductivities and excellent optical transparency as large-area wafers for integration with current microelectronic fabrication technology.

Modifying the properties of Graphene for use in electronics remains a significant challenge; for example, it is highly conducting and it lacks a band-gap, such that it can't be used in electronics components, though recent research has made considerable advances towards addressing this problem.

Ensuring consistent mechanical, thermal and physical properties is also a major challenge at this point in Graphene's development; these essential characteristics are required if materials formulations that include bulk Graphene are to be consistent in form and behaviour.

Perhaps a key issue (that applies to the manufacturing-at-scale of many materials) is that the synthesis and manufacture of Graphene by current and conventional techniques uses large quantities of toxic chemicals and usually produces hazardous waste, poisonous gases and environmentally-unfriendly materials.

If Graphene is to be adopted for use in the many applications where it shows it could become a game-changer, there is a need to develop environmentally-friendly manufacturing technologies using automated methods to enable low production costs.

This report includes an overview of Graphene developments with examples of applications areas, their potential and investability, with forecasts for their adoption against technology development in a 2, 5 and 10-year timeframe.

GRAPHENE DEVELOPMENTS: A STRONG FUTURE

Graphene still has a promising future. Although there are a few Graphene or Graphene Oxide based products on the market today, most development into potential Graphene-based products and application areas is taking place in the world's Graphene research centres, universities and laboratories, where small quantities of Graphene can more readily be produced.

To date this (mostly academic) research has produced some fascinating results showing great potential. There is a multitude of different application areas for Graphene-based materials – from electronics to water desalination and beyond. How research institutions are driving these developments in a selection of core industrial sectors is described below.

ELECTRONICS & ENERGY GENERATION/STORAGE

The high conductivity coupled with the other versatile properties of Graphene make it a near-perfect fit for a wide range of applications in the electronics industry, including transparent conductors, improved thermal management, electronic displays and printed electronics. Yet, very few Graphene-based electronic devices exist commercially as Graphene's major electronic advantage is also its biggest weakness; being a great conductor of electricity it doesn't have a band gap as with semiconductor materials such as Silicon and so it can't be switched off-and-on as is required by electronic devices such as transitors.

Yet, research continues to delve into and discover the full scope of Graphene's electronic capabilities and application areas.

It is easy to get carried away. Graphene's potential extends beyond the realms of current electronic devices and into the realm of where science fiction could evolve into science fact.

Computing

Graphene could radically improve the processing power of computer chips, as well as significantly decrease their physical size. In 2014, IBM created a Graphene chip 10,000 times faster than stand silicon-based chips.[1]

Graphene has also been touted as a potential silicon replacement[2] in common electric circuitry thanks to its low cost, lightweight, flexible and physically resilient features.

However, Graphene's high conductivity is also its Achilles Heel as there is no easy way to control or modulate an electrical current due to its lack of a band gap. This is the gap between valence and conduction bands in a material that, when crossed, allows for a flow of electrical current. Until this control issue is resolved, Graphene cannot be used in computer chips or electronic circuitry.

Researchers from the Georgia Institute of Technology claim to have produced Graphene samples with a band gap of 0.5 electron volts, which they say should be enough for Graphene to function as a semiconductor. If true, this could lead to Graphene supplanting silicon as the semiconductor of choice, enabling much faster electronics to be made.[3]

Electronic displays

Electronic displays, specifically touchscreens, LCDs and organic LEDs, is an area where we could soon expect to see Graphene used on a commercial scale thanks to its high electrical conductivity and optical transparency. Graphene, even its current under-developed form, is potentially able to match the properties of the most widely used material in this area.

[1] http://www.extremetech.com/extreme/175727-ibm-builds-graphene-chip-thats-10000-times-faster-using-standard-cmos-processes

[2] http://www.extremetech.com/computing/169583-all-graphene-computer-chip-could-steer-us-past-the-22nm-bottleneck

[3] Hicks, J., A wide-bandgap metal-semiconductor-metal nanostructure made entirely from graphene, Nature Physics (2012). http://dx.doi.org/10.1038/NPHYS2487.

Thermal management- Heat Spreading

Heat dissipation in electronics and optoelectronics has hampered the further development of systems in these fields. Graphene could resolve this issue and a team of researchers from Chalmers University of Technology have developed an efficient way of cooling electronics by using functionalized Graphene nanoflakes.[4]

“Essentially, we have found a golden key with which to achieve efficient heat transport in electronics and other power devices by using Graphene nanoflake-based film. This can open up potential uses of this kind of film in broad areas, and we are getting closer to pilot-scale production based on this discovery,” says Johan Liu, Professor of Electronics Production and Head of the Electronics Materials and Systems Laboratory at the Department of Microtechnology and Nanoscience MC2 at Chalmers University of Technology in Sweden.

Flexible screens

Imagine a smart phone or a tablet computer that you could roll up and pop under your arm like a newspaper. Such durable and highly flexible touchscreen displays are a fascinating application area for Graphene.

Combined with Plastic Electronics manufacturing capabilities being rapidly developed, large-area production of electronics grade Graphene could prove to be the missing-link that makes Plastic Electronics a part of our everyday lives.

The first step to this lofty ambition is develop a Graphene-based screen which could, for example, be used on a mobile phone’s screen. Scientists at the Brookhaven National Laboratory (BNL) have found that placing Graphene on top of common industrial-grade glass is a cheap and effective way to improve the resilience of such screens. The screen can also be tuned, paving the way to produce Graphene-based electronics.

This fine-tuning process is already carried out with silicon and is known as ‘doping’. This involves adding tiny concentrations of positively or negatively charged impurities that tweak silicon’s electrical properties. Doping is a great tool to match a semiconductor to a specific application, but it is a delicate and costly process that adds to the material’s complexity and can decrease its lifespan.

The next step for Graphene-based research in this area will be to investigate the doping mechanism of Graphene and carefully study the material’s resilience during exposure to real-world operating conditions. Initial results suggest that the glass-Graphene method is much more resistant to degradation than many other doping techniques.

Academic research has seen some success in this field, with the first Graphene-based flexible display device unveiled in the UK in 2014.[5] This e-reader-style reflective display uses flexible Graphene electrodes in place of metals and bendy plastic instead of glass for the screen.

Mobile phone giants Samsung and Nokia have invested heavily into projects to develop bendable screens that use Graphene in place of the brittle, unbending indium tin oxide layer used to make the touchscreens found in today’s smartphones and tablets.

Samsung is said to have produced a few working prototypes, but the expensive Graphene production processes currently available have delayed commercial development and a working device is yet to be released to the marketplace.

[4] Han, H., Zhang, Y., Wang, N., Samani, M.K., Ni, Y., Mijbil, Z., Edwards, M., Xiong, S., Saaskilathi, K., Murugesan, M., Fu, Y., Ye, L., Sadeghi, H., Bailey, S., Kosevich, Y., Lambert, C., Liu, J., and Volz, S., 2016. ‘Functionalization mediates heat transport in graphene nanoflakes’. Nature Communications, 7.

[5] http://www.rsc.org/chemistryworld/2014/09/first-flexible-graphene-display-paves-way-folding-electronics

Photovoltaic (Solar) Cells

Photovoltaic cells turn light into electricity. Silicon is already used in this application area, but it can only generate electricity from certain wavelengths of light, whereas Graphene works across all wavelengths. The thinness and flexibility of Graphene also means it could be used to develop photovoltaic cells in clothing or even on windows screens or curtains to power your home.

Optical Communications

Optical communications could supersede electronic communication methods due to their low energy consumption rates. With power-hungry communications phenomena, such as devices used in the Internet of Things (IoT), current silicon photonics has a problem: it needs ten-times more energy than we can currently provide.

A collaboration of research from University of Cambridge (UK), The Hebrew University (Israel) and John Hopkins University (USA) under the Graphene Flagship initiative published a paper demonstrating how Graphene could provide a simple solution to this issue.[6] In the paper, Graphene is interfaced with silicon on a chip to make highly responsive barrier photodetectors.

Energy Storage

Storing energy in batteries and capacitors is problematic. Batteries can hold a lot of energy, but take time to charge, and capacitors can be charged quickly, but cannot hold onto that energy for very long, in comparison to batteries.

Graphene may deliver value here as development efforts look for a “supercapacitor” that can provide both long-term energy storage and rapid charging capability without compromise.

Graphene-enhanced lithium-ion batteries and micro-supercapacitors are both being investigated to reach this goal with the mobile phone industry eager to reap the rewards from such boosted battery designs.

‘Optical Boom’

A highly speculative notion is that a flow of electric current can, under certain circumstances, exceed the speed of slowed-down light and produce a kind of ‘optical boom’.

This (highly speculative) discovery represents a possibly entirely new way of converting electricity into visible radiation and could therefore lead to a wide variety of new applications.

Funded by the US Army, researchers at MIT, Israel, Croatia and Singapore used light instead of flowing electrons to move and store data to massively increase microchip operating speeds to far higher levels compared to those in today’s chips.

Although still theoretical, the discovery adds a new dimension to Graphene’s potential to produce incredibly fast microchips. Scientists at IBM Research have been exploring how Graphene can be used to create new chips that exploit the way electrons move faster through Graphene than through other semiconductor materials. The optic boom allows electrons to pass through Graphene at up to a million metres per second or 1/300th the speed of light in a vacuum.

This represents an efficient and controllable way of producing light from electricity compared to light produced by LEDs or compact fluorescent lights on a scale compatible with current microchip technology.

These Graphene-based systems could potentially be key on-chip components in the development of new, light-based circuits, which are considered a major new direction in the evolution of computing technology toward ever-smaller and more efficient devices.

[6] Goykhman, I., Sassi, U., Desiatov, B., Mazurski, N., Milana, S., De Fazio, D., Eiden, A., Khurgin, J., Shappir, J., Levy, U., and Ferrari, A., 2016. On-Chip Integrated, Silicon-Graphene Plasmonic Schottky Photodetector with High Responsivity and Avalanche Photogain. Nano Lett., 16(5), pp 3005–3013.

Bioelectric Sensors

Graphene offers a large surface area, high electrical conductivity, thinness and strength, which makes it a solid candidate for the development of bioelectric sensory devices in the field of biological engineering.

Such sensory devices could offer fast and efficient monitoring of entities such as cholesterol, glucose levels, haemoglobin levels or even provide a viable DNA sequencing method. They could also accelerate the development of novel drugs, improve toxin detection, food quality control, medical diagnostics and the analysis of biochemical reactions.

The Moscow Institute of Physics and Technology (MIPT) is patenting sensitive biosensor chips based on Graphene and its derivatives. The key feature of the sensor is the use of a thin layer or Graphene or Graphene oxide for biomolecular immobilisation.[7]

At the bleeding edge of research, there have even been suggestions of developing a "toxic" form of Graphene to target and destroy cancer cells or other diseases or using it in the process of tissue regeneration.[8]

It's a fascinating topic but it is worth remembering that rigorous safety, clinical and regulatory trials would be required to fully access the biocompatibility of such applications, which would slow down their development. Current estimations suggest that it will not be until 2030 when we will begin to see Graphene widely used in biological applications.[9]

AUTOMOTIVE & SPECIALIST MATERIALS

The automotive industry is under pressure to deliver faster, lighter and safer vehicles that use less fuel to match the environmental concerns prevalent in this sector, and the wider commercial environment.

This sector also demands a diverse range of parts and products, all of which do very different functions and could benefit from the various properties Graphene presents.

Next-generation Vehicles

Some interesting research has been presented for the potential uses of Graphene in next-gen vehicles. For example, researchers have demonstrated a catalyst made from Graphene doped with cobalt could be used to produce hydrogen from water; Graphene could be used to convert the heat produced by the vehicle's engine into electricity to drive its air condition system or power the car's batteries; and Graphene-based self-cleaning and corrosion-resistant coatings would improve a vehicle's life.

This latter application area is already close to finding a commercial solution with Tata Steel and the EPRSC (Engineering and Physical Sciences Research Council) in the UK studying Graphene-based steel coatings to prevent corrosion.[10]

Composite Graphene Materials

The drive for lighter vehicles could also be greatly assisted by Graphene's lightweight nature.

The automotive industry is developing a vast range of advanced composite materials to achieve this goal, but if these materials were coupled with Graphene then the resulting parts would not only be lighter, they would also have an improved tensile strength, flame retardant properties and provide a gas barrier. Based on these multifunctional properties, Graphene/polymer composites are promising as both structural and functional composites, with integration of functionalities within the automotive sector.

[7] http://www.nanowerk.com/nanotechnology-news/newsid=41854.php

[8] http://www.manchester.ac.uk/discover/news/graphene-shows-potential-as-novel-anti-cancer-therapeutic-strategy

[9] http://www.graphenea.com/pages/graphene-uses-applications#.V-rTdvArLIU

[10] https://www.epsrc.ac.uk/newsevents/news/extremeconditions

There are still several challenges to overcome to develop a fundamental understanding of Graphene and its integration with composite materials. The lack of a large-scale industrial production process, mentioned previously, is one such issue.

Unsurprisingly, cost is one of the most challenging aspects of adapting Graphene for automotive applications, and it will require collaboration across the entire value chain to reduce the manufacturing costs associated with using this material.

Another problem, which is more specific to the automotive industry, is the expected low ductility of Graphene-based composite structures. Ductility, which is the ability of the material to deform under tensile stress, is especially important in metalworking. Metals that deform under stress by cracking, breaking or shattering cannot be manipulated using metal-forming processes. This has obvious implications in vehicle production processes as new methods will need to be developed, but concerns are also raised in terms of vehicle safety.[11]

While the applications of Graphene for next-generation vehicles are tantalising, it seems sensible for automotive manufacturers to focus on designing Graphene composite structures that address these ductility issues. A Graphene-based composite that offers high stiffness, strength and safe failure modes would open up the automotive industry to a range of additional opportunities.

AEROSPACE & SPECIALIST MATERIALS

An ongoing goal for the aerospace sector is to reduce weight to save fuel, reduce costs and therefore be more environmentally friendly.

In a similar vein to the automotive industry, technologies that deliver lightweight materials with improved tensile strength and toughness are of particular interest, which makes Graphene an obvious candidate for aerospace applications.

Another key requirement is the ability to withstand a large temperature range, specifically anywhere from -50°C to +50°C but much higher temperature resiliencies may be necessary. Graphene-reinforced polymers have the potential to provide these improvements, in a range of applications including:

- Fibre-reinforced laminates: these tough, thermally stable and conductive carbon fibre/Graphene-filled resins reduce the weight of primary aircraft structures.
- Epoxy adhesives: the increased thermal stability of such adhesives would allow them to be used in much more demanding applications, such as those typically encountered by many components surrounding aero-engines.
- Electrically conductive composites and coatings: could potentially replace the copper mesh currently used for lightning strike protection of composite aircraft structures – which would significantly reduce the aircraft's weight.
- Electrical packaging: the thermal stability, fire retardant nature and electromagnetic shielding properties of Graphene-filled thermoset plastics make them an ideal candidate for use in micro-electromechanical systems (MEMS), and encapsulation or potting of electronic components.
- Advanced coatings: tougher coatings have the potential to reduce the number of coats required, whilst coatings with improved surface finish can help to reduce drag (caused by surface roughness either from the coating itself, or from the build-up of dirt).

[11] Zaman, I., Manshoor, B., Khalid, A., and Araby, S., 2014. 'From clay to graphene for polymer nanocomposites – a survey'. Journal of Polymer Research, 21: 249–260.

EARLY STAGE APPLICATIONS

Graphene's unique properties with regards to liquids such as inks and water open the floodgates to more promising application areas. It also has surprisingly applications in the nuclear and defence industries.

Graphene Inks

Printed conductive patterns currently use a combination of poorly conducting carbon with other, often expensive, materials such as silver. Graphene inks could unlock a high-speed and low-cost technique for printing, opening a wide range of commercial applications including disposable sensors, intelligent packaging and RFID tags.

There are many companies producing Graphene inks, but none of them have the production scales to foster real commercial success. Recent work from the University of Cambridge used new Graphene-based inks to print at a rate of more than 100 metres per minute, which is comparable to commercial productions rates.[12]

Water (and other fluids) Filtration

Graphene allows water to pass through but it is almost completely impervious to gases and other liquids. Graphene and its derivatives could, therefore, be used in water filtration systems, desalination systems and even biofuel creation.

Researchers recently developed a Graphene-based water filter that is capable of filtering liquids nine times faster than anything else on the commercial market. It can also capture water-bound bacteria and viruses as anything larger than one nanometre cannot pass through the Graphene layer. The impact of delivering clean and safe drinking water to potentially millions of people and to the agriculture industry cannot be understated if and when a commercial product is developed.[13]

Furthermore, Graphene oxide can quickly remove radioactive material from contaminated water, according to research results from Rice University in the United States and the Lomonosov Moscow State University in Russia. Graphene oxide is particularly suited to this application as it can easily disperse in water and other organic solvents due to the presence of oxygen functionalities.

It's a remarkable property and the lost cost and biodegradable qualities of Graphene oxide make it an excellent candidate for such filtration applications.[14] For example, it could be used for in situ groundwater remediation or to aid the clean-up of contaminated sites, such as the Fukushima nuclear plant that was damaged by an earthquake and tsunami in 2011.

Such filtration effects could also cut the cost of hydraulic fracturing (also known as fracking) for oil and gas recovery, which would help reboot mining of rare earth metals.

Researchers at the University of Manchester have also tested Graphene's permeability with alcohol; they have been able to distil very strong samples of spirits, as only the water in the samples was able to pass through the Graphene.

Nuclear Decontamination

Another novel property of Graphene is its ability to filter different atomic isotopes of hydrogen (such as deuterium and tritium) from ordinary hydrogen. This leads to two important application areas discovered at the UKs first Graphene research hub at the University of Manchester.

The research found Graphene acts both as a "super sieve" to clean up nuclear waste contaminated by radioactive tritium and could also create "heavy water", which is a material composed of deuterium that is commonly used by nuclear reactors.[15]

[12] http://www.cam.ac.uk/research/news/new-graphene-based-inks-for-high-speed-manufacturing-of-printed-electronics

[13] http://phys.org/news/2016-03-revolutionary-graphene-filter-crisis.html

[14] Romanchuk, A. Y., Slesarev, A., Stepan, N., Kalmykov, D., Kosynkin, J. and Tour, M., 2012. 'Graphene Oxide for Effective Radionuclide Removal'. Physical Chemistry Chemical Physics.

[15] Lozanda-Hidalgo, M., Hu, S., Marshall, O., Mishchenko, O., Grigorenko, A.N., Dryfe, R.A.W., Radha, B., Grigorieva, I.V., and Geim, A.K., 2016. 'Sieving hydrogen isotopes through two-dimensional crystals'. Science, Vol. 351, Issue 6268: 68–70.

Bomb Detection

Graphene foam can outperform leading commercial gas sensors to detect potentially dangerous chemicals, according to a study from the US-based Rensselaer Polytechnic Institute.[16]

These Graphene gas sensors could aid law enforcement officers, bomb squads and other defence organisations. The sensor comprised of continuous Graphene nanosheets, which were grown into a foam-like structure that was roughly the size of a postage stamp. The flexibility and robustness of the sensor addresses the shortcomings of its predecessors, making a commercial product a distinct possibility.

Waterproofing

While Graphene is an extremely efficient water filter, research has uncovered methods to make Graphene either super repellent or superabsorbent to water.[17] There is tremendous commercial promise here when you consider the impact of an electronic system that's completely waterproof. Nokia is already working on developing a waterproof smartphone, for example.

Graphene Paint

Rusty vehicles could be a thing of the past, if Graphene paint hits the commercial sector. Graphene oxide is viable option as it provides a solid corrosion barrier and can also be applied to many surfaces, including metal, glass and even brick.

Once the paint has set, it also possesses the chemical and thermal stability of graphite, and the tensile strength of Graphene. It could even be applied to sand to create a tough and transparent coating that can hold the grains together and which can be formed into any desired shape.

Industrial spills of potentially dangerous chemicals, for example, could also be isolated by applying Graphene paint. Or ordinary copper and glass could be used to store the strongest acids with a coating of Graphene paint.[18]

Acoustic Detection

Researchers from the University of Belgrade in Serbia have developed world's first Graphene-based condenser microphone, which is 15 decibels higher in sensitivity than commercial microphones, at frequencies of up to 11kHz. But model stimulations indicate that a far more sensitive Graphene microphone is theoretically possible. At 300 layers thick, a Graphene vibrating membrane may be able to detect frequencies of up to 1MHz, approximately fifty times higher than the upper limit of human hearing.[19]

[16] Yavari, F., Chen, Z., Thomas, A., Ren, W., Cheng, H., Koratkar, N., 2011. 'High Sensitivity Gas Detection Using a Macroscopic Three-Dimensional Graphene Foam Network'. Nature, Scientific Reports 1, Article number: 166.

[17] http://news.vanderbilt.edu/2011/02/tuning-graphene-film-so-it-sheds-water

[18] http://www.techtimes.com/articles/15477/20140913/graphene-paint-rust-free.htm

[19] http://www.myidst.com/home5/international-defence-security-and-technology/technology/materials/the-wonder-material-graphene-moving-closer-to-realization-of-its-potential-through-new-production-techniques

Medical Imaging Contrast Agents

Graphene has also helped produce the very first pictures of a single protein as it is thin enough for the imaging electrons to pass through and reach the microscope's detector. These images provide a solid foundation in treating diseases caused by malfunctioning proteins, such as Huntington's and Alzheimer's disease.[20]

'Smart' Plasters & Dressings

Graphene's properties as an Anti-infective and Pro-thrombotic material have been suggested for 'smart' plasters and for hard-to-heal wound dressings, though the regulatory landscape for such coated medical devices has not yet been determined.[21]

Drug Delivery Technology

'Sheets' of Graphene oxide can be transformed into liquid crystal droplets spontaneously – like a polymer - by placing the material in a solution and manipulating the solution's pH; the Graphene droplets change their structure at the presence of an external magnetic field. Graphene in this situation shows a potential use of carrying drugs in the Graphene droplets and drug release upon reaching the targeted tissue when the droplets change shape under a magnetic field, though the activating distance might be problematic.[22]

Graphene strips with a drug decorating the surface or in rolled-up strips encapsulating the drug could be used to deliver the drug to a specific site if a release mechanism can be determined.[23]

Graphene as an Antibacterial

Graphene-based materials have been shown to be biocidal and are therefore a promising nanomaterial for the development of antibacterial surfaces. However, the effect of the physicochemical features of these materials and possible concurrent detrimental effects on their antibacterial activity or damage to surrounding materials has yet to be clarified.[24]

[20] https://www.newscientist.com/article/dn28744-first-ever-pictures-of-single-proteins-thanks-to-graphene-sheet

[21] http://ott.emory.edu/documents/breakfast_club/12029_graphene_coated_bandages.pdf

[22] Nano Research March 2012, Volume 5, Issue 3, pp 199–212

[23] Journal on Expert Opinion on Drug Delivery Volume 9, 2012 - Issue 11

[24] Advanced Healthcare Materials Volume 2, Issue 9 Pages 1181–1293

APPLICATION EXAMPLES & INVESTABILITY

Described in the previous section, there are numerous technologies where Graphene has distinct potential advantages over existing materials or can be used in novel application areas in a variety of industries; listed below are the sections covered where a brief application area is given against its investability and the pros and cons of its development:

A. Healthcare, Medical, Life Sciences and Biotechnology Applications

B. Electronics

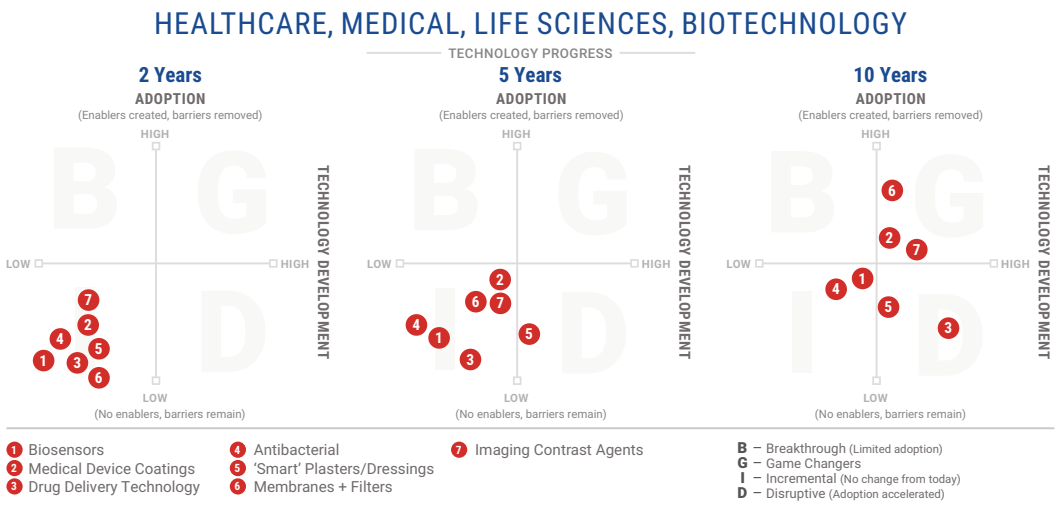
C. Automotive

D. Aerospace

E. Energy

F. Materials

A. Healthcare, Medical, Life Sciences and Biotechnology Applications



1. Biosensors

A promising candidate for making state-of-the-art nano-scale sensors and biosensors. Graphene has good conductivity and large specific surface area which in recent tests have enabled Graphene-based sensors/biosensors that have performed well with good accuracy, rapid-response times, high sensitivity and good selectivity, low detection limits, and long-term stability. They are ideally used as: gas sensors; electrochemical sensors for heavy metal ions; immunosensors; glucose sensors; hydrogen peroxide sensors; haemoglobin and myoglobin biosensors and it is believed Graphene will become widely used as a biosensor, though there is little market traction to date.

Pros: High sensitivity, broad range of applications, stability

Cons: Technology at a very low advancement rate; very low scale demonstrators, insufficient high-quality material available

Investability: Low, a decade-away from mass-production of niche sensors.

2. Medical Device Coatings

Graphene can be used as a biocompatible protective film for metals and metal matrix composites, potentially for biomedical applications; there is a need for toxicity testing, biocompatibility analysis and clear regulatory guidelines for use to be developed.

Pros: Biocompatible, probably non-toxic

Cons: Coatings technology for shapes and coating homogeneity not yet demonstrated, regulatory barriers

Investability: Low, other more established coatings still not available due to testing and trials timescales

3. Drug Delivery Technology

'Sheets' of Graphene oxide can be transformed into liquid crystal droplets spontaneously – like a polymer - by placing the material in a solution and manipulating the solution's pH; the Graphene droplets change their structure at the presence of an external magnetic field. Graphene in this situation shows a potential use of carrying drugs in the Graphene droplets and drug release upon reaching the targeted tissue when the droplets change shape under a magnetic field, though the activating distance might be problematic.

Graphene strips with a drug decorating the surface or in rolled-up strips encapsulating the drug could be used to deliver the drug to a specific site if a release mechanism can be determined.

Pros: Potential game-changer if ever possible for targeted drug delivery

Cons: No demonstration yet of possibility or mechanisms

Investability: Very low, decades away if ever possible, other delivery mechanisms (nanotubes and cages) still not trialled or through regulatory barriers

4. Antibacterials

Graphene-based materials have been shown to be biocidal and are therefore a promising nanomaterial for the development of antibacterial surfaces. However, the effect of the physicochemical features of these materials and possible concurrent detrimental effects on their antibacterial activity or damage to surrounding materials has yet to be clarified.

Pros: A strong biocide,

Cons: Shape and size effects on human tissue unknown, toxicity unknown, volume of material required on a global usage scale

Investability: Low-medium if used as a surface antibacterial only

5. 'Smart' Plasters and Wound Dressings

Graphene's properties as an Anti-infective and Pro-thrombotic material have been suggested for 'smart' plasters and for hard-to-heal wound dressings, though the regulatory landscape for such coated medical devices has not yet been determined.

Pros: Could be more effective than silver metal and lower toxicity

Cons: Shape and size effects unknown, regulatory hurdle as medical device

Investability: Low-medium if trials successful and regulatory barriers overcome

6. Membranes and Filters

Graphene oxide is potentially non-toxic and biodegradable (still being tested) and its surface is covered with epoxy, hydroxyl, and carboxyl groups that interact with cations and anions. As a result Graphene is known to be amphiphilic and can form (stable) suspensions in water or oil and can be dispersed in liquids showing excellent sorption capacities; its electrochemistry means that these suspensions can remove impurities/contamination and this has been demonstrated for copper, cobalt, cadmium, arsenate, and organic solvents contamination in various water and oil mixtures.

As a membrane, Graphene has been shown to allow water through but traps contaminants at a very small scale and down to ppb and ppt levels, though filter size and flow scale is an issue that means only very small filters for specialist applications have been created so far. Graphene membranes could be used to sieve hydrogen gas out of the atmosphere, where it is present in minute quantities, creating the possibility of electric generators powered by air.

Graphene has also been used in the development of condoms to create materials that are impenetrable by all STDs and are self-lubricating.

Pros: Could be a game-changer for liquids and gases filtration

Cons: Volume of material required and support of layers mechanisms/structures not yet developed for scale of requirement

Investability: Medium if support structures for the Graphene can be constructed and manufactured at scale over large areas for high flows.

7. Imaging contrast agents

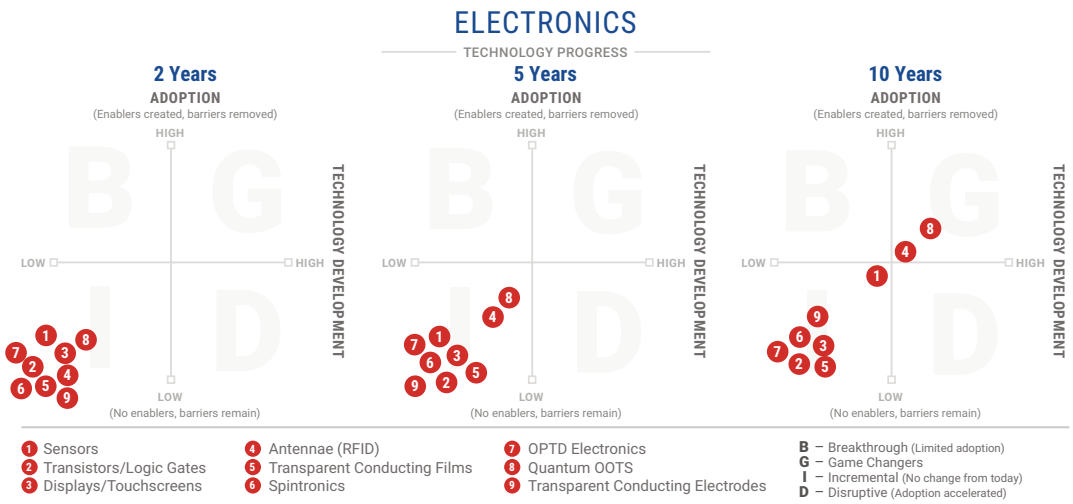
Graphene solutions and suspensions have been designed as MRI contrast agents; existing contrast agents decorated with Graphene have also been used in MRI imaging with some success. Graphene micro- and nano-particles have been used as contrast agents for photoacoustic and thermoacoustic tomography.

Pros: Could be a high-precision imaging contrast agent

Cons: No evidence base or trials in humans, regulatory barrier, no standards or metrology for size and shape consistency

Investability: Low until metrology and standards issues are solved and compliance is met

B. Electronics



1. Sensors

Graphene's large surface-to-volume ratio, optical properties, high electrical conductivity at room temperature, high carrier mobility and density, high thermal conductivity at room temperature make it a suitable material for novel sensor devices. Its considerable surface area compared to volume implies the possibility of high surface densities of molecules (biomolecules) that combined with electrical properties suggest it could be a biomolecule specific sensor where its use is believed will become widespread.

Biosensors can be used, among other things, for the detection of a range of analytes such as: gas sensors; electrochemical sensors for heavy metal ions; immunosensors; glucose sensors; hydrogen peroxide sensors; haemoglobin and myoglobin biosensors. Graphene-based nanoelectronic devices have also been researched for: use in DNA sensors (for detecting nucleobases and nucleotides); pH sensors; contamination sensors; strain and pressure sensors.

Graphene can enable sensors that are smaller and lighter and possibly be more sensitive/able to detect smaller changes in matter and respond more rapidly.

Pros: High sensitivity possibility, small size

Cons: No wafer-scale production of Graphene, microelectronics manufacturing capability yet for Graphene electronics (passive or active)

Investability: Low until homogenous material available in large wafer form and compatible with existing microelectronics manufacturing technologies.

2. Transistors and active components

A Graphene transistor is a nanoscale device based on Graphene, theoretically having electronic properties far superior to those of silicon; it is a device that is a single-electron transistor whereby a single electron passes through it at any one time.

Early researchers have built a Graphene transistor in 2007 with features including: room temperature operation; extreme sensitivity (due to its small size of one atom by ~10 atoms wide); and very low voltage operation.

Suggesting in the future Graphene-based processors could be very fast, low-power successors to silicon-based processors with ultrafast processing speeds (terahertz) and greater device density on microchips, though this has not yet been demonstrated and cross-talk between device elements might become an issue.

Pros: High device speeds possible, small size

Cons: No wafer-scale production of Graphene, microelectronics manufacturing capability yet for Graphene electronics (passive or active)

Investability: Low until homogenous material available in large wafer form and compatible with existing microelectronics manufacturing technologies.

3. Displays and Touchscreens

Graphene's high electrical conductivity and high optical transparency suggest it could be used for transparent conducting electrodes in such applications as: touchscreens; organic photovoltaic cells; LEDs; and organic light-emitting diodes (OLEDs). Its mechanical strength and flexibility are advantageous compared to indium tin oxide (ITO), which is brittle.

OLEDs with Graphene anodes have been demonstrated and the electronic and optical performance of Graphene-based devices are similar to devices made with ITO.

A prototype Graphene-based flexible display was demonstrated in 2014 though the problems of scale and number of screens required is considerable and material homogeneity and defect-free requirements have been hard to achieve to date.

Pros: High sensitivity and robustness/durability/flexibility possibility, small size

Cons: No wafer-scale production of Graphene, microelectronics manufacturing capability yet for Graphene electronics (passive or active)

Investability: Low until homogenous material available in large wafer form and compatible with existing microelectronics manufacturing technologies.

4. Nano Antennae (RFID)

Graphene-based nano-antenna can – theoretically - operate efficiently at very short (millimetre) radio wavelengths; it is believed that it will be possible to make a very small antenna that can radiate at much lower frequencies than classical metallic antennas of the same size.

Pros: High efficiency and operating frequencies possibility, small size

Cons: No wafer-scale production of Graphene, microelectronics manufacturing capability yet for Graphene electronics (passive or active). Insufficient R&D in this area.

Investability: Low until homogenous material available in large wafer form and compatible with existing microelectronics manufacturing technologies.

5. Transparent Conducting Films

Graphene-based transparent conducting films have been made by researchers with excellent electrical conductivity and high transparency, properties that are considered sufficient for many applications, such as transparent conductor films for touch panels.

Pros: High sensitivity and robustness/durability/flexibility possibility, small size

Cons: No wafer-scale production of Graphene, microelectronics manufacturing capability yet for Graphene electronics (passive or active)

Investability: Low until homogenous material available in large wafer form and compatible with existing microelectronics manufacturing technologies.

6. Spintronics

Spintronics is the study and exploitation in solid-state devices of electron spin and its associated magnetic moment, along with electric charge. Graphene is a promising material for spintronics applications owing to its capacity for room-temperature 'spin transport' over (relatively long) diffusion lengths of several micrometres. Graphene also has high electron mobility and a tuneable charge-carrier concentration but needs to be able to be magnetised to be a truly useful spintronics device, an enormous challenge currently.

Pros: High sensitivity, very high switching speeds possibility, small size

Cons: No wafer-scale production of Graphene, microelectronics manufacturing capability yet for Graphene electronics (passive or active). Little known about spintronics in general.

Investability: Very low until homogenous material available in large wafer form and compatible with existing microelectronics manufacturing technologies and significant R&D developments made.

7. Optoelectronics

Optical communications are increasingly important since they could enable far reduced energy consumption in telecommunications. Graphene, because of its unique portfolio of electronic properties related to its size and shape can potentially beat current silicon photonic technology in terms of energy consumption. There are numerous hurdles to overcome, though recent research has been promising this is still at the single-device scale.

Pros: High sensitivity and robustness/durability/low operating voltages possibility, small size

Cons: No wafer-scale production of Graphene, microelectronics manufacturing capability yet for Graphene electronics (passive or active). R&D at early stages

Investability: Very low until homogenous material available in large wafer form and compatible with existing microelectronics manufacturing technologies, R&D efforts considerably expanded.

8. Quantum Dots

Graphene quantum dots are fragments of Graphene and studies have found that in almost all cases, these are not single-layer Graphene but multi-layers of up to 10 layers from 10 to 60 nm in size. They have potential application in: imaging – particularly in bio imaging; therapeutics; sensors; drug delivery; LEDs and OLEDs; photodetectors; solar cells; and as fluorescent materials.

Pros: Already in production for simple uses

Cons: No metrology and standards available

Investability: Medium until these supersede current quantum dot materials.

9. Transparent Electrodes

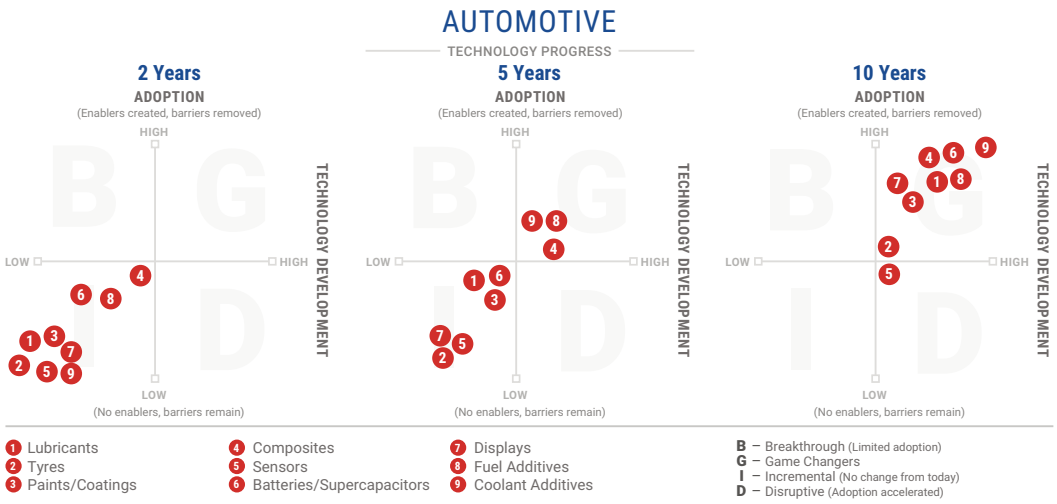
Graphene-based transparent conducting films have been made by researchers with excellent electrical conductivity and high transparency, properties that are considered sufficient for many applications, such as transparent conductor films for touch panels, electrodes, and nanowires.

Pros: High sensitivity and robustness/durability/flexibility possibility

Cons: No wafer-scale production of Graphene, microelectronics manufacturing capability yet for Graphene electronics (passive or active)

Investability: Low until homogenous material available in large wafer form and compatible with existing microelectronics manufacturing technologies.

C. Automotive



1. Lubricants

The addition of Graphene nanoparticles (nanoflakes) to liquids has been shown to significantly enhance some of their properties; adding Graphene nanoflakes (with their very high surface area-to-volume ratio and extreme properties) to lubricants enhances their ability to conduct heat, lubricate and protect from wear-and-tear. These are important properties in the automotive industry as better lubricants result in reduced engine wear, lower noise, and better and longer engine performance.

Recently researchers have found that adding just 0.01% Graphene nanoflakes compared to the total mass of lubricant improved its thermal conductivity by 17%, with almost no changes in viscosity; improved thermal conduction means the lubricant is better able to carry heat away from an engine.

Some researchers are optimistic and confident that Graphene-nanoflake enhanced lubricants could last ~ 20% longer than the currently available motor oils. They may be less costly to produce since less conventional (expensive) additives will be required; they could protect engines better than currently available lubricants because they reduce friction. The current challenge for adoption by the automotive industry is to develop (at scale) a Graphene nanoflake lubricant formulation that meets (or exceeds) current industry and regulatory standards and future automotive requirements.

Pros: Excellent performance enhancement, fuel savings, equipment lifetime improvements

Cons: Large volume of material required, industry uptake and resistance

Investability: High, especially in specialist applications

2. Tyres

Manufacturers adding Graphene to bicycle tyres claim they are lighter than ordinary tyres, are longer-lasting and more puncture resistant. It is claimed Graphene-enhanced tyres dissipate heat more efficiently, are stiffer when riding upright and soften on turns giving better traction. Other manufacturers claim the same results with the addition of ordinary carbon black to their rubber tyre formulation. The sheer volume of material required for automotive application limits the use of Graphene use in tyres perhaps only to specialist applications such as F1 racing vehicles' tyres and racing motorcycle tyres.

Pros: Performance enhancement, robustness, lifetime

Cons: Large volume of material required, industry uptake and resistance

Investability: High, especially in specialist applications (e.g. racing bicycles' tyres) though low volume market

3. Paints and Coatings

Graphene added to paints and coatings have been shown to modify the paint or coating beneficially: Graphene addition can create durable coatings and glazes which don't crack or shatter and are resistant to water, oil and other liquids including acids and bases. Graphene's excellent electrical and thermal conductivity can be used to make electrically and thermally-conductive paints; it can also be added to create anti-oxidant, scratch-resistant and anti-UVA paints and coatings.

The same can be stated for Graphene addition to create functional industrial coatings such as: high performance adhesives; anti-bacterial coatings; 'solar' paints that are capable of absorbing solar energy and transmitting it; anti-rust coatings; anti-fogging and self-cleaning glass and glass coatings; UV sunscreens and sunblocks; and non-stick coatings for domestic applications such as frying pans and cooking utensils. There has been a very-much-spray-on electronic coating that enables any flat surface (such as a door or wall) to be turned into a functional electronic coating which could act as a screen. coating that turns a regular wall into a screen.

Pros: Improved performance, durability

Cons: Formulations complicated, volume of material required for global marketplace

Investability: Medium if material can be manufactured to correct size and shape, and volume

4. Sensors

Graphene's large surface-to-volume ratio, optical properties, high electrical conductivity at room temperature, high carrier mobility and density, high thermal conductivity at room temperature make it a suitable material for novel sensor devices. Its considerable surface area compared to volume implies the possibility of highly sensitive accelerometers and gravitometers.

Graphene can enable sensors that are smaller and lighter and possibly be more sensitive/able to detect smaller changes in matter and respond more rapidly; there is a possibility that Graphene could be used in combustion sensors and oxygen/carbon monoxide ratio sensors though there is little evidence to suggest these are much more effective than existing solutions.

Pros: High sensitivity, broad range of applications, stability

Cons: Technology at a very low advancement rate; very low scale demonstrators, insufficient high-quality material available

Investability: Low, a decade-away from mass-production of niche sensors.

5. Batteries and Supercapacitors

Graphene can potentially give a dramatic improvement to battery-using electronics and electric vehicles through better electricity storage in conventional batteries and supercapacitors through using Graphene addition.

Graphene is used to enhance existing battery and supercapacitor technology; Graphene can reduce battery mass, make them more robust/durable and suitable for high-capacity energy storage and shorten charging times. Graphene can extend a battery's life-time through reducing the quantity of carbon that is coated on the battery materials or is added to battery electrodes.

Graphene can be used to increase energy density; for example, Li-ion batteries can be enhanced by introducing Graphene to the battery's anode using Graphene's excellent electrical (and thermal) conductivity and large surface area to improve performance.

Graphene-based supercapacitors have been developed (on a small scale so far) using Graphene to create a massive surface area in the Supercapacitor through its thinness to store nearly as much energy as Li-ion batteries, to charge and discharge in seconds and be sufficiently robust to be able to survive tens of thousands of charging cycles

Pros: High capacity, faster charging, lower mass

Cons: Technology at a very low advancement rate; very low scale demonstrators, insufficient high-quality material available

Investability: Low, a decade-away from mass-production of sufficient volume of public-usable batteries or supercapacitors

6. Displays

Graphene's high electrical conductivity and high optical transparency suggest it could be used for transparent conducting electrodes in such applications as: touchscreens; organic photovoltaic cells; LEDs; and organic light-emitting diodes (OLEDs). Its mechanical strength and flexibility are advantageous compared to indium tin oxide (ITO), which is brittle. It is unlikely that such LEDs and OLEDs will be sufficiently powerful to be used for automotive applications (headlamps, indicators and so on) though these might be usable for smaller, low power internal indicator lamps which will, in turn, reduce fuel consumption by a small amount.

OLEDs with Graphene anodes have been demonstrated and the electronic and optical performance of Graphene-based devices are similar to devices made with ITO.

A prototype Graphene-based flexible display was demonstrated in 2014 though the problems of scale and number of screens required is considerable and material homogeneity and defect-free requirements have been hard to achieve to date.

Pros: High sensitivity and robustness/durability/flexibility possibility, small size

Cons: No wafer-scale production of Graphene, microelectronics manufacturing capability yet for Graphene electronics (passive or active)

Investability: Low until homogenous material available in large wafer form and compatible with existing microelectronics manufacturing technologies.

7. Fuel Additives

Graphene – as functionalised nanoflakes and sheets - has been successfully added to advanced (rocket propellant) fuels with enhanced combustion temperatures and efficiency; this has not been replicated in petrol or diesel, however, except for specialist formulations for use in racing-car technology. However, perhaps the greatest advantage of functionalized Graphene sheets over traditional metal oxide catalysts used as fuel additives is that they do not leave any solid reaction products and the Graphene takes part in the combustion and is consumed with the fuel.

Pros: Potential game-changer for certain fuel types, environmentally friendly

Cons: Few apparent advantages over existing fuel additives in conventional fuels

Investability: Low until homogenous material available in quantities needed and advantages demonstrated in wide-scale trials.

8. Coolant additives

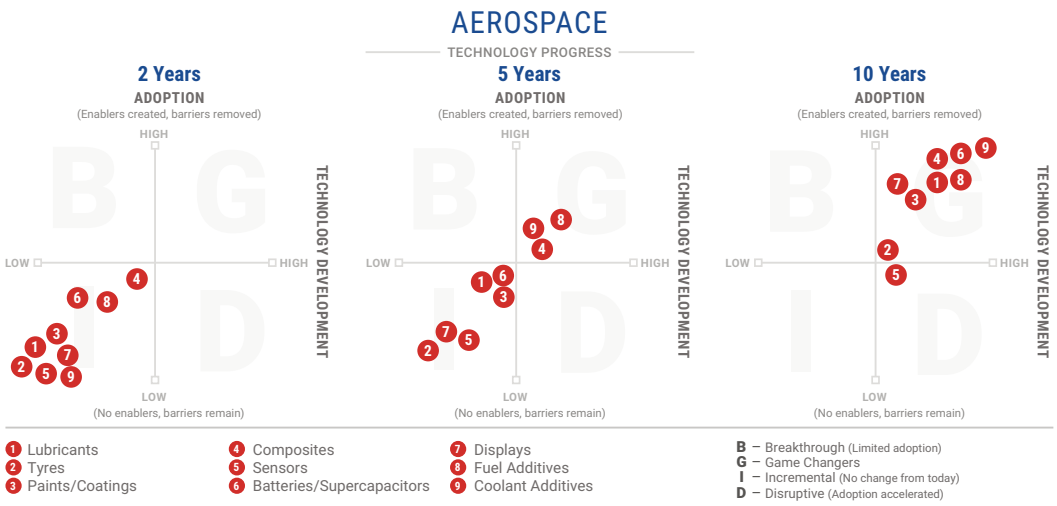
Graphene's high thermal conductivity suggests that it could be used as an additive in coolants and research work has shown that small additions - ~5% Graphene by volume – to conventional coolant mixes can enhance the thermal conductivity of the base fluid by as much as ~85%. However, there is no marked effect on fluid viscosity or improved pump lubrication as there is with conventional coolants. This addition might be limited to specialist applications if this is a permitted additive for the field of use (for example, in F1 racing vehicles).

Pros: Potential game-changer for certain coolant types, environmentally friendly

Cons: Few apparent advantages over existing coolant additives

Investability: Low until homogenous material available in quantities needed and advantages demonstrated in wide-scale trials.

D. Aerospace



1. Lubricants

The addition of Graphene nanoparticles (nanoflakes) to liquids has been shown to significantly enhance some of their properties; adding Graphene nanoflakes (with their very high surface area-to-volume ratio and extreme properties) to lubricants enhances their ability to conduct heat, lubricate and protect from wear-and-tear. These are important properties in the automotive industry as better lubricants result in reduced engine wear, lower noise, and better and longer engine performance.

Recently researchers have found that adding just 0.01% Graphene nanoflakes compared to the total mass of lubricant improved its thermal conductivity by 17%, with almost no changes in viscosity; improved thermal conduction means the lubricant is better able to carry heat away from an engine.

Some researchers are optimistic and confident that Graphene-nanoflake enhanced lubricants could last ~ 20% longer than the currently available motor oils. They may be less costly to produce since less conventional (expensive) additives will be required; they could protect engines better than currently available lubricants because they reduce friction. The current challenge for adoption by the aerospace industry is to develop (at scale) a Graphene nanoflake lubricant formulation that meets (or exceeds) current industry and regulatory standards and future aerospace requirements.

Pros: Excellent performance enhancement, fuel savings, equipment lifetime improvements

Cons: Large volume of material required, industry uptake and resistance

Investability: High, especially in specialist applications

2. Tyres

Manufacturers adding Graphene to bicycle tyres claim they are lighter than ordinary tyres, are longer-lasting and more puncture resistant. It is claimed Graphene-enhanced tyres dissipate heat more efficiently, are stiffer when riding upright and soften on turns giving better traction. Other manufacturers claim the same results with the addition of ordinary carbon black to their rubber tyre formulation. The sheer volume of material required for aerospace application limits the use of Graphene use in tyres for aviation.

Pros: Performance enhancement, robustness, lifetime

Cons: Large volume of material required, industry uptake and resistance, regulations and testing times

Investability: Low, high volume highly-regulated marketplace

3. Paints and Coatings

Graphene added to paints and coatings have been shown to modify the paint or coating beneficially: Graphene addition can create durable coatings and glazes which don't crack or shatter and are resistant to water, oil and other liquids including acids and bases. Graphene's excellent electrical and thermal conductivity can be used to make electrically and thermally-conductive paints; it can also be added to create anti-oxidant, scratch-resistant and anti-UVA paints and coatings. This might be particularly useful for aircraft and aviation use, both to make composite components electrically conducting and give a more resilient surface against rain and dust damage during flight.

The same can be stated for Graphene addition to create functional industrial coatings such as: high performance adhesives; 'solar' paints that are capable of absorbing solar energy and transmitting it; anti-rust coatings; anti-fogging and self-cleaning glass and glass coatings.

Pros: Improved performance, durability

Cons: Formulations complicated, volume of material required for global marketplace

Investability: Medium if material can be manufactured to correct size and shape, and volume

4. Sensors

Graphene's large surface-to-volume ratio, optical properties, high electrical conductivity at room temperature, high carrier mobility and density, high thermal conductivity at room temperature make it a suitable material for novel sensor devices. Its considerable surface area compared to volume implies the possibility of highly sensitive accelerometers and gravitometers.

Graphene can enable sensors that are smaller and lighter and possibly be more sensitive/able to detect smaller changes in matter and respond more rapidly; there is a possibility that Graphene could be used in combustion sensors and oxygen /nitrous oxide ratio sensors for aviation use though there is little evidence to suggest these are much more effective than existing solutions.

Pros: High sensitivity, broad range of applications, stability

Cons: Technology at a very low advancement rate; very low scale demonstrators, insufficient high-quality material available

Investability: Low, a decade-away from mass-production of niche sensors.

5. Batteries and Supercapacitors

Graphene can potentially give a dramatic improvement to battery-using electronics and electric vehicles through better electricity storage in conventional batteries and supercapacitors through using Graphene addition. As a mass-reducing agent in improved battery or supercapacitor technology for aviation this could be useful in light weighting aircraft and making a more robust (less combustible) battery and supercapacitor technology better suited to aviation use.

Graphene is used to enhance existing battery and supercapacitor technology; Graphene can reduce battery mass, make them more robust/durable and suitable for high-capacity energy storage and shorten charging times. Graphene can extend a battery's life-time through reducing the quantity of carbon that is coated on the battery materials or is added to battery electrodes.

Graphene can be used to increase energy density; for example, Li-ion batteries can be enhanced by introducing Graphene to the battery's anode using Graphene's excellent electrical (and thermal) conductivity and large surface area to improve performance.

Graphene-based supercapacitors have been developed (on a small scale so far) using Graphene to create a massive surface area in the Supercapacitor through its thinness to store nearly as much energy as Li-ion batteries, to charge and discharge in seconds and be sufficiently robust to be able to survive tens of thousands of charging cycles.

Pros: High capacity, faster charging, lower mass, potentially safer (for use in air travel)

Cons: Technology at a very low advancement rate; very low scale demonstrators, insufficient high-quality material available

Investability: Low, a decade-away from mass-production of sufficient volume of usable batteries or supercapacitors, aerospace regulatory requirements for testing and verification of safe for use in flight

6. Displays

Graphene's high electrical conductivity and high optical transparency suggest it could be used for transparent conducting electrodes in such applications as: touchscreens; organic photovoltaic cells; LEDs; and organic light-emitting diodes (OLEDs). Its mechanical strength and flexibility are advantageous compared to indium tin oxide (ITO), which is brittle. It is unlikely that such LEDs and OLEDs will be sufficiently powerful to be used for automotive applications (headlamps, indicators and so on) though these might be usable for smaller, low power internal indicator lamps which will, in turn, reduce fuel consumption by a small amount.

OLEDs with Graphene anodes have been demonstrated and the electronic and optical performance of Graphene-based devices are similar to devices made with ITO.

A prototype Graphene-based flexible display was demonstrated in 2014 though the problems of scale and number of screens required is considerable and material homogeneity and defect-free requirements have been hard to achieve to date.

Pros: High sensitivity and robustness/durability/flexibility possibility, small size

Cons: No wafer-scale production of Graphene, microelectronics manufacturing capability yet for Graphene electronics (passive or active)

Investability: Low until homogenous material available in large wafer form and compatible with existing microelectronics manufacturing technologies.

7. Fuel Additives

Graphene – as functionalised nanoflakes and sheets - has been successfully added to advanced (rocket propellant) fuels with enhanced combustion temperatures and efficiency; this has not been replicated in petrol or diesel, however, except for specialist formulations for use in racing-car technology; this is currently being trialled for advanced fuel formulations for military use. However, perhaps the greatest advantage of functionalized Graphene sheets over traditional metal oxide catalysts used as fuel additives is that they do not leave any solid reaction products and the Graphene takes part in the combustion and is consumed with the fuel, creating a potentially 'greener' aviation fuel.

Pros: Potential game-changer for certain fuel types, environmentally friendly

Cons: Few apparent advantages over existing fuel additives in conventional fuels

Investability: Low until homogenous material available in quantities needed and advantages demonstrated in wide-scale trials, aerospace regulatory issues.

8. Coolant additives

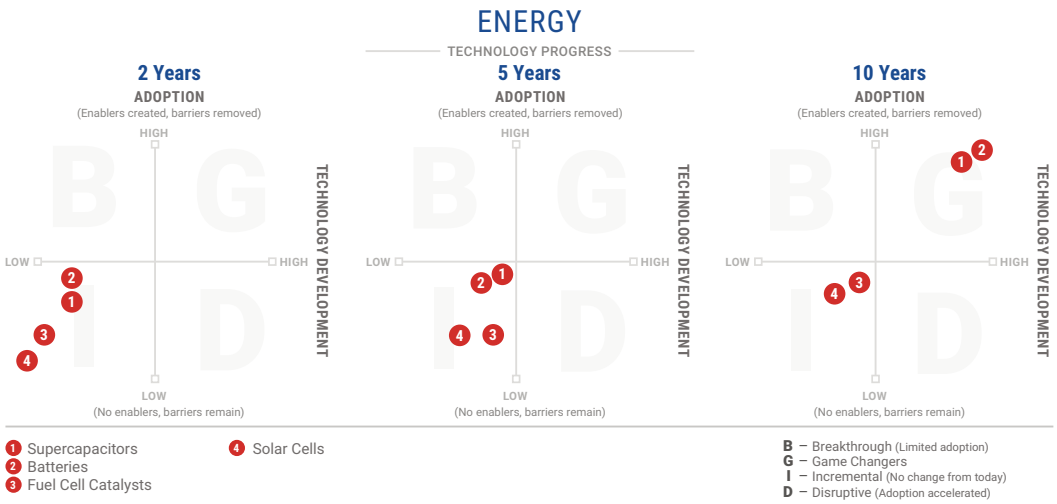
Graphene's high thermal conductivity suggests that it could be used as an additive in coolants and research work has shown that small additions - ~5% Graphene by volume – to conventional coolant mixes can enhance the thermal conductivity of the base fluid by as much as ~85%. However, there is no marked effect on fluid viscosity or improved pump lubrication as there is with conventional coolants.

Pros: Potential game-changer for certain coolant types, environmentally friendly

Cons: Few apparent advantages over existing coolant additives

Investability: Low until homogenous material available in quantities needed and advantages demonstrated in wide-scale trials, aerospace regulatory issues.

E. Energy



1. Supercapacitors

Supercapacitors differ from regular capacitors in that they can store far larger amounts of energy. They are also known as also known as electric double-layer capacitor (EDLC) or Ultracapacitors; they are high-capacity capacitor have with capacitance values much higher than other capacitors and lower voltage limits. Supercapacitors fall in the range between electrolytic capacitors and rechargeable batteries.

They typically store 10 to 100 times more energy per unit volume or mass than electrolytic capacitors, can accept and deliver charge much faster than batteries, and tolerate many more charge-discharge cycles than rechargeable batteries.

Supercapacitors are used in applications requiring many rapid charge/discharge cycles rather than long term compact energy storage: within cars, buses, trains, cranes and lifts, where they are used for regenerative braking, short-term energy storage or burst-mode power delivery.

Currently one limitation in the capacitance of supercapacitors is the surface area of the conductors and if one conductive material in a supercapacitor has a higher relative surface area than another, it will be better at storing electrostatic charge. Using Graphene rather than standard carbon in supercapacitors gives potentially a far higher surface are even than carbon black and can therefore produce far more efficient and higher energy storage supercapacitors than currently available.

Pros: High capacity, faster charging, lower mass

Cons: Technology at a very low advancement rate; very low scale demonstrators, insufficient high-quality material available

Investability: Low, a decade-away from mass-production of sufficient volume of public-usable supercapacitors

2. Batteries

By incorporating Graphene as an anode in a Lithium ion battery, it is believed possible to offer much higher storage capacities with much better longevity and charge rate batteries than standard Li ion batteries. Graphene-enhanced lithium ion batteries could be used in much higher energy usage applications such as electric vehicles, or they can be used as lithium ion batteries are now, in smartphones, laptops and tablet PCs but at significantly lower levels of size and weight. Many claims of Graphene enhanced Li polymer batteries have been reported, however these seem consistent with existing manufactured Li polymer batteries that use conventional carbon nanotubes.

Pros: High capacity, faster charging, lower mass

Cons: Technology at a very low advancement rate; very low scale demonstrators, insufficient high-quality material available

Investability: Low, a decade-away from mass-production of sufficient volume of public-usable batteries

3. Fuel Cell Catalysts

Graphene is impermeable to all gases and liquids though can allow protons to pass through it; this phenomenon could revolutionise fuel cells (and other hydrogen-based technologies) as they require a membrane or barrier that only allows protons (hydrogen stripped of its electrons) to pass through it.

It has been found that protons pass through Graphene easily (particularly at raised temperatures) and even if the Graphene is covered with catalytic platinum nanoparticles; this makes Graphene attractive for possible uses as proton-conducting membranes, which are at the heart of modern fuel cell technology.

Despite being well-established and using Boron Nitride membranes effectively, fuel-cell technology requires further improvements to make it more widely used. One of the major problems is a fuel crossover through the existing proton membranes, which reduces their efficiency and durability. Graphene membranes which are thinner and more efficient than currently available Boron Nitride membranes suffers less fuel crossover and catalyst poisoning which can improve performance and competitiveness of fuel cells.

Pros: Longer lifetime, more efficient fuel cells

Cons: Technology at a very low advancement rate; very low scale demonstrators, insufficient high-quality material available

Investability: Low, a decade-away from mass-production of sufficient volume of fuel cells, existing technology still taking time to get to market acceptability.

4. Solar Cells

Hybrid Graphene-perovskite solar cells showing good stability during exposure to sunlight and an efficiency of over 18% have been demonstrated; Perovskite solar cells are rapidly emerging as the most promising photovoltaic technology, though their stability is still questionable.

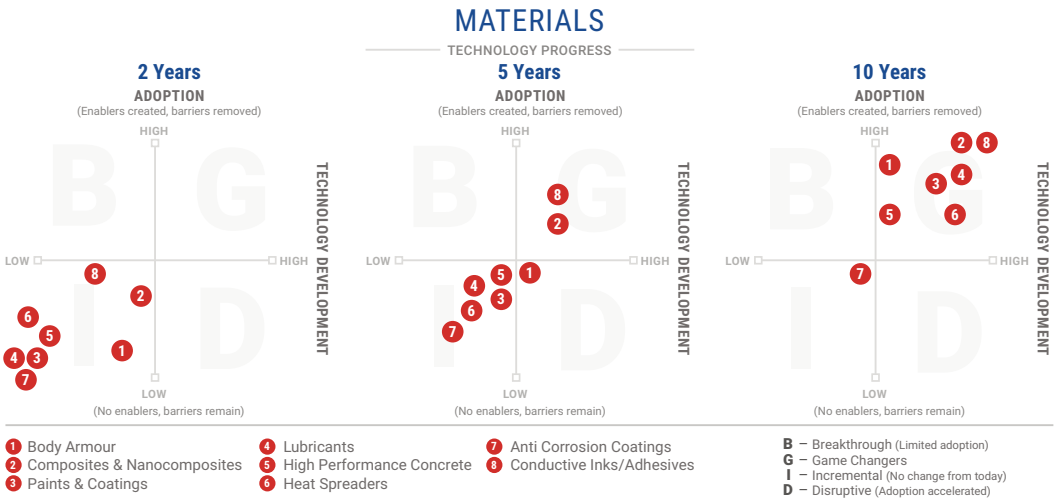
Air and humidity degrade cell performance, as does continuous exposure to sunlight and heat, setting back some of the advantages of Graphene-enhanced solar cells over other types of solar cells. Graphene and Graphene-related materials are known for their applications as protective layers - these could lead to a new high-efficiency hybrid perovskite solar cell containing both Graphene flakes and a Graphene Oxide layer with efficiencies of more than 18%.

Pros: Improved efficiency, additional energy generation phenomena

Cons: Technology at a very low advancement rate; very low scale demonstrators, insufficient high-quality material available

Investability: Low, a decade-away from mass-production of sufficient volume of public-usable solar cells, market nearly saturated with Si-based efficient solar panels.

F. Materials



1. Body armour

Graphene's unusual ability to absorb sudden impacts – it is 10 times better than steel at dissipating kinetic energy - could make it an excellent choice for lightweight ballistic body armour or a component of future body armour technology.

Pros: Energy dissipation

Cons: Technology at a very low advancement rate; very low scale demonstrators, insufficient high-quality material available

Investability: Low, a decade-away from mass-production of sufficient volume of materials

2. Composites & Nanocomposites

Recent advances in composites manufacturing processes have enabled Graphene-enhanced structuralresin panels to be created.

The Graphene-enhanced resin is stronger than composite materials made without added Graphene, which also enables the reduction in the amount of fibres in the composite material, resulting in a significant weight and cost reduction. This use of Graphene will have considerable implications for cost, performance and fuel economy in vehicles/aircraft and composite-using industries if applied widely in the manufacturing process.

Graphene has become more widely used as an additive to sports equipment to give added advantages to composite-based tennis racquets, golf clubs and the like.

Additions to non-composites such as Concrete have shown some advantages though 1kg of Graphene is needed per tonne of concrete and more than 1 billion tonnes of specialist concrete are produced a year; Graphene manufacturing technology is decades behind market requirements for Concretes and composites.

Pros: Enhanced materials produced

Cons: Technology at a very low advancement rate; very low scale demonstrators, insufficient high-quality material available, niche applications in sports, F1 racing, military uses

Investability: Low, a decade-away from mass-production of sufficient volume of Graphene as an additive to composites or concretes for non-highly-specialist use.

3. Paints & Coatings

Graphene added to paints and coatings have been shown to modify the paint or coating beneficially: Graphene addition can create durable coatings and glazes which don't crack or shatter and are resistant to water, oil and other liquids including acids and bases. Graphene's excellent electrical and thermal conductivity can be used to make electrically and thermally-conductive paints; it can also be added to create anti-oxidant, scratch-resistant and anti-UVA paints and coatings. This might be particularly useful for aircraft and aviation use, both to make composite components electrically conducting and give a more resilient surface against rain and dust damage during flight.

The same can be stated for Graphene addition to create functional industrial coatings such as: high performance adhesives; 'solar' paints that are capable of absorbing solar energy and transmitting it; anti-rust coatings; anti-fogging and self-cleaning glass and glass coatings.

Pros: Improved performance, durability

Cons: Formulations complicated, volume of material required for global marketplace

Investability: Medium if material can be manufactured to correct size and shape, and volume

4. Lubricants

The addition of Graphene nanoparticles (nanoflakes) to liquids has been shown to significantly enhance some of their properties; adding Graphene nanoflakes (with their very high surface area-to-volume ratio and extreme properties) to lubricants enhances their ability to conduct heat, lubricate and protect from wear-and-tear. These are important properties in the automotive industry as better lubricants result in reduced engine wear, lower noise, and better and longer engine performance.

Recently researchers have found that adding just 0.01% Graphene nanoflakes compared to the total mass of lubricant improved its thermal conductivity by 17%, with almost no changes in viscosity; improved thermal conduction means the lubricant is better able to carry heat away from an engine.

Some researchers are optimistic and confident that Graphene-nanoflake enhanced lubricants could last ~ 20% longer than the currently available motor oils. They may be less costly to produce since less conventional (expensive) additives will be required; they could protect engines better than currently available lubricants because they reduce friction. The current challenge for adoption by the aerospace industry is to develop (at scale) a Graphene nanoflake lubricant formulation that meets (or exceeds) current industry and regulatory standards and future aerospace requirements.

Pros: Excellent performance enhancement, fuel savings, equipment lifetime improvements

Cons: Large volume of material required, industry uptake and resistance

Investability: High, especially in specialist applications

5. High Performance Coatings

Graphene-enhanced specialist paints and coatings have shown outstanding performance results in proof of concept studies into its use in anti-corrosive coatings and high-self-lubricating surfaces, particularly in ISO standard accelerated weathering and anti-corrosion tests where Graphene-enhanced paints and protective coatings have been shown to give a six-fold improvement in barrier and anti-corrosion properties at low loading levels.

Pros: Improved performance, durability

Cons: Formulations complicated, volume of material required for global marketplace

Investability: Medium if material can be manufactured to correct size and shape, and volume

6. Heat Spreaders

Graphene added to conventional heat spreaders in microelectronics has been show to give some advantages in thermal management, though this is not believed to be substantially different from using other similarly carbon (and diamond) enhanced heat spreading materials.

Pros: Good performance possibility,

Cons: Manufacturing capability and compatibility, sufficiently better than existing technologies and materials?

Investability: Low, probably insufficient need compared with benefits of use.

7. Anti-corrosion Coatings

Graphene-enhanced specialist paints and coatings have shown outstanding performance results in proof of concept studies into its use in anti-corrosive coatings, particularly in ISO standard accelerated weathering and anti-corrosion tests where Graphene-enhanced paints and protective coatings have been shown to give a six-fold improvement in barrier and anti-corrosion properties at low loading levels.

This has been seen to be advantageous in reducing ship hull fouling and barnacle adhesion.

Pros: Improved performance, durability

Cons: Formulations complicated, volume of material required for global marketplace

Investability: Medium if material can be manufactured to correct size and shape, and volumes required

8. Conductive Inks/Adhesives

Graphene has a high charge carrier mobility, high thermal and excellent chemical stability; combined with its intrinsic flexibility, Graphene has been demonstrated for several applications in printed electronics including chemical and thermal sensors, supercapacitors and more that can be screen-printed onto a variety of substrates, including flexible plastics and shaped surfaces.

Plastic electronics and other applications where Graphene-enhanced solutions are needed, such as inks and dyes need to be specially formulated to match the substrates used and processing and printing methods employed (such as screen printing processes etc.) according to manufacturing demand. Features of Graphene-enhanced inks such as electrical conductivity, drying time, flexibility Vs. cracking and so on are considerations.

Pros: Improved performance, durability

Cons: Formulations complicated, volume of material required for global marketplace

Investability: Medium if material can be manufactured to correct size and shape, and volume

Conclusions

Graphene has huge potential as a material in application and as a component part of other applications - there are myriad uses for Graphene, mostly as an additive to existing materials to enhance their performance or durability.

However, until metrology for Graphene size and shape can be demonstrated, until Graphene with required shape and size can be manufactured to agreed standards and quality, repeatably and in an environmentally friendly fashion, until sufficient volumes can be manufactured and overcome regulatory hurdles for manufacture and use in a variety of industries, Graphene has at least a decade of R&D before it will be used as more than a component of a more complex formulated material.

In recent years, there has been a massive expansion in scientific research, as well as advances in the understanding of graphene and its properties. This has generated further research on related two-dimensional materials.

There has also been great interest in acquiring intellectual property protection across a wide range of potential graphene processes and applications, as demonstrated by the expansion of patent applications.

Universities, public research institutions, and companies in Europe, Asia, and the US, as well as in other countries, are active in graphene research and commercialization. A growing number of companies have entered the graphene domain, with some early products already on the market, while policy initiatives and programmes to stimulate graphene research and commercialization have been launched in the UK, at the European Union level, and elsewhere.

Novel properties, including ultra-high electrical and thermal conductivities, wide-range optical transmittance and excellent mechanical strength and flexibility, makes graphene a promising material for a host of electronic applications.

Although many leading device manufacturers are evaluating graphene's potential, most of them have internal research and development activities or are developing partnerships with graphene-material suppliers. But today's graphene supply chain is widely dispersed and makes choosing the right supplier difficult.

A large (and growing) number of start-up companies are looking to catch graphene market opportunities in their initial stage. Securing graphene IP appears to be crucial in gaining a strong competitive position. A higher level of standardization in graphene technology will be a key factor in rising to meet future commercial challenges. The lack of suitable graphene quality characterization tools provides opportunities for companies developing specialized tools. The development and industrial production of new graphene applications requires a reliable supply of consistently high-quality graphene.

Yet, at the same time, there is also uncertainty about the trajectory and character of graphene commercialization. Market expectations and forecasts vary. Manufacturing and industrial scale-up are current areas of concern. And while there is an expectation these issues can be resolved with further research, development, investment, and experience, the performance-price competitiveness of graphene compared to other materials, both old and new, remains a longer-term issue.

While there is an emergent graphene value chain, we have yet to see how this will develop and, in particular, what will be the relative roles of large established firms and new small start-up companies in this process. To date, relatively few products enabled by graphene are available in the market and these products mostly offer incremental improvements over existing technologies.

The process of developing not only more graphene-enabled devices and products, but also more transformational outputs, is still at an early stage. Such products will need not only to be producible at scale, but also commercially viable, with a premium of price and/or performance over incumbents, and able to gain market acceptability (without significant environmental health and safety concerns).

The choice of the graphene production technique is of crucial importance to a device manufacturer because it influences not only the graphene size, quality and costs, but also the design of the production line for device manufacturing.

Graphene undoubtedly is a very promising material in the field of nanotechnology today. Its intriguing combination of spectacular properties, as well as a host of potential commercial applications, have grabbed the widespread interest of scientists and engineers the world over.

Graphene's potential applications are vast and ever growing; In order to realize its full potential for practical applications, one has to resolve the most challenging problem: economically viable mass production of high-quality graphene via environmentally friendly processes.

Fortunately, it is quite evident from the foregoing discussions that this situation is about to change soon, with new innovative graphene-synthesis routes appearing on the scene.

Graphene will fundamentally change the feasibility and efficiency of many future technologies, and in turn these future technologies will fundamentally change our lives.

APPENDIX

The report also gives an up-to-date listing of the landscape of leading manufacturers, Graphene R&D companies and materials vendors.

LANDSCAPE OF LEADING GRAPHENE PRODUCTS MANUFACTURERS, GRAPHENE R&D COMPANIES AND MATERIALS VENDORS

Tabulated below is an overview of the leading companies manufacturing Graphene-based products, researching Graphene applications and manufacturing Graphene and related Graphene materials25.

The geographical spread of companies is illuminating; there are almost as many companies in the US (at 56 companies in 2016) as Europe (with 68 companies in 2016); the far east has ~27 companies and Australia has ~14 companies as of 2016.

25 With direct and complete reference to https://www.graphene-info.com/companies

Company 25	Details 25
Haydale	Supplies Split Plasma treated carbon materials - graphene flakes/GNPs, graphene-based inks and CNTs. The company also offers customer R&D services and a lab for hire in the UK. Haydale is mostly focused on composite materials. Towards the end of 2015, Haydale raised around £6.0 million in an open share offer. Haydale's revenues in FY2015 reached £644,000 (up from £19,000 in 2014) while total income (which includes government grants) reached £1.48 million (up from £129,000). Most of the increase in income came from Haydale Composite Solutions. Haydale FY2015 loss reached £2.38 million. (AIM:HAYD)
Applied Graphene Materials	Established in 2010 as a spin-off from Durham University to develop a new graphene synthesis method and produce graphene materials. AGM's technology is a unique patented scalable 'bottom-up' CVD approach to produce graphene. AGM mainly targets graphene composites, coatings, lubricants, thermal management solutions and energy storage devices. In FY2015, AGM reported revenues of £41,000 (up from £4,000 pounds in FY2014) and a pretax loss of £4 million. AGM reported a significantly-broadened collaboration opportunity pipeline and provided over 120 evaluation samples to customers in more than 20 countries. Towards the end of 2015 the company announced plans to raise over £10 million. (AIM:AGM)

Company 25	Details 25
Carbon Sciences	A public company trading on the NASDAQ (OTC:CABN) and is developing a graphene production process technology that was originally invented at the University of California, Santa Barbara (UCSB). The process transforms natural gas into commercial size sheets of graphene that can be fine-tuned with application-specific electrical and materials properties. Carbon Sciences is also funding an R&D initiative at UCSB to develop a graphene-based optical modulator, a critical fiber optics component needed to enable ultrafast communication in data centers for cloud computing.
Graphene 3D Lab	Focusing on development of high-performance graphene-enhanced materials for 3D printing. The company was spun-off Graphene Labs with support from Lomiko Metals (who holds 15% of the company). In August 2014 graphene 3D Lab went public after a reverse merger with Matnic Resources. In March 2015 Graphene 3D Lab launched the world's first conductive graphene filament for 3D printing. And in August 2015 the company acquired its parent company, Graphene Labs. In December 2015, G3L raised CDN$1 million in a private placement. (TSX:GGG)
Talga Resources	An Australia-based company focused on graphite mining and graphene supply and application development. The company produces small-scale graphene products and has plans to construct a graphene demonstration plant in central Germany. Talga is developing graphene inks, graphene energy storage devices and is collaborating with both Haydale and Tata Steel on future graphene applications. Talga Resources is a public company trading in the Australian Stock Exchange In March 2015 Talga raised $4.2 million USD in a discounted placement. (ASE: TLG).
Cientifica	Began trading in October 2013 when they raised only £241,000 ($389,000) to invest and acquire graphene application businesses. The company signed a couple of collaboration and investment agreements, but in 2014 failed to raise more money and trading in the company's shares stopped towards the end of 2014. (AIM:CTFA)
Aixtron AG	A provider of deposition equipment to the semiconductor industry, and the company offers the BM Pro systems (previously called Black Magic systems). These systems are used to deposit graphene (and CNTs) using both chemical vapor deposition (CVD) and plasma enhanced chemical vapor deposition (PECVD). Aixtron trades in the NASDAQ (ticker: AIXG).
CVD Equipment Corporation	A US-based company that offers a variety of process and support equipment for both R&D and production facilities. CVD Equipment also has a wholly-owned subsidiary called CVD Materials Corporation that manufactures and sells nanomaterials, including several graphene materials. CVD Equipment trades in the NASDAQ (ticker: CVV).

Company 25	Details 25
Graphene Nanochem	A UK based company that holds the exclusive license to a process known as Catalyx which uses a catalyst to extract graphene from biogases (such as methane). This process can potentially mean low-cost graphene production. The company also offers graphene-enhanced lubricants for use in the extraction of shale gas, and signed an off-take agreement for their entire production capacity (135,000 ton) in the near future. Graphene Nanochem is trading in the UK's AIM (AIM:GRPH).
Valence Industries	An Australian industrial manufacturing company that produces high grade flake graphite products. In March 2014 Valence launched the Graphene Research Centre in collaboration with the University of Adelaide, with hopes to start initial graphene product sales in the first half of 2014. Valence is a public company that trades in Australia (ASX:VXL).
Strategic Energy Resources	An Australian based explorer with a diversified portfolio of mineral assets. In May 2014 the company announced it is resolved to focus on graphene related investments. SER is a public company, trading in the Australian Stock Exchange(ASX:SER).
Sunvault Energy	A Canadian-based company that develops renewable energy solutions. The company is developing graphene-based supercapacitor technology for use in solar cell arrays. In November 2015 Sunvault announced that is has completed the development of a graphene-enhanced smartphone battery case that uses the company's supercapacitor technology, and aims to crowd-fund this project. Sunvault is a public company that trades on the NASDAQ (OTC:SVLT)

2-D Tech

2-DTech makes and supplies 2D materials, including CVD-made graphene, graphene platelets, graphene oxide and other 2D materials. The company also offers prototyping of graphene based devices.

2-DTech was spun-off by the University of Manchester and was acquired by advanced engineering materials maker Versarien in April 2014 for £440,000. The company signed an agreement to become a project partner of the National Graphene Institute (NGI) in November 2014.

http://2-dtech.com

2D Carbon Tech

2D Carbon Tech was established in China in December 2011 with an aim to develop and produce graphene films. The company is currently offering CVD-produced graphene films on copper, glass, silicon or PET, and also graphene-based touch panels.

2D Carbon Tech's production capacity for graphene films is about 30,000 m2/year.

http://www.cz2dcarbon.com/

3D Graphtech Industries

3D Graphtech Industries was established in 2014 by Kibaran Resources and 3D Group to research and develop graphite and graphene applications for 3D printing. 3D Graphtech will source its graphite exclusively from Kibaran's Tanzanian graphite mine.

Since its establishment, 3D Graphtech did not release any information and the company does not have a web page.

Abalonyx

Abalonyx, founded in 2005 in Norway develops functional nano materials (nano-composites, nano-laminates and coatings) based on graphene derivatives. The company's main focus is functional coatings for the renewal energy sector. Abalonyx aims to build an IP portfolio for future licensing and production.

Abalonyx developed a new scalable process (modified version of the Hummers method) for the efficient production of high purity Graphene Oxide. The company is offering GO produced at its mass production (8 ton/year) facility launched in 2014.

http://abalonyx.no

ACS Material

ACS Material is a US-based company focused on advanced nanomaterials development and production. The company offers CVD grown graphene (single-layer graphene, graphene oxide, graphene nanoplates, carboxyl graphene and graphite oxide).

http://acsmaterial.com

AdNano Technology

AdNano Technology, based in Karnataka, India, offers multi-wall carbon nanotubes (MWCNTs) and graphene sheets. The company also offers related analytical services.

http://ad-nanotech.com

Advanced Graphene Products

Advanced Graphene Products (AGP) is a private company based in Poland that is focused on high quality graphene and graphene components production. The company produces monolayer graphene and multilayer graphene on different substrates (also those provided by customers).

AGP uses a unique and highly innovative production method that allows to fully control the outcome, resulting in a perfectcoverage and homogeneity making it the best product for industrial and laboratorial use.

http://advancedgrapheneproducts.com

Aixtron AG

Aixtron AG is a provider of deposition equipment to the semiconductor industry. The company's technology solutions are used to build advanced components for electronic and opto-electronic applications based on compound, silicon or organic semiconductor materials.

For graphene development and production, Aixtron offers the BM Pro systems (previously called Black Magic systems). BM Pro systems can be used to deposit graphene using both chemical vapour deposition (CVD) and plasma enhanced chemical vapour deposition (PECVD). Aixtron has sold over ten BM Pro systems to research institutes around the world.

Aixtron trades in the Frankfurt Stock Exchange and in the NASDAQ Stock Exchange (AIXG).

http://aixtron.com

American Graphite Technologies (AGT)

American Graphite Technologies (AGT) is a mineral exploration and technology development company. AGT has 100% ownership of 100 mineral claims in Quebec, Canada (close to Focus Graphite's proven graphite resource). AGT is also involved with graphene-related research.

In March 2013 AGT and CTI Nanotechnologies announced the successful production of graphene paper test samples. In September 2013 AGT launched a project with Ukraine's Kharkiv Institute of Physics and Technology to develop graphene- based working material for 3D printing.

AGT trades in the NASDAQ (OTCBB: AGIN).

http://americangraphitetechnologies.com

Alabama Graphite

Alabama Graphite, a Canadian based company, conducts graphite exploration and development at two graphite mines in Alabama, USA.

In March 2015, Alabama Graphite announced that it has found naturally occurring flake graphene at its Coosa Property in Alabama, USA. The company found several graphene types: few-layer graphene (2-5 layers), multi-layer graphene (2-10 layers), and graphite nanoplates (less than 100 nm thick).

Alabama Graphite trades in the Canadian stock exchange (TSX:ALP.V) and also on the NASDAQ (OTC: ABGPF). In July 2015, Alabama Graphite raised $2.875 million in a private placement.

http://americangraphitetechnologies.com

AMO GmBH

AMO is a German research service provider for material nanofabrication, with competence in nanofabrication, nanoelectronics, nanophotonics and biotechnology. AMO offers graphene flakes, fabrication of graphene transistors, catalytically produced graphene and custom-made graphene substrates.

http://amo.de/?id=567

Anderlab Technologies

Anderlab, based in Mumbai, India, is involved with carbon nanomaterial development and manufacturing.

The company developed a proprietary scalable graphene production technology, and they claim they can manufacture graphene on a ton scale. They are also developing graphene inks and nanocomposites.

http://anderlab.co

Annealsys

Annealsys is a manufacturer of Rapid Thermal Processing (RTP) and Chemical Vapor Deposition (CVD) systems. The company's systems offer multi-process capabilities in the same reactor, and besides graphene production units, the company also offers DLI-CVD system solutions for MoS2 deposition.

http://www.annealsys.com

Angstron Materials

Angstron Materials (owned by Nanotek Instruments and based in Ohio, USA) develops and produces nano graphene platelets (NGPs), and also provides pristine graphite and single layer graphene. Angstron is active in supercapacitors, graphene- modified lubricants, li-Ion battery materials and graphene-enhanced polymers.

In July 2015, the company secured $5 million in new capital to increase manufacturing capacity. In October 2015 Angstron established a sister company called EnerG Nano, with plans to raise around $20 million for the new company which will produce energy storage devices using Angstron's graphene materials.

http://angstronmaterials.com

Apex Graphene

Apex Graphene was established in 2013 in the US with an aim to specialize in CVD graphene commercialization. The company describes itself as a "substrate provider", and currently they offer two graphene products: a transparent conductive film, and a heat spreader sheet, both can go up to 15 meters in length.

http://www.apexgraphene.com

Applied Graphene Materials

Applied Graphene Materials (AIM:AGM) was established in 2010 as a spin-off from Durham University to develop a new graphene synthesis method and produce graphene materials. AGM's technology is a unique patented scalable 'bottom-up' CVD approach to produce graphene.

AGM mainly targets graphene composites, coatings, lubricants, thermal management solutions and energy storage devices. In FY2015, AGM reported revenues of £41,000 (up from £4,000 pounds in FY2014) and a pre-tax loss of £4 million. AGM reported a significantly-broadened collaboration opportunity pipeline and provided over 120 evaluation samples to customers in more

than 20 countries. Towards the end of 2015 the company announced plans to raise over £10 million.

http://AppliedGrapheneMaterials.com/

Applied Nanotech

Applied Nanotech is focused on developing new products for the PEN family of companies using nanotechnology approaches. Its team of PhD level scientists and engineers works with companies to solve technical problems and create innovations, producing a competitive advantage for the PEN family.

Applied Nanotech was founded in 1989, went public in 1993, and for the majority of its history focused on next generation display applications. However, in late 2005, to diversify from one "make or break" technology, it expanded its focus to other areas leveraging its previous work. From 2006 to the present, it has made substantial progress in these areas. The

company has organized its efforts into four divisions each of which has significant potential: Nanomaterials, Nanoelectronics, Nanosensors, and Nanoecology.

The company works with diverse nanomaterials like CNTs, graphene films and other nanoparticles.

www.appliednanotech.net

Archimedes Polymer Technologies

Archimedes Polymer Technologies (established in 2008 in Cyprus) is a specialist developer of nanocomposite materials. The company develops nanomaterials-based solutions for polymers, metals and ceramics. APT also offers graphene nanoplatelets. APT is involved with several European projects that use graphene-based materials, including TransCond, which aims to replace high volatile organic content in electrically conductive coatings. http://archimedesinternational.eu

Asbury Carbons

Asbury Carbons, established in 1895 in New Jersey, US, claims to be the world's largest independent processor and merchandiser of graphite. Asbury mines refines and markets graphite and a broad array of carbon-based products.

Asbury produces graphene and also sells natural graphite to companies involved with graphene.

http://asbury.com

AVANSA Technology & Services

AVANSA Technology & Services, based in India, offers analytical testing and consultancy services for industries with emerging nano- and micro-technology-based products. The company also provides a wide range of nanotechnology-based research services and products.

The company offers direct material sales and supplies few-layer graphene, functionalized graphene, reduced graphene oxide and also graphene in solvents. http://avansa.co.in

BASF

BASF, based in Germany, is one of the world's largest chemical companies—with over 350 production sites worldwide. BASF has been involved with graphene research since 2008 in collaboration with the Max Planck Institute. The company was also producing CNTs, but quit the CNT market in May 2013.

In September 2012 BASF and the MPI launched a joint R&D operation, the Carbon Materials Innovation Center (CMIC), to research graphene and other carbon-based materials.

http://basf.com

Biogenic Reagents

Biogenic Reagents produces low cost, high-performance carbon products made from renewable resources. The company produces activated carbon for mercury and emissions control, metallurgical carbon for iron and metals production and thermal carbon for energy generation.

In August 2013 the company announced it has begun commercial production of a graphene-based "ultra-adsorptive carbon" compound made from renewable biomass.

http://biogenicreagents.com

BGT Materials

BGT Materials Limited (previously BlueStone Global Tech) is a Manchester, UK based graphene producer. BGT offers high- quality, fully customizable graphene on several substrates (Quartz, Copper, Silicon and others). BGT Also offers a range of graphene and graphene oxide based products, including suspensions, inks and membranes.

In September 2013 BGT announced plans to collaborate with Manchester University on several graphene projects, including research into supercapacitors, plasmonics and filtration membranes. BGT is the first industrial partner of the £60-million National Graphene Institute at the University of Manchester

http://bgtmaterials.com

Bora Bora Resources

Bora Bora Resources is an Australian based graphite exploration company with a suite of high grade graphite projects in Sri Lanka.

In June 2014, BBR signed an agreement to exclusively supply Monash University with graphite from its Matale Graphite project in Sri Lanka. The same agreement also gives Bora Bora the exclusive commercialization rights. BBR is a public company, trading in the Australian Securities Exchange (ASX: BBR).

BT-Corp

Bottom Up Technologies Corporation (BT-Corp) was established in 2012 in India with an aim to manufacture graphene and multiwall CNTs, develop carbon nanomaterials based applications and provide consulting on nanotechnology issues.

BT-Corp currently produces lab-scale graphene, graphene oxide and related products. The company also sells CVD manufacturing equipment.

http://www.bt-corp.com

CalBattery

CalBattery is a Los Angeles-based startup that develops silicon-graphene lithium-ion battery anode material. The company develops materials and will also produce high-end batteries themselves in low quantities.

In September 2014, CalBattery introduced high-voltage, LCO cathode materials and high voltage electrolytes and also a new generation carbon-nano material for advanced lithium battery applications.

http://clbattery.com

Calevia

Calevia is a Canadian startup company established in August 2013 by Grafoid and ProScan Rx Pharma to co-develop a graphene-based cancer thermal treatment platform. This new platform aims to overcome the side effects and strong limitations of common cancer therapies.

http://calevia.com

Cambridge Graphene

Cambridge Graphene was established in May 2014 as a spin-off from Cambridge University to commercialize graphene inks based on research work at Cambridge University.

Cambridge Graphene is developing a scalable and cost-effective method of graphene (and other layered nanomaterials) ink production based on a liquid phase exfoliation technology that turns graphite into graphene in a water-based solution (without chemicals such as organic acids and without thermal treatment). As Cambridge Graphene does not start with Graphene Oxide, this results in graphene inks with superior properties without chemical contamination.

http://www.cambridgegraphene.com

Cambridge Nanosystems

Cambridge Nanosystems is a start-up company that was spun-off from the University of Cambridge with an aim to supply graphene materials (and also Single Walled Carbon Nanotubes - SWCNT).

The company currently produces high quality (metal-free) graphene flakes (200-500 nm). The company's capacity is several kg/day, but they are now building a 5-ton factory in Cambridge.

In addition to the graphene flakes, the company developed graphene-based inks and is developing composite materials, mainly for thermal management.

http://cambridgenanosystems.com

Carbon Nano-Material Technology

Carbon Nano-Material Technology is a South Korean refined graphite and graphene carbon materials manufacturer. It holds several patents and further patents pending relating to processes for the manufacture of these materials at significantly lower costs than other manufacturers.

The company is already said to be selling value added graphite products in the market using its proprietary portfolio of technologies. Carbon Nano-Material Technology has developed mass-production technology at a cost of 20 to 30% of existing technology in-house for the first time in the world by enhancing catalyst production and synthesis in the existing production process of carbon nano-material

Western Mining Network recently purchased 51% of Carbon Nano-Material Technology.

http://www.carbonnano.co.kr

Carbon Sciences

Carbon Sciences is developing a graphene production process technology that was originally invented at the University of California, Santa Barbara (UCSB). The process transforms natural gas into commercial size sheets of graphene that can be fine-tuned with application-specific electrical and materials properties.

Carbon Sciences is also funding an R&D initiative at UCSB to develop a graphene-based optical modulator, a critical fibre optics component needed to enable ultrafast communication in data centres for cloud computing. Carbon Sciences is a public company trading on the NASDAQ (OTC:CABN).

http://www.carbonsciences.com

China Carbon Graphite Group

China Carbon Graphite Group is a Chinese company based in Chengguan Town (Xinghe) that manufactures and sells graphite- based products in China. CCG's products include graphite electrodes, fine grain graphite blocks and high purity graphite. CCG is also active in graphene technology research.

CCG trades in the NASDAQ's OTC market (ticker: CHGI).

http://chinacarboninc.com

Cientifica

Cientifica, established in October 2013 in the UK, was focused on graphene applications. The company plan was to acquire and build businesses that make use of graphene materials.

Cientifica was a public company - they started trading on October 2013 in the UK's AIM stock exchange (ticker: CTFA) after taking over Avia Health Informatics shares and disposing of the old business. The company raised a net sum of £241,000 ($389,000). The company later tried to raise more money but failed, and trading in their shares stopped in September 2014. As per our knowledge, this company is no longer active.

http://cientifica.com

CrayNano

CrayNano was spun off from the Norwegian University of Science and Technology (NTNU) to commercialize a new technology to grow gallium arsenide (GaAs) nanowires on graphene using molecular beam epitaxy. The new hybrid electrode material offers excellent optoelectronic properties.

http://crayonano.com

CTDAT

CTDAT was launched in 2014 in Mexico as a consultancy firm that specializes in graphene production technologies. CTDAT developed a patent-pending process to exfoliate graphene from graphite.

The company is able to produce graphene oxide and reduced graphene oxide from ore mineral graphite. CTDAT is a private company with close contact with Arizona University, UNAM and UNISON.

CTI Nanotechnologies

CTI Nanotechnologies is developing graphene-related technologies. The company is collaborating with American Graphite Technologies, and in March 2013 CTI and AGT announced they had successfully produced graphene paper test samples.

CVD Equipment Corporation

CVD Equipment Corporation (a US-based company) offers a variety of process and support equipment for both R&D and production facilities. CVD Equipment also has a wholly-owned subsidiary called CVD Materials Corporation that manufactures and sells nanomaterials, including several graphene materials

In August 2013 CVD announced it will jointly develop graphene-based Li-Ion battery electrodes with Graphene Batteries.

http://cvdequipment.com/

CVD Materials Corporation

CVD Materials Corporation, a subsidiary of CVD Equipment manufactures and sells nano materials. The company offers monolayer graphene, multi-layer graphene, 3D graphene, nanotubes and nanowires.

http://www.cvdmaterialscorporation.com

Directa Plus

Directa Plus was established in 2005 in Italy to develop innovative nanomaterial production processes. The company developed its own exfoliation process (which they call G+) that can be used to produce super-expanded graphite, pristine GNPs, water-dispersed GNPs and fine nanographite powder (all of them marketed under the G+ brand).

In 2014, the company inaugurated its 30-ton graphene plant in Lomazzo, Como. In April 2015 Directa Plus received a grant of €5.5 million.

http://www.directa-plus.com

Deyang Carbonen

Deyang Graphene Science and Technology (also known as Deyang Carbonen) is a graphene producer with an annual capacity of 1.5 tons. Deyang Carbonen plans to expand its facilities to 300 yearly tons).

The company also develops graphene applications, such as anti-corrosion coating and heat conducting materials.

http://www.carbonene.cn/

FlexEnable

FlexEnable develops OTFT-based backplanes for flexible displays, suitable for both EPD and OLED technologies. The company was spun-off from Plastic Logic in February 2015 to further develop the technology and license it for display makers.

FlexEnable has a track record of groundbreaking graphene innovation and industrialization. Last year the company successfully demonstrated a truly flexible display based on a transparent graphene conductor, which was integrated into its flexible transistor array.

http://www.flexenable.com

Focus Graphite

Focus Graphite (previously Focus Metals) is a mid-tier junior graphite company, mine developer and technology company based in Ottawa, Canada. It is the owner of the highest grade (roughly 16%) technology graphite resource in the world (at Lac Knife in Quebec). The company's goal is to become an industry leader by becoming the lowest cost producer of technology- grade graphite.

The company is collaborating on graphene research with Grafoid (of which it owns 40%). Focus Graphite is a public company and trades in the OTC market (ticker: FCSMF).
http://focusgraphite.com

Future Carbon

Future Carbon, based in Germany, develops and manufactures carbon nanomaterials and carbon supercomposites. In April 2013, Future Carbon acquired several graphene and CNT related patents from Bayer.

http://www.future-carbon.de

Garmor Inc.

Garmor Inc, based in Orlando, Florida, was spun-off the University of Central Florida to develop a new cost-effective and environmentally-friendly graphene oxide flakes production process. Garmor aims to manufacture and sell graphene.

In April 2013 the company received $300,000 from the Institute for Commercialization of Public Research. In June 2015 Garmor increased its production capacity to 20 tons per year. Garmor offers their production system as a turn-key solution, so customers can produce graphene oxide on-site. The 20-ton capacity is for a single machine, and Garmor aims to increase its in-house capacity to 100 tons per year.

http://garmortech.com

General Graphene Corporation

General Graphene has developed a manufacturing system that aims to provide graphene sheets in industrial quantities at marketable prices, making it available to the material innovators of the world. General Graphene has focused its efforts on making graphene affordable for mass applications.

Combining fundamental graphene production methods licensed from the University of Texas (UT) and Oak Ridge National Laboratory (ORNL) with General Graphene's own improved production-scaling trade secrets and pending intellectual property, General Graphene has demonstrated a bench-tested process for mass production of high-quality, large graphene sheets.

http://www.generalgraphenecorp.com

Gnanomat

Gnanomat, based in Madrid, Spain, developed a proprietary patented liquid-phase procedure to exfoliate graphite to graphene. The single-step process produces high-quality graphene micro platelets. The process uses cheap, biodegradable solvents.

The company seeks to find industrial partners to license the technology and scale it to an industrial scale.

http://www.gnanomat.com

Golden Formula

Russia-based Golden Formula is a producer of a unique nano-absorbent high reactivity carbon mixture (HRCM). The

company develops and produces filters and water purification systems based on the HRCM mixture. HRCM is mostly composed of graphene-materials, produced by Golden Formula themselves.

http://goldenformula.net/

Grafen Chemical Industries

Grafen Chemical Industries, based in Turkey, was established in 2004 to develop and produce industrial materials including nanomaterials, adhesives and engineering polymersin. Grafen claims to have developed a novel fabrication method allowing it to synthesize graphene of excellent quality and with considerable yield.

In February 2013 Grafen signed an agreement with Angstron Materials for the supply of pristine and oxidized graphene for an EMI application. In March 2014, Grafen raised 1.8 million from a Dubai-based investment company.

http://grafen.com.tr

Grafentek

Grafentek, established in 2013 in Turkey, aims to mass produce graphene flakes to be used in Li-Ion battery anodes. The company develops its own production technology. Grafentek also distributes Graphene Supermarket's graphene products in Turkey.

http://grafentek.com

Grafoid

Grafoid is a private company based in Canada that produces graphene on a commercial scale using their proprietary extraction process. The company is also active in high-growth, scalable graphene projects, graphene patents and material applications. In May 2013 the company announced that they (together with Graphite Zero, of which it holds a majority stake) will start mass production of affordable high-quality graphene materials under the MesoGraf brand.

Grafoid collaborates on graphene research with Focus Graphite (which owns 40% of the company). Focus Graphite also provides Grafoid with its high-quality graphite. Grafoid is also co-developing graphene-based polymer and non-polymer applications with Rutgers University.

In July 2013 the company raised $3.5 million from private investors. In February 2015, Grafoid received a $8.1 million CAD ($6.46 USD) grant from the Canadian government.

In August 2013 Grafoid established a new company called Calevia with Rx Pharma to develop a graphene-based cancer treatment platform.

http://grafoid.com

GrafTech International

GrafTech International is a global company with more than 120 years of experience in the carbon and graphite industry. GrafTech makes an expanded natural graphite foil that keeps most of the properties of the Graphene (thermal, electrical, and possibly acoustic) and they manufacture them in flexible sheets from 20um to 1mm thick and in widths up to about 50 inches.

GrafTech says that its graphite-foil is used in Apple's iPhone, Samsung's TVs and many other devices. The company is public and trades in the NYSE (ticker: GTI).

http://graftech.com

GRAnPH Nanotech

GRAnPH Nanotech (based in Spain) is a provider of single-layer graphene products and other carbon-based nanostructures and nanocomposites. GRAnPH developed their own patented technology for producing graphene, based on research done at the University of Alicante in Spain.

http://granphnanotech.com

Graphenano

Graphenano, based in Alicante, Spain and founded in 2011 is a graphene and carbon nanofiber producer that is collaborating with the University of Castilla La Mancha in Ciudad Real. The company manufactures high quality graphene in industrial quantity, with sheets sizes 50x50 cm.

In 2014 Graphenano launched a graphene-based paint called Graphenstone that is super-strong and can also help protect buildings from environmental damage. Towards the end of 2015 the company started to install a manufacturing plant for batteries with Graphene Polymer in Yecla, (Murcia) Spain. The new plant will begin operations in early 2016.

http://graphenano.com

Graphendo

Graphendo was established towards the end of 2014 by Innovatie Centrum Kunststoffen and Z3D Labs with an aim to produce purely synthetic and 100% single-layered graphene oxide.

Graphene 3D Lab

Graphene 3D Lab, Inc. was spun-off Graphene Labs in November 2013 to focus on development of high-performance graphene-enhanced materials for 3D printing. Graphene 3D Lab is a public company, trading in the Canadian stock exchange (TSX:GGG, OTC: GPHBF) following a reverse-merger with Matnic Resources in August 2014. Lomiko Metals is a stakeholder in the company.

In August 2015, Graphene 3D Lab announced the purchase of former parent company Graphene Laboratories.

http://graphene3dlab.com

Graphene Batteries

Graphene Batteries, based in Norway, is developing safe and durable graphene-based high energy battery materials. The company aims to build an IP portfolio and later license it for production.

In August 2013 Graphene Batteries announced it will jointly develop graphene-based Li-Ion battery electrodes with CVD Equipment.

http://graphenebatteries.no

Graphene Corporation (Elcora Resources)

Graphene Corporation, a subsidiary of Elcora Resources and based in Canada, aims to become a vertically integrated carbon company - from graphite mining to graphene production. The company has full operational control and a 40% equity interest in Sakura graphite Mine in Sri Lanka.

Elcora Resources is a public company that trades in the Toronto stock exchange (TSXV: ERA)

http://elcoraresources.com

Graphene Devices

Graphene Devices, founded in 2009 and based in Niagara Falls, NY, US, is a startup that explores novel uses for graphene and ways to optimize its production. The company uses a process developed at the University of Buffalo.

Graphene Devices was awarded over $600,000 for several projects in 2010 by the US federal and state authorities. It is also funded by Excell partners VC.

http://graphenedev.com

Graphene Energy

Graphene Energy is working toward next generation nano-technology-based supercapacitors that will have at least twice the storage capacity of commercially available capacitors. Their technology utilizes graphene for the electrode material.

http://grapheneenergy.net

Graphene ESD

Graphene ESD was established in 2014 in the US with an aim to develop graphene-based supercapacitor technology developed by Graphene Laboratories and Stony Brook University.

Graphene Labs long-time partner Lomiko Metals is a major shareholder in Graphene ESD.

http://graphene-esd.com

Graphene Industries

Graphene Industries was established in March 2007 to capitalize on the advances made by Professor Andre Geim's research group at Manchester University in the UK.

Graphene Industries is a commercial supplier of graphene for micro- and nanoelectronic fabrication and research. The company supplies graphene materials to MU's 2-DTech.

http://grapheneindustries.com

Graphene Frontiers

Graphene Frontiers, based in Pennsylvania, US, was established in 2011 based on new graphene-production technology developed at the University of Pennsylvania. Graphene Frontiers uses "Atmospheric Pressure Chemical Vapor Deposition" (APCVD) roll-to-roll room-pressure process to

synthetically grow graphene.

In September 2013 the company was granted $744,000 from the NSF to scale their production capacity. In July 2014, the company raised $1.6 million and launched a new brand of highly-sensitive GFET-based biological and chemical sensors.

http://graphenefrontiers.com

Graphene Laboratories

Graphene Laboratories develops and markets functional graphene materials and devices. Graphene Labs operates two online stores: Graphene Supermarket and Maximum Materials, which both offer online graphene-related products and other advanced materials.

In February 2013 Graphene Labs signed a strategic alliance agreement with Lomiko Metals to co-develop a vertically integrated supply chain and graphene-related products.

In August 2015, Graphene 3D Lab announced the purchase of its former parent company Graphene Laboratories.

http://graphenelab.com

Graphene Leaders Canada

Graphene Leaders Canada (GLC) is a Canadian-based graphene supplier and application developer (mainly focused on the energy sector at this time). The company developed its own graphite-exfoliation method to produce graphene and uses Canadian mined graphite to produce GO and rGO materials.

GLC is currently selling to academia and research companies; however, they plan to offer a web store for their graphene products in 2014 and to engage industry for both materials and development services. Overall, their focus is to develop application solutions to all industry sectors.

http://www.grapheneleaderscanada.com

Graphene Lighting

Graphene Lighting PLC is a spin-out company based on a strategic partnership with the National Graphene Institute (NGI) at The University of Manchester to create graphene applications.

The UK-registered company aims to produce graphene lightbulbs based on technology developed at Manchester U. Thecompany is set to become publicly traded in Canada, via reverse takeover with Oriana Resources.

Graphene Nanochem

Graphene Nanochem is a UK based company that manufactures performance specialty chemicals and advanced nanomaterials from renewable sources including waste materials. The company offers several products for the oil and gas sectors.

Graphene Nanochem holds the exclusive license to a process known as Catalyx which uses a catalyst to extract graphene from biogases (such as methane). This process can potentially mean low-cost graphene production. They are also developing graphene-enhanced lubricants for used in

the extraction of shale gas, graphene-based Li-Ion batteries and graphene water treatment systems.

In September 2014, Graphene Nanochem signed a licensing and offtake agreement for the entire production of the graphene- enhanced PlatDrill lubricant to Scomi-Oiltools, which is estimated at 135,000 tonnes over the next five years.

Graphene Nanochem started trading in the UK's AIM stock exchange (ticker: GRPH) in March 2013 following a £32.5 ($50 million) fund raising.

http://graphenenanochem.com

Graphene Nanotech

Graphene Nanotech is a Spanish startup that aims to develop products based on epitaxial graphene grown on SiC (silicon carbide) substrates.

http://www.graphenenanotech.eu

Graphene Platform Corp

Graphene Platform Corp (previously iTRIX), established in 2000 and based in Tokyo, Japan refocused its business to graphene in 2011. The company maintains a fully equipped applications lab in Yokohama, Japan and produces CVD graphene and epitaxial graphene on SiC for both commercial and R&D use.

GPC has a graphene subsidiary in the US called Graphene Platform Inc, and is also a major shareholder in Cambridge Graphene Platform.

http://grapheneplatform.com http://itrix.co.jp/graphene/index.html

Graphene Sensors

Graphene Sensors was established in 2011 in Canada, with an aim to commercialize graphene-based sensors for the medical market.

The company is developing its GS7 biosensor technology (for the early detection of potentially cancerous cells), and is also developing chemical sensors. In May 2015 the company announced a $36 million Joint-Venture with Meditel to commercialize the GS7 sensors.

http://www.graphene-sensors.com

Graphene Square

Graphene Square is based in Seoul, Korea, and was founded with the cooperation of Seoul National University. The company provides CVD-grown graphene products and related products, accessories and services. Graphene Square also markets a low-cost thermal CVD system enabling users to synthesize their own large-area, high-quality graphene samples in a lab environment.

http://graphenesq.com

Graphene Technologies

Graphene Technologies, founded in 2007 and based in Novato, California, US, developed a unique patented and eco-friendly way to synthesize graphene (and other carbon-based materials) from carbon dioxide (CO2).

Graphene Technologies is planning to become a high-volume graphene producer, making both single-layer and few-layer graphene sheets and other graphene-based materials. Their production process can produce graphene in all sizes: from large sheets to small quantum-dots materials.

http://graphenetechnologies.com

Graphenea

Graphenea is a privately-held company based in Spain that is focused on the production of high quality graphene for industrial applications. The company produces single-layer graphene sheets, bi-layer graphene, multi-layer graphene, graphene oxide and other materials—on any substrate the customer provides. The company is also involved with graphene application research.

Graphenea is the main graphene supplier for Europe's $1 billion Graphene Flagship project that was launched in October 2013. In 2015, the company announced plans to construct a new graphene pilot plant in a $2.5 million investment.

http://graphenea.com

Graphenelab limited

GrapheneLab Limited is a privately-held UK-based graphene producer established in 2015. The company produces chemically-pure low-cost GNPs, based on low-temperature physical exfoliation of natural or artificial graphite in deionized water.

The company also develops applications for thermal interface material, Li-Ion batteries and composite materials.

http://www.i-graphenelab.com

Graphenest

Portugal-based Graphenest developed a novel method for large production of high quality graphene nanoplatelets and their functional derivatives from natural graphite.

http://www.graphenest.com

Graphenex

Graphenex is an R&D start up, established in 2014 and based in the UK, that aims to develop prototype high energy supercapacitors based on graphene materials. The company aims to develop the technology and then team up with supercapacitor companies to commercialize it.

http://www.graphenex.co.uk/

Graphensic

Graphensic was established in November 2011 in Sweden as a spin-off from the Linköping University. The company plans to produce single-layer graphene on hexagonal silicon carbide for the electronic equipment market and related markets. Graphensic's technology uses a high temperature process to produce epitaxial graphene on SiC. The high temperature provides better uniformity.

Graphensic is part of the LEAD business incubator, and in January 2013 the company raised $500,000 from LEAD.

http://graphensic.com

Graphite Zero

Graphite Zero was spun off the National University of Singapore (NUS) graphene centre with an aim to develop and produce MesoGraf graphene-based materials. The company uses Focus Graphite's high quality graphite and transforms it into economically scalable graphene products. Graphene Zero states it will soon start mass producing MesoGraf at a very low cost.

Grafoid holds a majority stake in Graphite Zero and handles the company's business development and marketing.

GrapheneTech

GrapheneTech (owned by Eficiencia Energética Aplicada) is a Spain-based company, focused on manufacturing graphene in the form of nanoplates. The company specializes in producing graphene on a large scale for different industrial applications using a patented method that allows it to offer prices adapted to industrial needs, contrary to complex and costly methods.

In 2013, the company initiated a pilot plant for industrial production from the technology developed by its R&D team.

http://www.graphene-tech.net/

Graphitene

Graphitene, established in 2013 in the UK, produces graphite compounds, graphene and GO in lab-scale in collaboration with the Aabo Akademi University in Finland and the Northern Research Institute in Narvik, Norway.

In 2015 the company's small-scale manufacturing plant in the UK commenced production. The company is also engaged in various graphite and graphene R&D projects.

http://www.graphitene.com

Hangzhou GeLanFeng Nanotechnology

Hangzhou GeLanFeng Nanotechnology was established in 2011 to focus on graphene and related 2D materials.

GeLanFeng supplies monolayer and few-layer CVD graphene and MoS2 and also graphene flakes (GNP) powders, mostly to University research teams and high-school students. The company also develops graphene applications and IP.

http://www.gelanfeng.net

Haydale

Haydale (a subsidiary of the ICL Group) supplies Split Plasma treated carbon materials - graphene flakes/GNPs, graphene- based inks and CNTs. The company also offers customer R&D services and a lab for hire in the UK.

Haydale's products are available online in their site in the UK, and their exclusive sales agent in the US is Cheap Tubes. Haydale is a public company, trading in the UK's AIM (ticker: HAYD).

http://haydale.com

IBM

International Business Machines Corporation (IBM) is a multinational technology and consulting corporation based in the US. IBM operates several research labs around the world and they are researching graphene related technologies - mostly graphene based transistors and photo detectors.

In July 2014, IBM launched an ambitious 5-year $3 billion research initiative to find a silicon replacement for computer chips.

Graphene is one of the materials under consideration.

http://ibm.com

Incubation Alliance

Incubation Alliance was established in 2007 in Kobe, Japan to manufacture and supply carbon materials. The company offers so-called "graphene flower" materials: substrate-free and catalyst-free multi-layer graphene material made by direct synthesis. It also offers graphene flowers dispersed in solvents, which are basically regular 2D graphene sheets.

http://incu-alliance.co.jp/en-index.html

Intel

Intel Corporation, based in the US, is the world's largest semiconductor chip maker (based on revenue). The company supplies chips for PCs, mobile devices and more. Intel is researching graphene to be used in future electronic devices.

In September 2013 Intel's CEO stated that the company was seeing "great progress" with graphene, but graphene-based products were still "several generations away."

http://intel.com

KNano

KNano (the full name is Xiamen Knano Graphene Technology Co) is a start-up company based in China that mass produces graphene nanoplatelets and is also involved with polymer-graphene composites. The company offers several types of graphene platelets on their website.

http://knano.com.cn/En/index.aspx

LeaderNano (Jiling)

LeaderNano, based in Jiling, China, develops and produces advanced nanomaterials - including graphene, graphene oxide, nitrogen and boron doped graphene, GNPs and other materials (such as MoS2 and WS2).

In January 2015 LeaderNano launched its first graphene production line that can produce 2-3 tons of graphene powder a year, as part of the first phase of the company's graphene industrial park.

http://www.leadernano.com/

LG

LG Corporation, based in South Korea, is a multinational conglomerate corporation that is involved with electronics, displays (LCD, plasma and OLEDs), telecom, chemicals and more.

LG has an active graphene research group and holds many graphene patents.

http://lg.com

Lomiko Metals

Lomiko Metals is an exploration stage Canadian company that aims to acquire and develop mineral resources in Canada. It primarily explores graphite, zinc and gold. Lomiko owns several resource properties containing high-grade graphite, and the company has signed a strategic alliance with Graphene Labs to co-develop a vertically integrated graphene supply chain.

Lomiko holds 15% in public Graphene 3D Lab, has a stake in newly formed graphene supercapacitor developer Graphene ESD, and has also an internal graphene R&D department.

Lomiko Metals is a public company and trades in the TSX (ticker: LMR.V).

http://lomiko.com

Mason Graphite

Mason Graphite is a Canadian mining company focused on the exploration and development of its 100% owned Lac Gueret graphite project in north-eastern Quebec.

In January 2014, Mason Graphite acquired 40% of graphene R&D company NanoXplore. Mason Graphite is a public company, trading in the Toronto stock exchange (ticker: LLG).

http://www.masongraphite.com

Mega Graphite

Mega Graphite was established in 2009 in Ontario, Canada with an aim to mine, process, purify and supply natural graphite. The company holds four graphite mines in Canada as well as the Uley Graphite Mine in South Australia.

http://megagraphite.com

Moorfield

Moorfield is a UK-based company, founded in 1989, that designs and manufactures a wide range of R&D-scale laboratory systems. The company focuses on vacuum deposition products and CVD synthesis.

Moorfield's nanoCVD systems offers compact, scalable and turn-key CVD systems for high-throughput graphene and CNT production. Moorfield's NanoCVD is exclusively distributed in the U.S by Graphene Laboratories.

http://moorfield.co.uk
http://nanocvd.co.uk

Morgan Advanced Materials

Morgan Advanced Materials, based in the UK and founded in 1856, is an advanced materials technology company with a global presence. The company is active in many markets, including medical instruments, aerospace, power generation and trains. It is also active with carbon processing for over 150 years.

In August 2014, Morgan Advanced Materials signed a joint-development agreement with the University of Manchester to scale-up a new graphene manufacturing process.

MAM is listed on the London Stock Exchange (LON:MGAM).

http://www.morganadvancedmaterials.com

mPhase Technologies

mPhase develops battery technologies. Its flagship product (not yet released) is the AlwaysReady Smart NanoBattery—which offers reliability, extended life and safe disposal. mPhase is exploring the printing of its "Smart NanoBattery" using graphene (and possibly other advanced materials).

http://mphasetech.com

MTI Corporation

MTI Corporation, based in California, US, was established in 1994 to manufacturer oxide crystals and substrates. The company also offers lab equipment and furnaces—and they have a range of tube furnaces for graphene growth.

http://mtixtl.com/tubefurnaceforgraphene.aspx

Nanjing JCNano

Nanjing JCNano, based in Nanjing, China, produces and supplies several carbon-based materials including graphene, graphene oxide, graphite oxide and carboxyl graphene. The company started producing graphene in 2009 using a CVD process.

http://jcno.net/index.php?langid=en

Nano Carbon (Poland)

Nano Carbon was established in 2011 in Poland to engage in graphene research and production. The company uses technology developed at the Institute of Electronic Materials Technology in Warsaw and is co-owned by mining giant KGHM and the Polish Armaments Group (PGZ)

Towards the end of 2013 Nano Carbon started commercial production, and they offer their graphene materials via their online store.

http://www.nano-carbon.pl

NanoCarbon Pty Limited

NanoCarbon Pty Limited was established in 2014 in Australia with an aim to commercialize graphene technologies developed at the University of Wollongong. The technology is related to the manufacturing surfactant-free graphene, and the company hopes to build the first pilot production line by July 2015.

The company will also be involved with graphene applications - such as high barrier films, lithium ion batteries, and water purification.

NanoGrafen

NanoGrafen was established in 2013 in Turkey as a nanotechnology R&D and consulting company. The company produces high-quality graphene and develops graphene-based applications.

NanoGrafen also provides technical consultancy on the development of graphene based composites, the preparation of master batches and formulation developments.

http://www.nanografen.com.tr

Nanografi

Nanografi is a Turkish-based company established in 2011 to develop and produce nanomaterials, including carbon based materials such as graphene and CNTs.

Nanografi currently offers several kinds of graphene flakes (GNPs), and silicon-graphene nano composites.

http://www.nanografi.com

NanoInnova Technologies

NanoInnova Technologies is based in Madrid and was spun off the Universidad Autónoma de Madrid. NanoInnova designs, develops and commercializes instrumentation and nanostructured surfaces for research groups. The company offers graphene-oxide, reduced graphene-oxide and other materials.

http://nanoinnova.com

NanoIntegris

NanoIntegris (a subsidiary of Raymor Industries) produces, purifies and processes several grades of conductive carbon, carbon nanotubes and few-layer graphene flakes. The company uses different exfoliation methods to produce the graphene.

Nanointegris service the industrial and academic R&D market with over 600 clients worldwide.

http://nanointegris.com

Nanomedical Diagnostics

Nanomedical Diagnostics Inc. is based in San Diego, CA, and began operating in late 2013. The company's focus is on real-life products and applications that enable personalized healthcare by improving the ease, speed, and cost of diagnostics.

Nanomedical Diagnostics is a biotech company that creates practical and scalable graphene biological field effect transistor (BioFET) products. Its ongoing mission is applying cutting-edge capabilities to supply affordable monitoring and diagnostic platforms.

The company develops their AGILE technology (Automatic Graphene ImmunoLinked Electronic) that aims to link advanced nanotechnology to biology and electronics for faster sample processing, greater accuracy, portability and cost savings.

http://www.nanomedicaldiagnostics.com

Nanophill

NanoPhyll is a Canada-based private company dedicated to improving efficiencies in the photocatalytic and photovoltaic markets through the application of customized graphene.

Applications are for coatings that are self-cleaning, anti-bacterial, anti-fogging as well as for the creation of next generation low cost solar cells. Primary market is the building and construction sector both internal (VOC mitigation, germ/virus destruction, etc.) and external (self-cleaning, green power generation, etc.). Introducing graphene to this mature market should increase efficiencies significantly, enabling clients to grow value and market share.

http://www.nanophyll.com

NanoXplore

NanoXplore was established in 2011 in Canada with an aim to provide carbon nanomaterials (including graphene) services and products.

NanoXplore is currently focused on their own graphene production method. NanoXplore says that their proprietary technique to produce graphene from graphite is a low-energy, low-cost and scalable electrochemical conversion process.

Mason Graphite holds a 40% stake in the company.

http://nanoxplore.ca

National Graphite Corporation

National Graphite Corporation (NGC), based in the US, is focused on bringing the Chedic Graphite Mine back into commercial production. In June 2013 NGC signed an agreement with American Graphene to jointly explore graphene opportunities and employ a new sonication process to reduce graphite to graphene.

NGC is a public company (OTCQB: NGRC).

http://nationalgraphitecorp.com

National NanoMaterials

National NanoMaterials was established in 2010 to commercialize technology developed at Texas State University and to produce high quality nano materials. The company offers functionalized graphene materials under the Graphenol brand. Graphenol can be supplied with amine, amide, ester, carboxylic or hydroxyl functional groups. The product is delivered as a dispersion in surfactant-free water or organic solvent as mostly single or double sheets.

National NanoMaterials also offers research assistance services.

http://nationalnanomaterials.com

Ningbo Morsh Technology

Ningbo Morsh Technology was established by Shanghai Nanjiang in 2012 in Ningo, Zhejiang. It uses technology developed at the Chongqing Institute, which was licensed to Shanghai Nanjiang.

Ningbo Morsh Technology has an ambitious plan to establish a new production line that was supposed to begin production toward the end of 2013 (we have no information regarding the status of this line). The new fab's annual capacity is 300 tons (and if it is online, it is the world's largest graphene fab by far). Reports say the investment in that line exceeded 100 million yuan ($16 million). Ningbo Morsh Technology supplies graphene to Chongqing Morsh Technology, which is building a production line in Chongqing that will be used to produce 15" single-layer graphene films.

Chongqing Morsh aimed to begin production in early 2014 and supply those films to Guangdong Zhengyang, used to produce transparent conducting films (TCFs) to be used as touch panels for mobile phones. The company's capacity is about 10 million touch panels in a year. As we said before, we do not know the status of this project.

http://morsh.cn

Nokia

Nokia, based in Finland, is a multinational corporation that was once the world's leading mobile phone maker. Nokia Research Center, with its 10 laboratories worldwide, is exploring new technologies mostly for mobility applications.

Nokia is involved with graphene research, and the company takes part in the European €1 billion Graphene Flagship research project.

http://nokia.com https://research.nokia.com

Northern Graphite Corporation

Northern Graphite Corporation is a Canadian mine development company. Its main asset is the Bissett Creek graphite project located 100 km east of North Bay, Ontario. The company is also involved with graphene research.

Northern Graphite trades in the Canadian stock exchange (ticker: NGC) and in the OTCBB (ticker: NGPHF).

http://www.northerngraphite.com

Oxford Advanced Surfaces

Oxford Advanced Surfaces Group, based in the UK, designs, develops and manufactures advanced materials for surface modification, adhesion promotion and nano-material applications based on its highly reactive chemical core platform technology called Onto.

In March 2014, OASG announced that it is investigating the use of its Onto technology platform to chemically functionalize

graphene. OASG is a public company that trades in the UK's AIM (ticker: OXA).

http://www.oxfordsurfaces.com

Perpetuus Carbon

Perpetuus Carbon is a graphene producer based in the UK. In early 2014, the company announced that it will soon begin graphene production with a capacity of 100 tons (which will be extended to 500 tons by the end of 2014).

The company makes surface modified graphene materials, tailored according to customer specifications. The price of their graphene materials is about £50 per kilogram. Perpetuus also conducts R&D (via its Perpetuus Research and Development subsidiary) mostly focused on graphene inks. The company also develops transparent conductive flexible films, stress strain actuators and printable coatable electrodes for use in lithium Ion batteries.

http://perpetuuscarbon.com

Picosun

Picosun, based in Espoo Finland, was established in 2004 to develop Atomic Layer Deposition (ALD) reactors for micro- and nanotechnology applications.

The company is developing ALD-based graphene deposition using their advanced PEALD (plasma-enhanced ALD) system.

http://www.picosun.com

PlanarTech

PlanarTech is a US-based company (with manufacturing in Korea) that offers economical process equipment, analytical equipment and training services for emerging 2D materials (graphene, boron nitride, molybdenum disulphide, etc.).

PlanarTech also provides a wide range of process equipment for other nanomaterials, as well as market entry and business development consulting services for the Asian market with a particular focus on Korea.

http://planartech.com

Qingdao Huagao Energy Technology

Qingdao Huagao Energy Technology was established in China to produce graphene materials and develop graphene applications.

QHET current offers several types of graphene and graphene-oxide materials, and is exploring graphene applications in Li-IOn batteries, supercapacitors and semiconductors. The company expects to have an annual production capacity of hundreds of kilograms of single-layer graphene.

http://www.hgky.net/en

Quantum Seed

Quantum Seed is a technology development company, founded in 2012 to commercialize technology developed at the University of California – Riverside. Quantum Seed currently develops several technologies, including high-efficiency thermal interface materials with graphene and metal fillers and graphene-enhanced hybrid phase-change materials for thermal management of Li-ion and other high-power density batteries.

http://www.quantumseedllc.com

QuantumWise

QuantumWise is a provider of software solutions for nanotechnology developers. The company works in close collaboration with the Nano-Science Center at the Niels Bohr Institute of Copenhagen University.

QuantumWise offers a system of integrated software modules (called Atomistix Toolkit, or ATK) that can accurately calculate properties associated with electron distribution and transport. It can be used to compute the spin transport in graphene and magnetic nanowires.

http://quantumwise.com

R-Nano

R-Nano, based in Portugal and owned by RichAnswers-Nanomaterials, supplies laboratory supplies for the graphene industry. The company currently offers single-layer graphene sheets on silicon and copper.

http://r-nano.com

Redex Nano Lab

Redex Nano Lab (RNL), based in Ghaziabad, UP, India, was established in early 2011 with the aim of becoming a nanotechnology pioneer. The company commercialized several nanomaterials, including CNTs and graphene products.

RNL currently produces graphene sheets and nanoflakes using CVD, and also offers customized production.

http://redexnano.com

RS Mines

RS Mines (previously GS International & the RS Group), based in Sri Lanka, owns several 99.99% natural high purity crystalline vein graphite mines in Sri Lanka - including their flagship mine, the Queen's Mine. The company is also producing graphite oxide (GO) products, offering them via an online store.

http://graphite.com.co

Saint Jean Carbon

Saint Jean is a publicly traded junior mining exploration company with graphite mining claims on five 100% Company-owned properties located in the province of Quebec in Canada. The five properties include the Walker property, a past producing mine, the Wallingford property, the St. Jovite property, East Miller and Clot Property. The Company also holds the Page graphite property in Ontario.

In April 2015, SJC decided to enter the graphene market and signed an agreement with Graphenea.

http://www.saintjeancarbon.com

Saivens Materials

India's Saivens Materials provides high purity nano materials including CNTs, graphene and inorganic materials. Saivens' graphene product, branded RexSheet, is a high purity (over 90%) graphene sheet with a customized aspect ratio, grown using CVD.

http://saivens.com

Samsung

Samsung Group, based in South Korea, is a multinational conglomerate company involved with electronics, mobile phones, displays (LCD, Plasma and OLEDs), materials, insurance, finance, advertising, heavy industry and more.

Samsung is researching graphene and is the company with the most graphene-related patents in the world.

http://samsung.com

SECO/WARWICK

The SECO/WARWICK Group is a multinational heat processing furnace and equipment provider. The company is a full-service manufacturer, providing engineering, research & development, manufacturing, turnkey installation, commissioning and aftermarket service.

For the graphene market, the company offers GraphMaster, CVD reactors for large-format graphene production.

http://www.secowarwick.com

Shandong Yuhuang Chemical

Shandong Yuhuang Chemical (Group) is a China-based petrochemical group that produces and markets a range of chemicals, including propylene, isobutene, butadiene, isoprene, Styrene, Toluene, and others. It was founded in 1986 and is located in Heze City, Shandong Province, China.

http://en.yuhuanghuagong.com

Shanghai SIMBATT Energy Technology

Shanghai-based SIMBATT Energy Technology develops, produces and markets graphene powder materials. SIMBATT currently offers intercalated graphite, graphene oxide, graphene powder, doped graphene powder, graphene quantum dot and other materials.

Towards the end of 2012, SIMBATT inaugurated its graphene production centre that can produce 1-5 layer graphene powder in kilograms.

http://www.simbatt.com.cn/en/default.html

SiNode Systems

SiNode Systems was established in 2013 to commercial a novel anode Li-ion battery technology developed at Northwestern University. SiNode's anode uses a composite material of silicon nano-particles and graphene in a layered structure.

In April 2013 SiNode was chosen as the top startup company in the 2013 Rice Business Plan Competition, and their grand prize was valued at $911,400. In August 2014, the company announced a joint-development agreement with Merck's AZ Electronic Materials.

http://sinodesystems.com

Skeleton Technologies

Skeleton Technologies is a developer and manufacturer of high energy and power density ultra-capacitors. The company provides green and cost-effective energy storage solutions for the automotive, transportation, industrial and renewable energy markets.

Skeleton Technologies' SkelCap line of ultra-capacitors is based on patented technologies of ultra-capacitor design and advanced nanostructured carbon allowing for higher energy and power density than competitors. The company has devised a process that uses silicon carbide to make what it calls "curved graphene".

In June 2015 Skeleton Technologies raised €9.8 million from a consortium led by a strategic investor in the electrical equipment sector. Following the investment, Skeleton launched the world's first graphene-enhanced supercapacitors.

http://skeletontech.com/

Solan Corp

Solan Corp is an early-stage startup company based in that US that developed graphene-based applications (including inductors, solar cells, photo-detectors, OLEDs and digital electronics) based on technology that was licensed by Feng Liu, professor and chair of the U's Materials Science and Engineering Department.

http://www.solancorp.com

Sony

Sony, based in Japan, is one of the leading consumer electronics companies in the world. Sony is developing graphene technologies - including a roll to roll production process that can produce graphene sheets up to 100 metres in length.

http://www.sony.com

Strategic Energy Resources

Strategic Energy Resources (SER) is an Australian based explorer with a diversified portfolio of mineral assets. The company is exploring and developing assets with prospective large discoveries in Western Australia, South Australia and Victoria.

In May 2014 SER announced it is resolved to focus on graphene related investments to move the company forward. The company holds a stake in Valence Industries, also involved with graphene. SER is a public company trading in the Australian stock exchange (ASX:SER).

http://www.strategicenergy.com.au

Sunvault Energy

Sunvault Energy is a Canadian-based public company (stock symbol SVLT-OTC:BB) that develops renewable energy solutions. Sunvault aims to revolutionize the way energy is generated and stored, offering a way to cost-effectively and seamlessly bridge old-world utility infrastructure with today's renewable energy.

The company deals with electrical energy generation through photovoltaics (PV) and the SunVault approach is the seamless integration of power generation and storage down to the molecular level, into a standardized self-contained system.

The company is developing graphene-based supercapacitor technology for use in solar cell arrays. In November 2015 Sunvault announced that is has completed the development of a graphene-enhanced smartphone battery case that uses the company's supercapacitor technology, and aims to crowd-fund this project.

http://www.sunvaultenergy.com

Talga Resources

Talga Resources is an Australia-based company focused on graphite mining, graphene supply and application development. The company produces small-scale graphene products and has plans to construct a graphene demonstration plant in central Germany.

Talga develops graphene inks and graphene energy storage devices, and is collaborating with both Haydale and Tata Steel on future graphene applications.

Talga Resources is a public company trading in the Australian Stock Exchange (ASE: TLG). In March 2015 Talga raised $4.2 million USD in a discounted placement.

http://www.talgaresources.com

The Sixth Element Materials

The Sixth Element Materials Technology company, based in Chengzhou, China, is developing and producing graphene flakes, graphene oxide and related materials.

The company says its current graphene-powder production capacity is 100 tons per year, with plans to increase it to 1,000 tons by 2016.

http://www.thesixthelement.com.cn/en

The Centre for Process Innovation (CPI)

The Centre for Process Innovation is a UK-based technology innovation centre. It is a non-profit institute funded by the UK government, the private sector (through contract R&D services) and matched-funding EU projects.

The CPI's open innovation model enables clients to develop products and prove processes with minimal risk. By utilizing its proven assets and expertise, companies can take their products and processes to market faster.

In 2014, The CPI announced the establishment of a new £14 million Graphene Applications Innovation Centre that will build on existing capabilities to provide facilities and expertise to help companies develop, prove, prototype and scale up graphene based products and processes.

http://www.uk-cpi.com

Theragnostic Technologies

Theragnostic Technologies was established in 2012 as a spin-off from Stony Brook University to develop a new efficient graphene-based MRI contrast agent that is safer and cheaper than current gadolinium-based agents.

The company unveiled its product, called ManGraDex, in June 2015. The ManGraDex is not ready for commercial deployment

yet. Theragnostic is supported by the NIH Commercialization Accelerator Program.

http://www.theragnostictechnologies.com

Thomas Swan

Thomas Swan is a privately held global chemical manufacturing company. The company produces a broad range of additives, resins and active pharmaceutical ingredients, custom manufacture work and advanced materials. The company claims to bethe world leader in the manufacture of single-wall carbon nanotubes.

In March 2014 Thomas Swan launched graphene powder and water/surfactant dispersed graphene nanoplatelets. Thomas Swan has a pilot graphene line (capacity 1Kg/day) and is now expanding its capacity to 10 tons per year, supported by the EU's Horizon 2020 funding.

http://www.thomas-swan.co.uk

True 2 Materials

True 2 Materials relies on a simple, high speed manufacturing process (patents pending) that enables production of large, substrate independent graphene and graphene oxide films. Volume production and specific tuning of the films will make it possible for the company's partners to bring G and GO based products to commercial markets across multiple industries.

The company uses proprietary methodology to make its own graphene. From this graphene powder it make its own inks, paints, resins etc. The company also produces substrate-free films, meaning they are not on copper, or silicon etc. These are, according to the company, less than 10 atoms thick films that are free of any substrate. In this way they can be put onto a substrate easily with no need for "roll to roll".

The company states that it is nearly ready to sell products, but it only selling through joint development.

http://true2materials.com/

Two Carbon

Two Carbon is an advanced material technology company building high performance product solutions for the outdoor consumer.

By designing next-generation outdoor products using graphene technology, Two Carbon brings greater performance through stronger, lighter, and more durable products. Two Carbon is at the forefront of building enhanced wearable product solutions.

The company's main innovation is with Hexo-g, that brings greater product performance through stronger, lighter, and more durable products.

http://www.twocarbon.com/

TW Nano Materials

TW Nano Materials is a supplier of single- and multi-layer graphene oxide (GO) and functionalized graphene oxide (FGO). The company reportedly supplies these materials to several industrial partners.

The company is headquartered in the U.S (California), with production facilities in China and Sweden.

http://tw-nano.com

United Nanotech Innovations

United Nanotech Innovations (UNI), owned by Darwish Bin Ahmed Group, is an India-based nano technology company that produces graphene materials, MWCNTs, nano composites and also offers nanotechnology R&D services. The company can supply graphene materials in large quantities (several tons per year).

http://www.unitednanotech.com

Valence Industries

Valence Industries is an Australian industrial manufacturing company that produces high grade flake graphite products.

In March 2014 Valence launched the Graphene Research Centre in collaboration with the University of Adelaide. Valence is a public company that trades in Australia (ASX:VXL).

http://www.valenceindustries.com

Veeco Instruments

Veeco Instruments makes process equipment for several markets. The company's main business segments are LEDs (and OLEDs), PVs and data storage. It also provides molecular beam epitaxy (MBE) products that can be used for graphene deposition.

http://veeco.com

VG Scienta

VG Scienta offers vacuum components, surface science instruments and complete design and manufacture of standard and special vacuum systems for scientific use. The company was established as a merger between Vacuum Generators and Gammadata Scienta.

Regarding graphene (and other 2D materials), the company offers CVD deposition systems and also PVD and sputtering systems based on metal evaporation using thermal cells or E beam.

http://www.vgscienta.com/productlist.aspx?MID=404

Vorbeck Materials

Vorbeck Materials is a U.S company that develops graphene-based inks for the printed electronics market called Vor-X. Vorbeck Materials states that Vor-X and plastic or rubber composites feature extreme levels of strength, dimensional stability, conductivity, and environmental resistance, opening new application and design possibilities.

The company's ink was used in the first ever graphene-based product, the Siren anti-theft packaging device. The company also develops graphene-enhanced batteries, and currently offers a flexible graphene-enhanced (non-chemistry) Li-Ion battery pack.

http://vorbeck.com

Vulvox Nanobiotechnology Corporation

Vulvox Nanobiotechnology Corporation, based in Long Island, NY, researches and develops manufacturing processes for ultra- high-strength graphene materials for ballistic armor and structural materials applications. The company is also researching other R&D applications in the areas of power generation, electric motors and high temperature materials processing.

http://vulvox.tripod.com

Wuxi Graphene Film

Wuxi Graphene Film, based in the Huishan Economic Development Zone in Wuxi, is producing graphene-based touch films.

Wuxi Graphene Film has a pilot production line that can produce about 5 million films annually, and is currently offering several types of flexible touch panels.

http://graphenefilm.cn/en/index.asp

XEFRO

XEFRO was formed in 2011, following successful experiments to develop a graphene based heating element. The company develops (and claims to soon sell) central heating systems using graphene.

The company designed several products using graphene, namely the gRAD central heating system and the g2o hot water system. It seems that the gRAD hangs on the wall and is made of carbon fibre sheet, the graphene-printed IR element, a vertical tube array, and stain gloss or carbon fibre finish.

The heating system was supposed to be available starting in July 2015, but as far as we know it is not ready yet.

http://www.xefro.com

XFNano

XFNano was established in Nanjing in 2009 with an aim to develop graphene materials and applications, based on technology from Nanjing University.

The company offers CVD graphene materials, in addition to CNTs and other organic and non-organic nanomaterials.

http://en.xfnano.com

XG Sciences

XG Sciences is a private company based in Michigan, USA. XG Sciences develops and markets graphene nanoplatelets under the xGnP brand. XGnPs can be used to replace CNTs at a lower cost. xGnP can also replace nanoclay and provide electrical conductivity and improved mechanical properties. The company's technology was originally developed at Michigan State University.

In August 2013 XGS launched a new graphene-based anode material for Li-Ion batteries. In August 2012 the company started production in their new 80-ton facility in Lansing, Michigan. In 2014 Samsung Ventures placed a strategic investment in XGS as the two companies aim to co-develop graphene-enhanced batteries.

http://xgsciences.com

Xolve

Xolve (previously Graphene Solutions) is a manufacturer of purified and size selected carbon nanotubes, graphene and nanographene. The company is working to commercialize simple room temperature processing of graphene and other nanoparticle composites, solutions and coatings.

In December 2010 Xolve raised $2 million from both strategic and financial investors. In January 2015 Xolve raised $1.8 million (of a proposed $2.8 million funding round).

http://xolve.com

XP Nano Material

XP Nano Material was established in 1998 in China to develop and produce nanomaterials. The company currently produces graphene, CNTs, nano powders and other materials.

http://nanocnts.com

ZhongTuo Materials Technology

ZhongTuo Materials Technology (previously Harbin Mulan), based in China and established in 2000, is engaged in the sale of carbon and graphite materials. They provide monolayer flake graphene oxide, monolayer graphene ultra-fine powder, graphene nanoplatelets, graphene oxide membrane (thin film), graphene solutions (dispersible in water, DMF solvent) and additional graphene materials.

http://www.materialstech.cn/

Phone: +44 (0) 330 323 0247
Web: www.innovationdb.com
Email: contact@innovationdb.com

Global House, 1 Ashley Avenue, Epsom, Surrey, United Kingdom KT18 5AD