GRAPHENE

A MIRACLE MATERIAL

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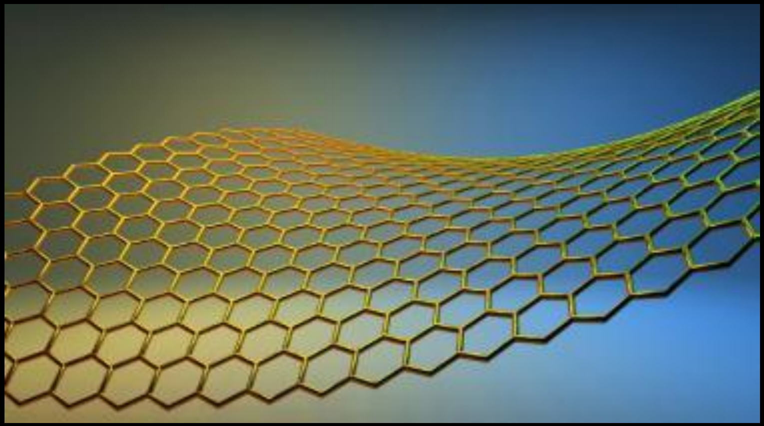
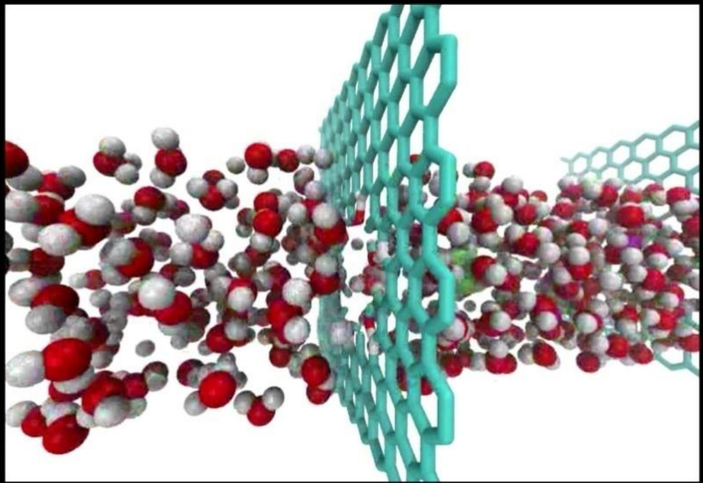
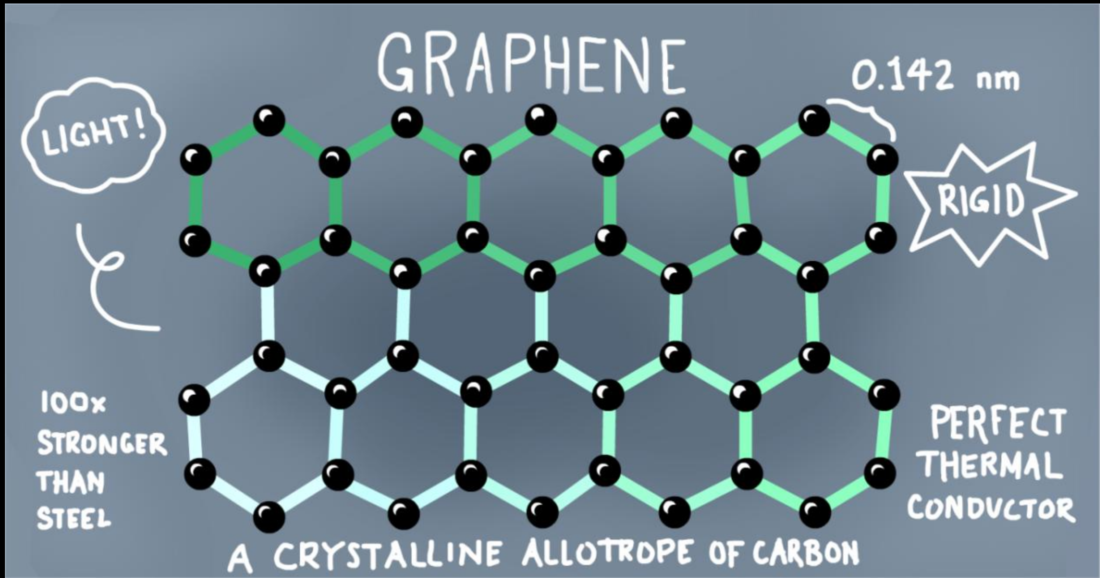
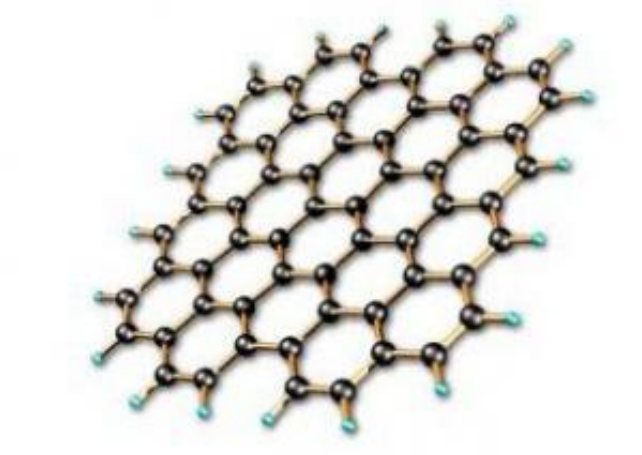
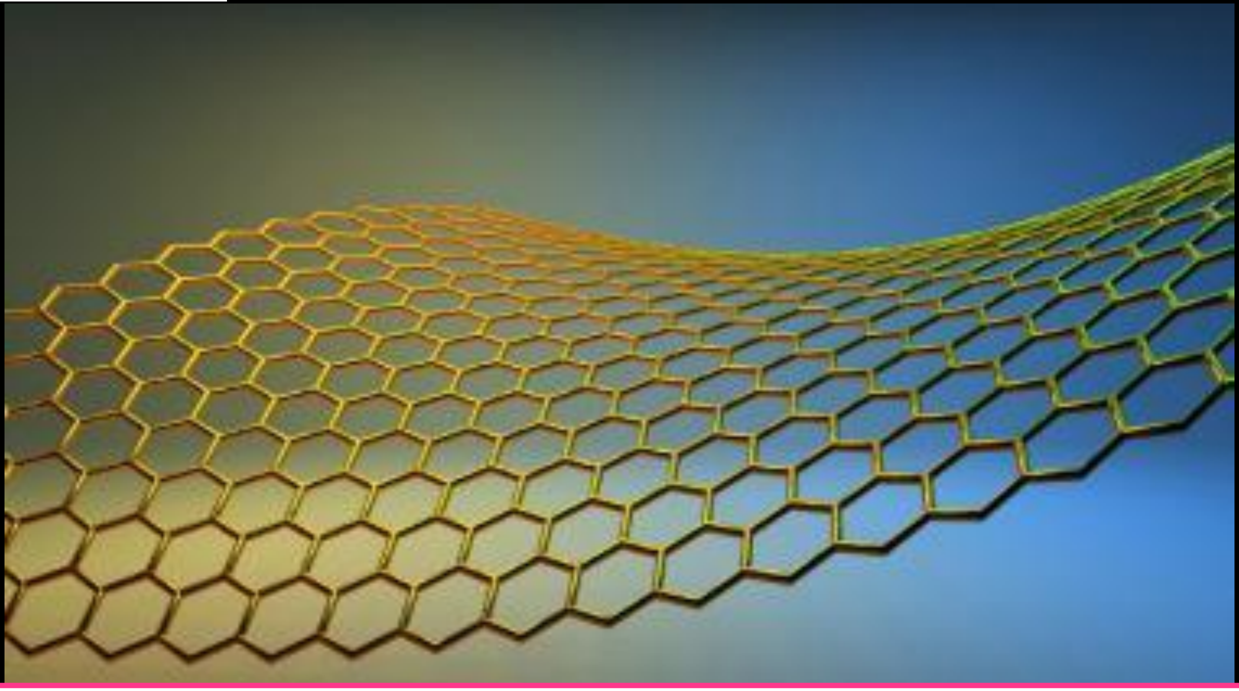










Graphene is an exciting material that is getting a lot of attention
2010 Nobel prize in physics to Andre Geim & Konstantin Novoselov,
who first isolated Graphene in 2004.

GRAPHENE

- **Graphene is an allotrope of carbon that exists as a two-dimensional planar sheet. One way to think of graphene is as a single atomic graphite layer. Graphene is technically a non-metal but is often referred to as a quasi-metal due to its properties being like that of a semi-conducting metal.**

- **Graphene is a two dimensional mesh of carbon atoms arranged in the form of a honeycomb lattice. It has earned the title "miracle material" thanks to a startlingly large collection of incredible attributes - this thin, one atom thick substance (it is so thin in fact, that to stack around 3 million layers of it to make a 1mm thick sheet) is the lightest, strongest, thinnest, best heat-and-electricity conducting `material ever discovered, and the list does not end ..**

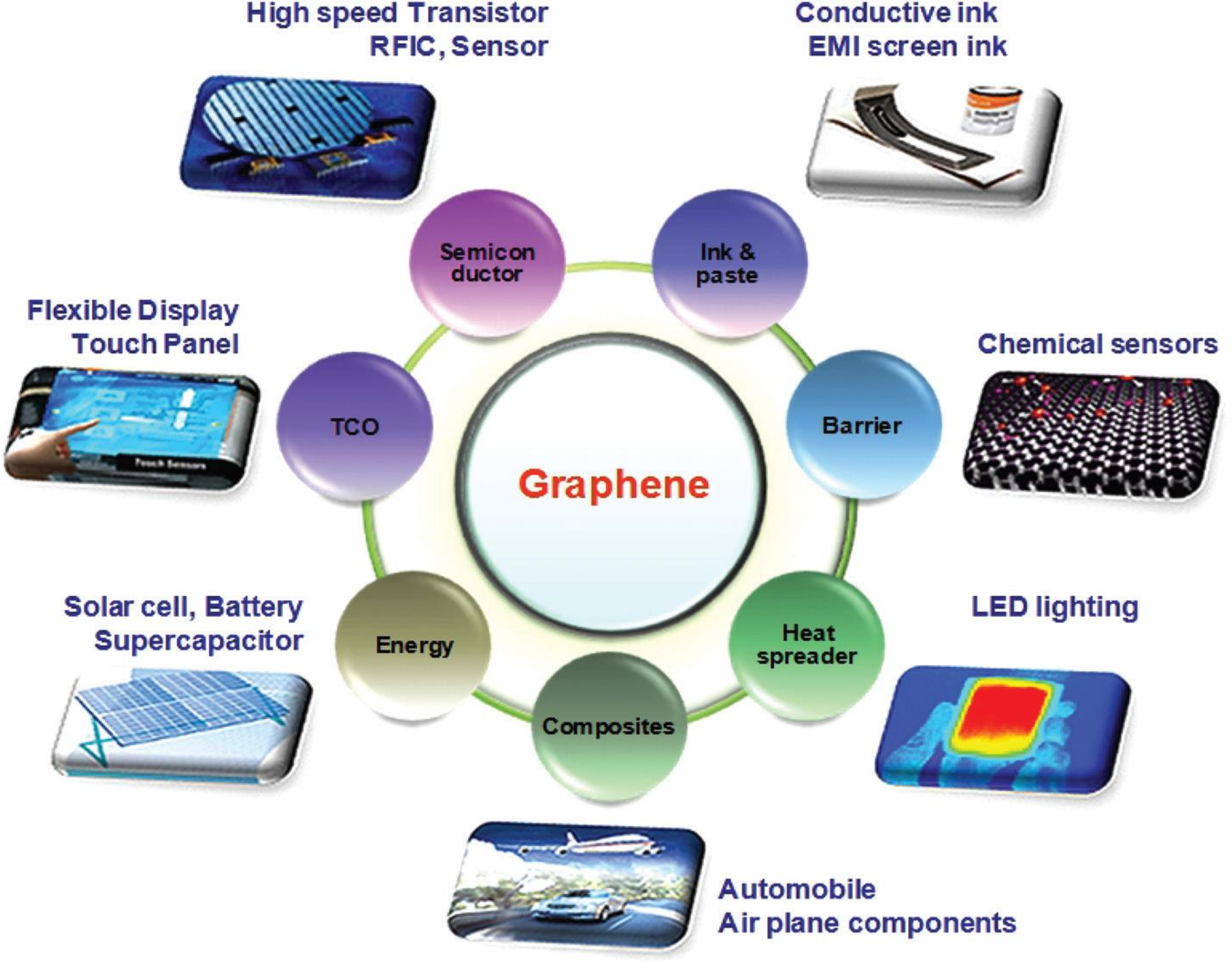
GRAPHENE The 'miracle material' that could revolutionize our world

What is it?

Graphene is a one-atom thick layer of carbon arranged in a honeycomb lattice. When millions of these are stacked one on top of another they form graphite – a mineral consisting of carbon which is found in pencils.

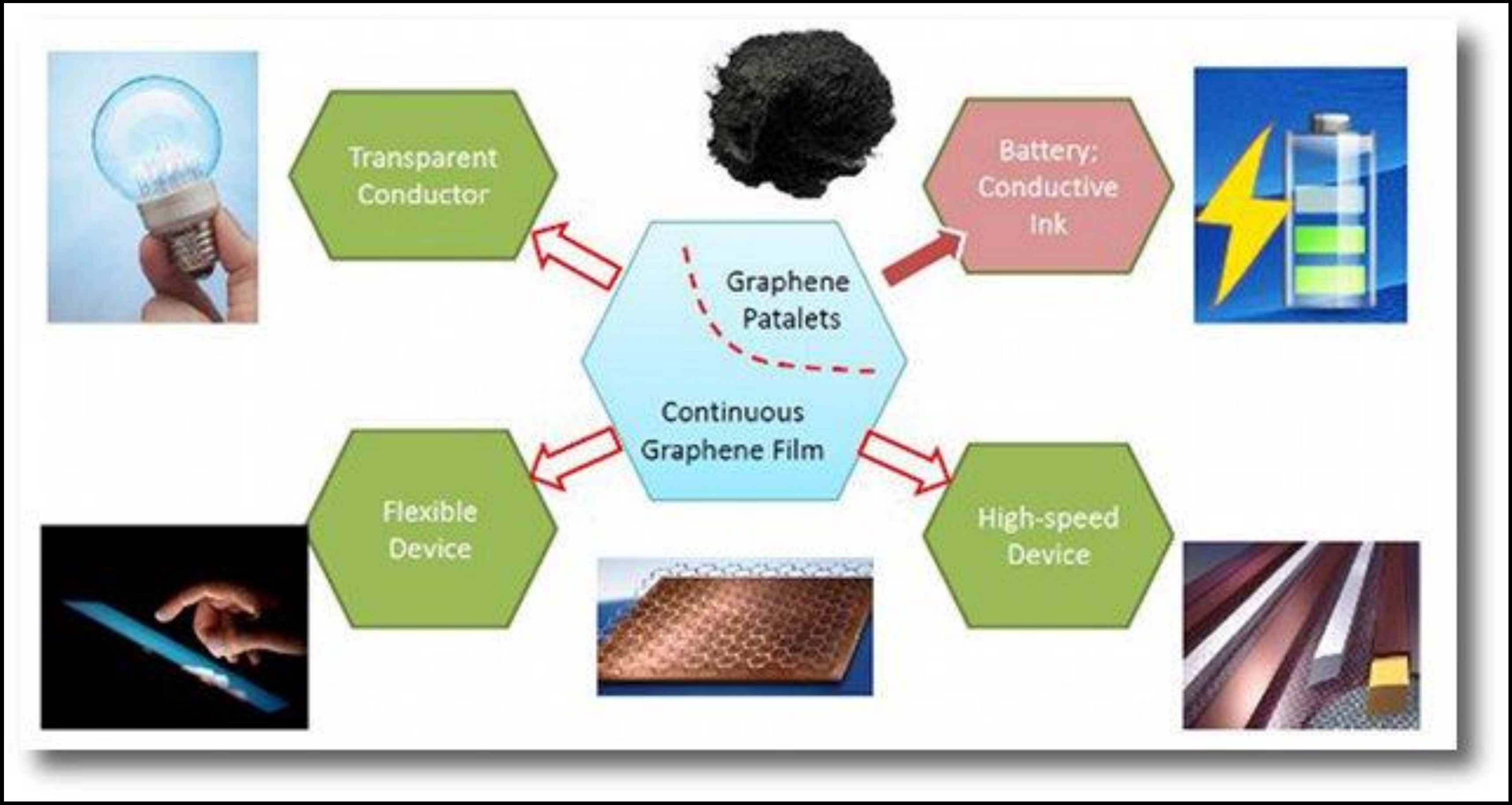
Graphene was discovered in 2004 at the UK's University of Manchester by physicists Andre Geim and Konstantin Novoselov when they isolated a single-layer of graphene using Scotch Tape before going on to demonstrate its remarkable conductive and resilient properties.

Geim and Novoselov's work earned them the Nobel Prize in physics in 2010 and today researchers are in a race to realize its technical and commercial capabilities.


High speed Transistor
RFIC, Sensor
Conductive ink
EMI screen ink
Semicon ductor
Ink & paste
Flexible Display
Touch Panel
Touch Sensors
Chemical sensors
TCO
Barrier
Graphene
Solar cell, Battery
Supercapacitor
Energy
Heat spreader
LED lighting
Composites
Automobile
Air plane components

Graphene

- Graphene is a one-atom-thick layer of carbon atoms arranged in a hexagonal lattice. It is the building-block of Graphite (which is used, among others things, in pencil tips), but graphene is a remarkable substance on its own - with a multitude of astonishing properties which repeatedly earn it the title "wonder material".
- Graphene is the thinnest material known to man at one atom thick, and also incredibly strong – about 100 times stronger than steel. On top of that, graphene is an excellent conductor of heat and electricity and has interesting light absorption abilities. It is truly a material that could change the world, with unlimited potential suits almost any industry.
- Graphene is an extremely diverse material, and can be combined with other elements (including gases and metals) to produce different materials with various superior properties. Researchers all over the world continue to constantly investigate and patent graphene to learn its various properties and possible applications, which include:
- Touchscreens (for LCD or OLED displays), Transistors, Computer chips
- Energy generation- Batteries, super capacitors
- Water filters
- Solar cells etc


Transparent
Conductor
Battery;
Conductive
Ink
Graphene
Patalets
Continuous
Graphene Film
Flexible
Device
High-speed
Device

WELCOME TO THE GRAPHENE AGE

George Osborne on a visit to the Manchester University lab of Professors Geim and Novoselov

SOLAR PANELS

MIT professors have shown how graphene could be used to make the electrodes in organic solar cells cheaper, lighter and more flexible than in current systems

AIR TRAVEL

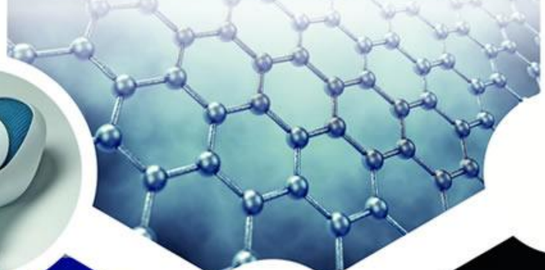
Using graphene would enable aeroplane manufacturers to develop extremely strong yet light components – bringing down weight and therefore reducing fuel costs

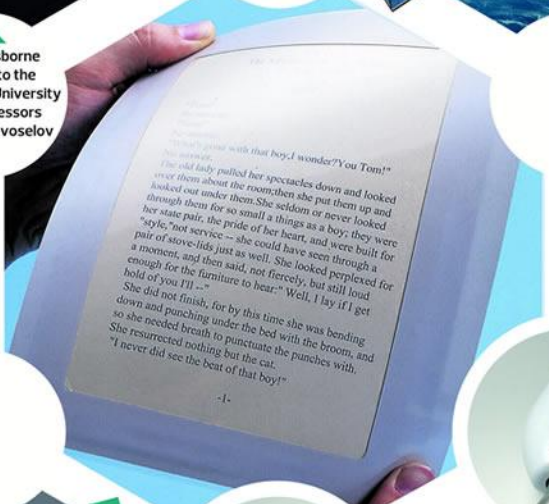
MOBILE PHONES

Nokia is exploring the potential uses of graphene in mobile devices. Aside from smaller, more flexible phones, it may allow built-in solar power and transparent electronics

A CLOSER LOOK AT GRAPHENE

Graphene is a one-atom thick form, or allotrope, of carbon – other allotropes include diamond and graphite. It is often described as an atomic-scale chicken wire constructed of carbon atoms and their bonds. When graphene sheets are stacked, three million sheets would be needed to create a 1mm thickness. It's been claimed that it is the strongest material known to man, that a clingfilm-thick layer could support an elephant. Despite its strength it can be stretched by 20% without being damaged. It is also an excellent conductor of electricity and the best conductor of heat that has been discovered





FLEXIBLE SCREENS

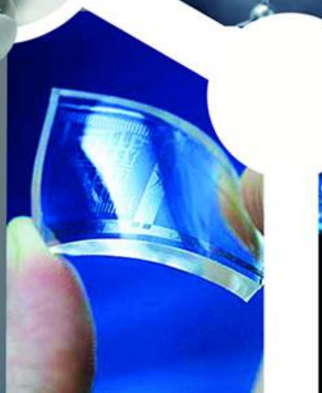
Researchers in South Korea have produced a continuous layer of graphene 63cm wide. This has opened up possibilities in electronics. "You could theoretically roll up your iPhone and stick it behind your ear like a pencil," claims one scientist

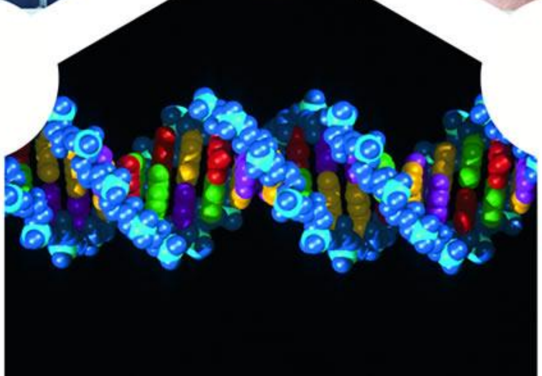
PROSTHETICS

Aside from allowing for the construction of stronger, more flexible and lighter limbs, its conductivity opens up new possibilities for its use in the electrodes used to turn brain signals into movement

COMPUTER CHIPS

Geim and Novoselov have been working on demonstrating how graphene could replace silicon as the key material in electronic circuits. IBM is one of many electronics firms experimenting with graphene conductors





DNA SEQUENCING

Researchers at British firm Oxford Nanopore, building on discoveries made at Harvard, claim that using graphene could reduce the cost and speed up the process of DNA sequencing

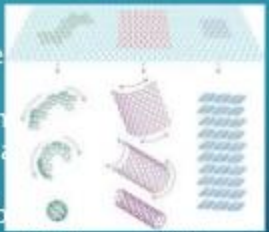
GRAPHIC: PETE GUEST

GRAPHENE: Structural Properties

* Hexagonal structural element of some carbon allotropes including graphite, charcoal, carbon nanotubes and fullere

* Graphite (layered material) formed by stacks 41 of graphen separated by 0.3 nm and held together by weak vander Wa

* Each atom forming 3 bonds with each of its nearest neighb known as the sigma bonds.

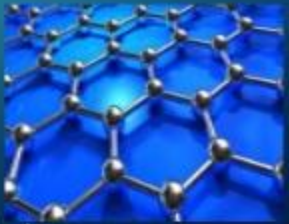


a) Fullerene b) Nanotube c) Graphite

* Fourth valence electron is in the $2p_z$ state oriented perpendicular to the sheet of graphite forms a conducting sigma bond.

* Two dimensional sp^2 hybridized forms of carbon

* Zero band gap semiconductor with 2 linearly dispersing bands that touch at the corners of the first Brillouin zone

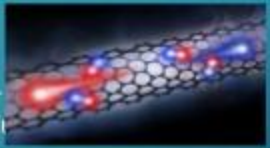


Honey comb structure of Graphene

GRAPHENE: Characteristics

ELECTRONIC PROPERTIES

* High Electron Mobility at room temperature, with reported values in excess of 15,000 cm2/Vs.
* Intrinsic graphene is a semi-metal or zero-gap semiconductor
* Low resistivity and better current capacity & temperature condu
* Graphene is estimated to operate at terahertzfrequencies i.e. trillions of operations per second.



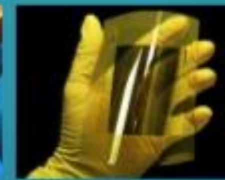
OPTICAL PROPERTIES

* An unexpectedly high opacity for an atomic monolayer, it absorbs $\pi\alpha$= 2.3% of white light, where α is the fine-struct
* Graphene can be saturated readily under strong excitation over the visible to near-infrared region, due to the universal optical absorption

MECHANICAL PROPERITIES

* Strongest materials ever tested
* Breaking strength 200 times greater than steel, a bulk strength

BIOLOGICAL ENGINEERING



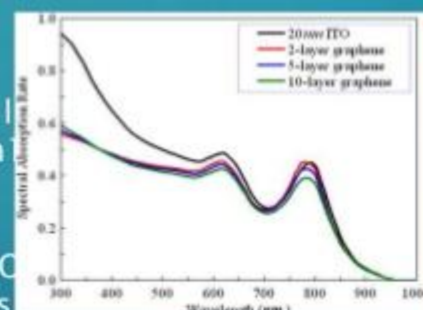
Graphene Advantages

* Large Surface Area
* High Electrical Conductivity
* Thinness and Strength

Uses

* Efficient Bioelectric Sensory Devices
* Able to monitor Glucose level, chole
  DNA sequencing, Haemoglobin level
* Toxic Graphene as anti-cancer treat
* Process of Tissue Regenration

OPTICAL ELECTRONICS



Graphene Advantages

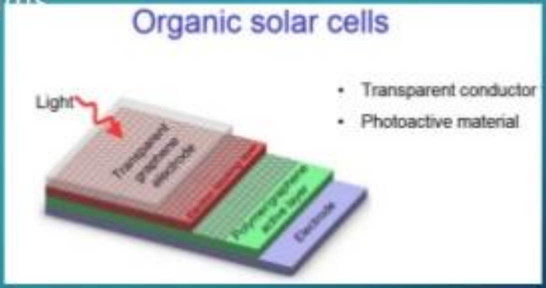
* Optically transmit more than 90% of l
* Conductivity more than 1x 106 Ω1m
* Completely Transparent material
* High Tensile strength and Flexible
* Able to replace Indium Tin Oxide (ITO
  due to less cost and better properties

Uses

* Touchscreens
* Liquid Crystal Display (LCD)
* Organic Light Emitting Diodes (OLEDs)

PHOTOVOLTAIC CELLS

Currently: silicon wafers, thin films

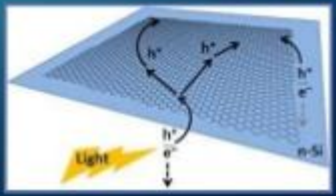


Graphene Advantages

* Transparent conducting electrode
* Robust, conductive, abundant
* Cheaper than ITO
* Enhanced light trapping
* Efficient charge transport (1D)

A new design:

* Layer of graphene (transparent cathode)
* Conductive polymer (maintains integ
* ZnO nanowire layer (electron transpo
* PbS quantum dots (hole transport)
* Au layer (anode)

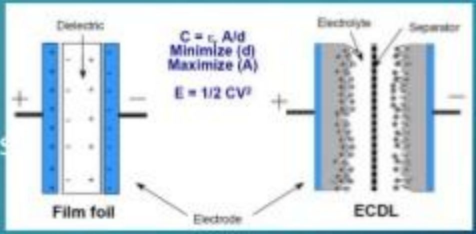


* 4.2% conversion efficiency (5.1% for ITO)
* Cheaper to produce

SUPER CAPACITORS

ULTRA/SUPER CAPACITORS

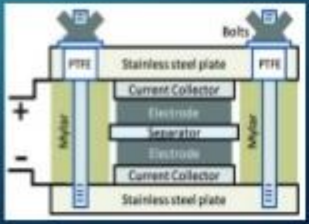
100 years old technology enhanced by modern materials based on polarization electrolytes, high surface area electrodes and extremely small charge seperation



ECDL (Electro Chemical Double Layer) Capaci

Graphene Advantages

* High surface area to weight ratio (2600 m^2/g)
* High conductivity
* Measured specific capacitance 135 F/g



Super Capacitor Model

Uses

* Electric vehicles
* Backup powering
* High power capability
* Cell phones

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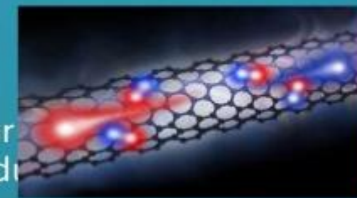

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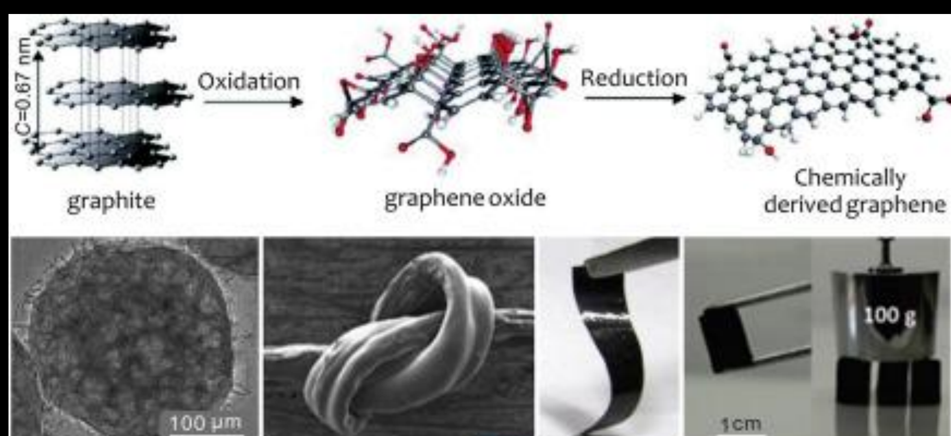
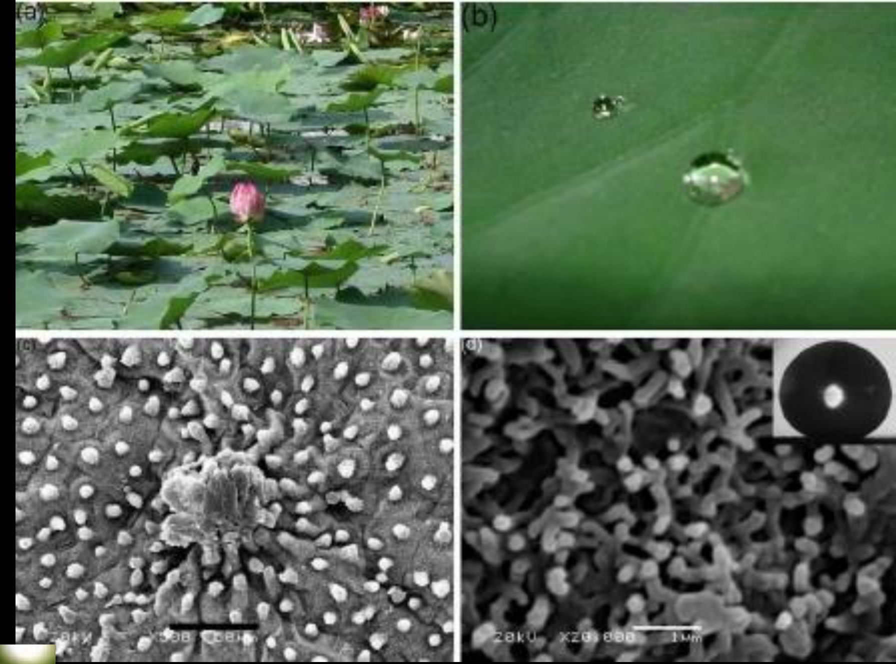
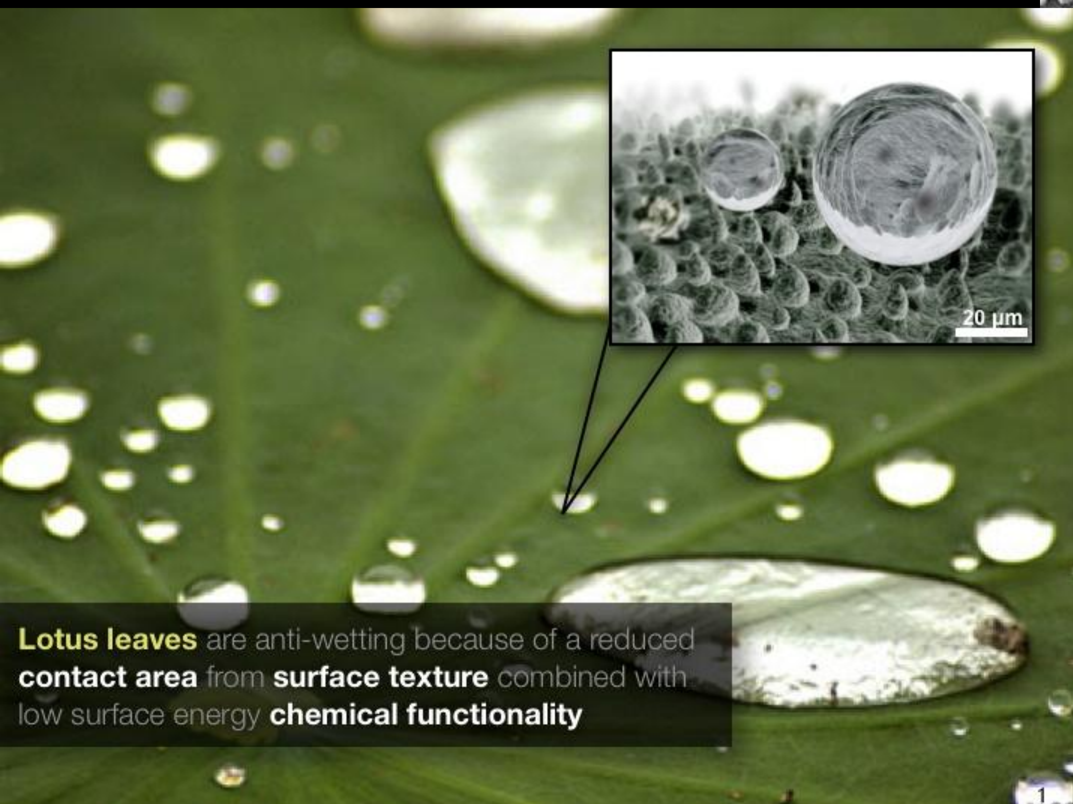
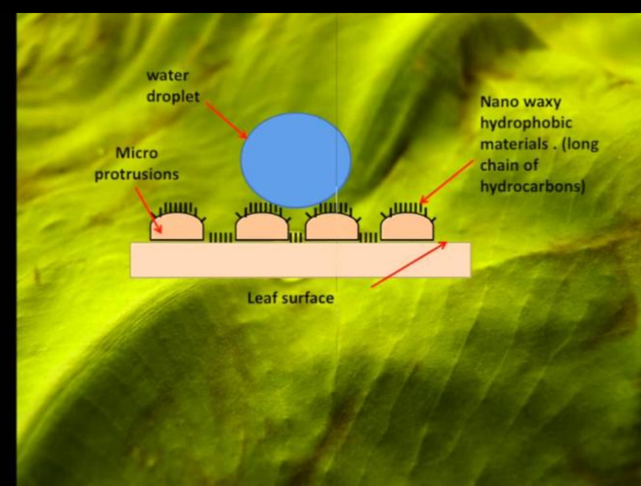


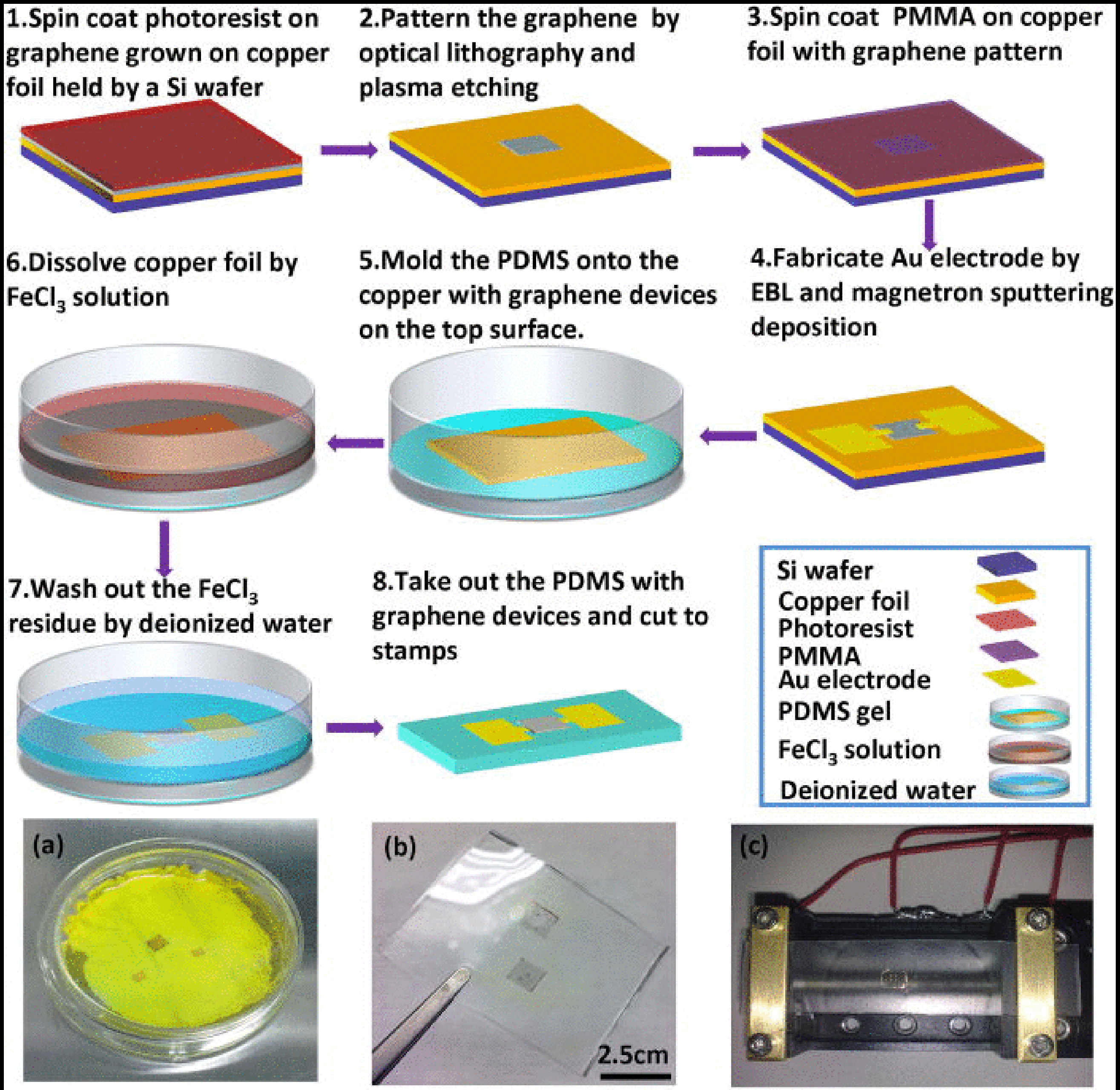
Hydrophobic nature







Used in Lab on chip-LOC



Electrochemical Energy Storage

Batteries are a compact method of converting chemical energy into electrical energy

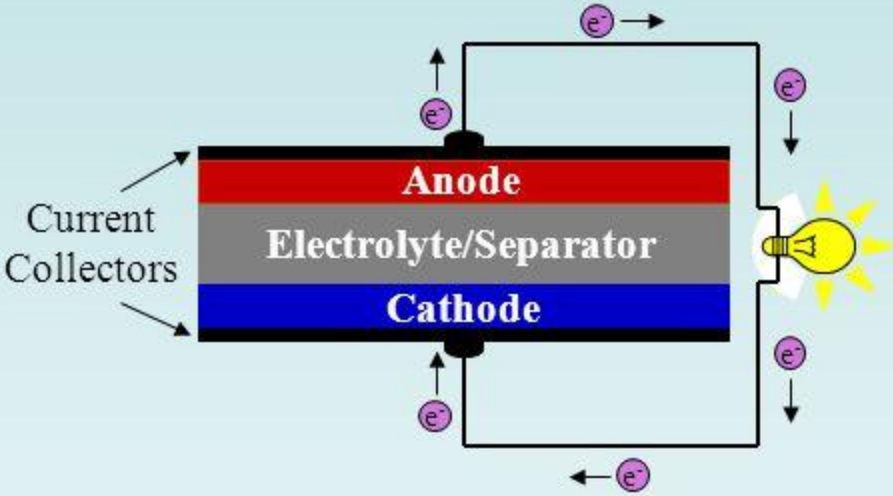
Other methods, fuel cell, photovoltaic cell, electrochemical capacitors etc.

Primary: Non-rechargeable
Secondary: rechargeable

Voltage➔ Potential difference between anode and cathode. Related to energy of reactions

Capacity➔ amount of charge stored (usually given per unit mass or volume)

C-rate → charging/discharging rate, 1C is current needed to discharge in 1 hour



Anode (Oxidation):

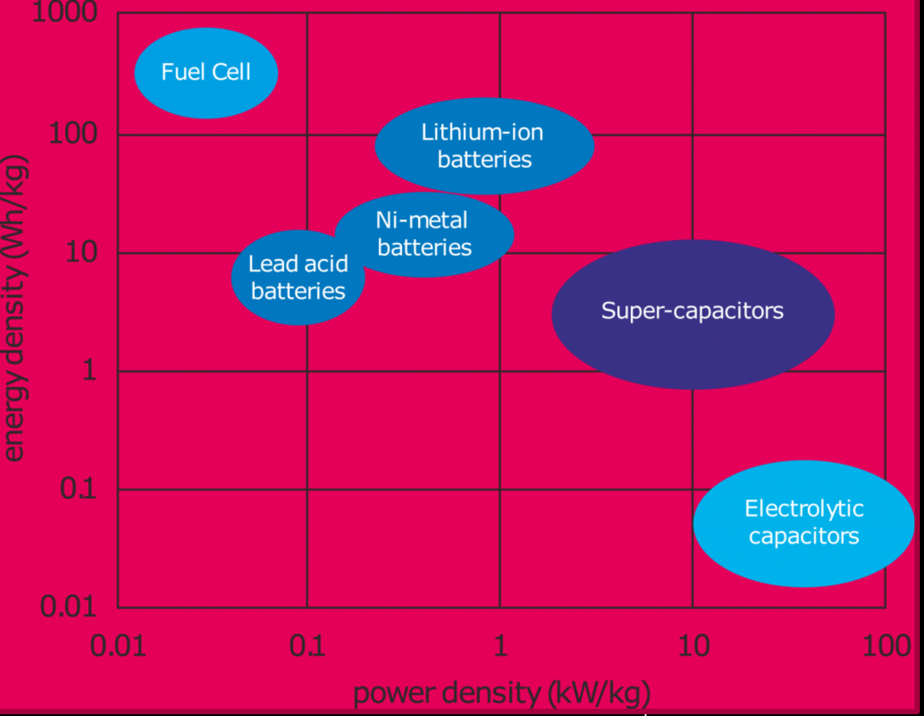
$$Zn + 2\ OH^- \Leftrightarrow Zn(OH)_2 + 2e^- \qquad E = 1.25\ V$$

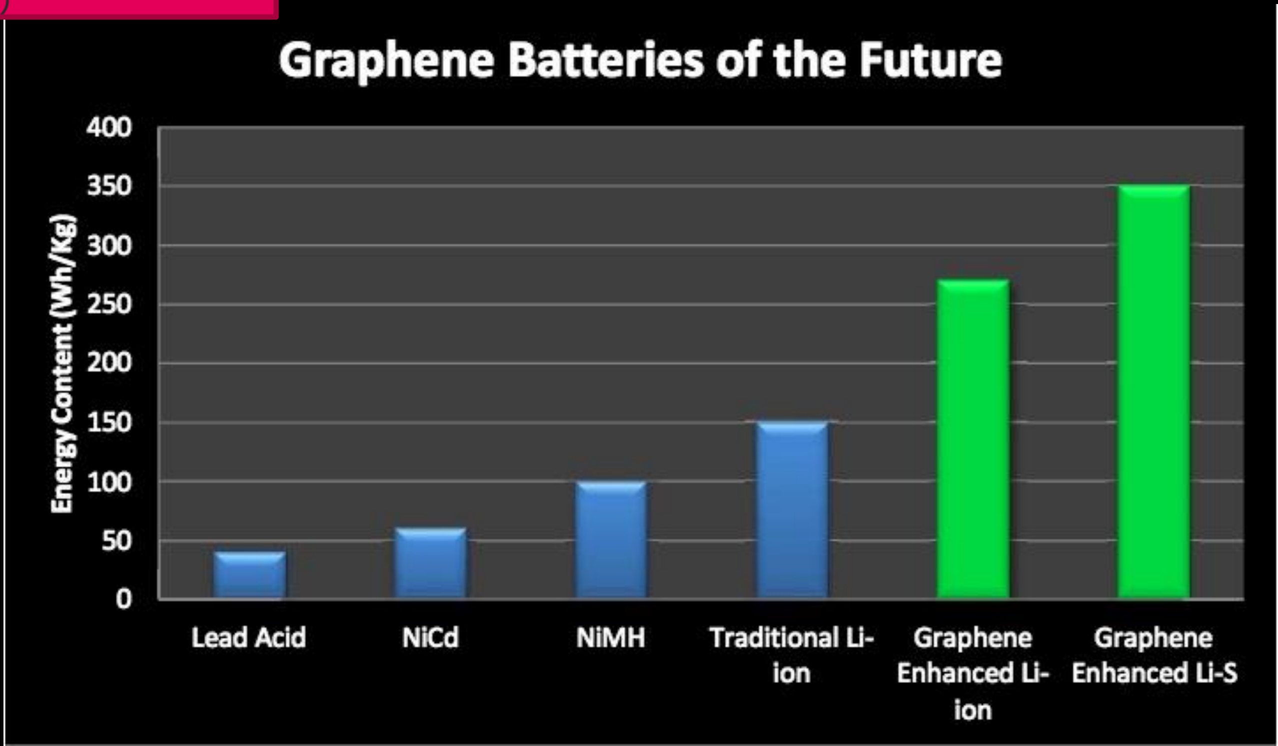
Cathode (Reduction):

$$Ag_2O + H_2O + 2e^- \Leftrightarrow 2\ Ag + 2\ OH^- \qquad E = 0.34\ V$$

All work the same, but the details are different

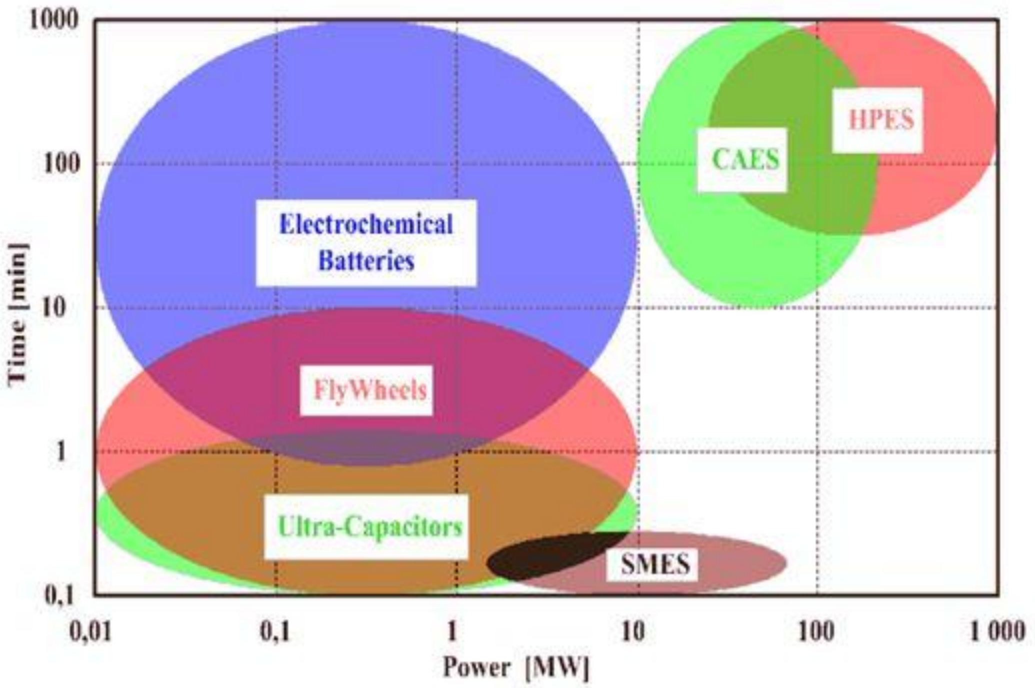
Graphene usage in batteries



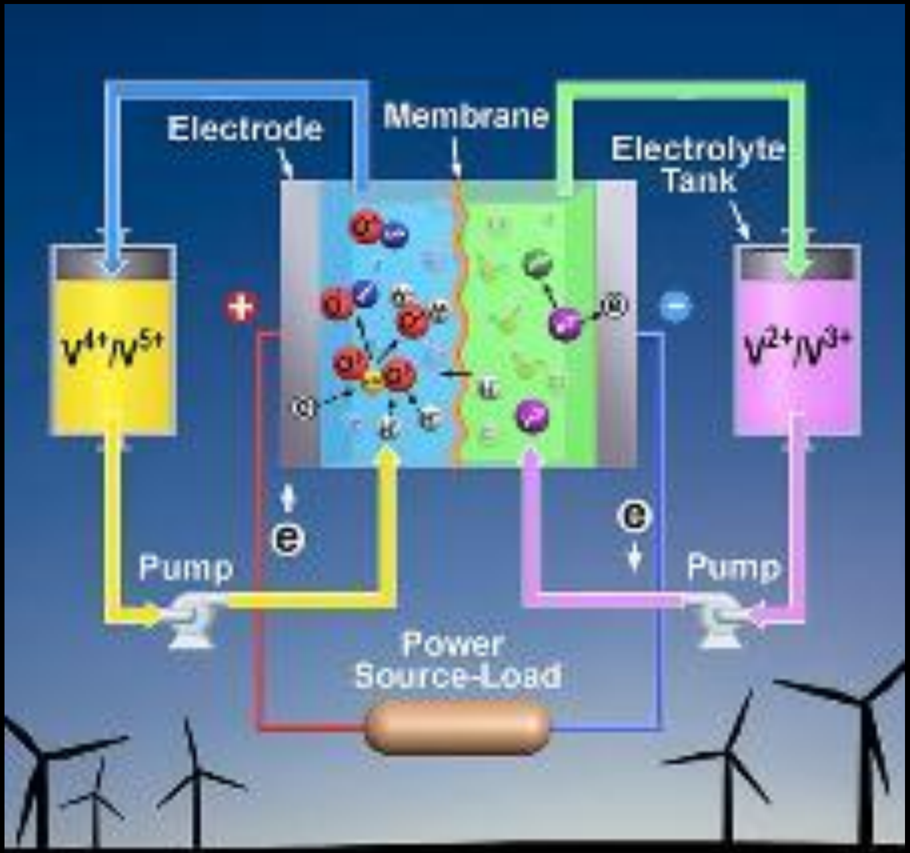


Energy Storage Technologies & Devices

- CAES & HPES
  - Large scale utility applications
- SMES
  - High power short term utility applications
- Electrochemical Batteries
  - Long term, low & midium power applications
- Flaywheels & Ultra-capacitors
  - Short term, low & midium power applications



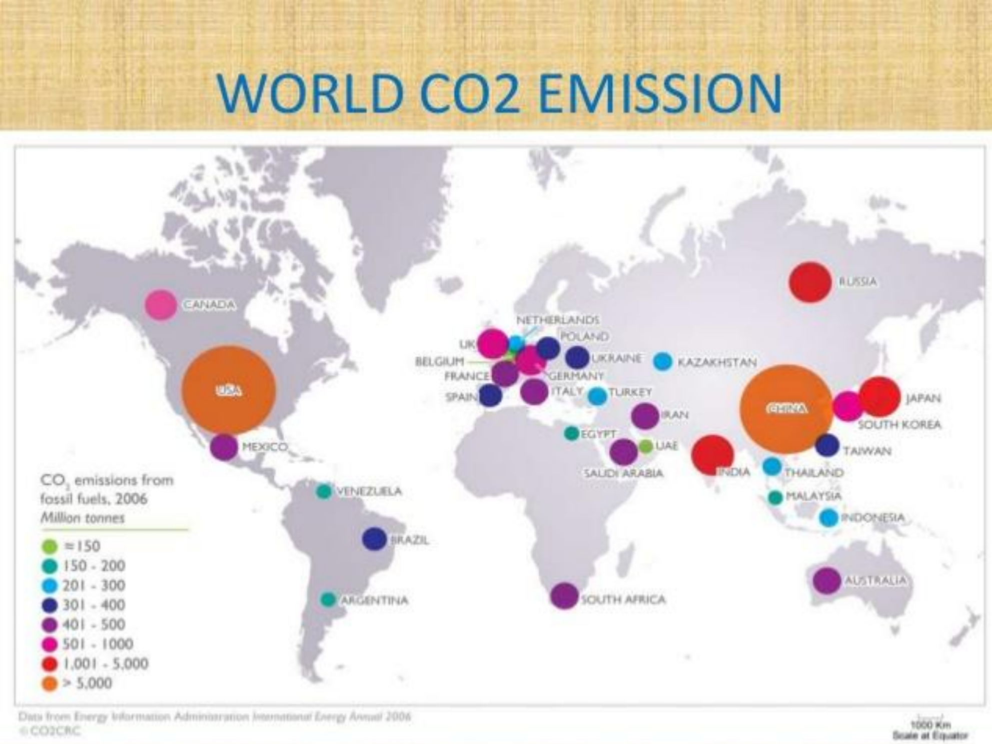
Redox flow battery

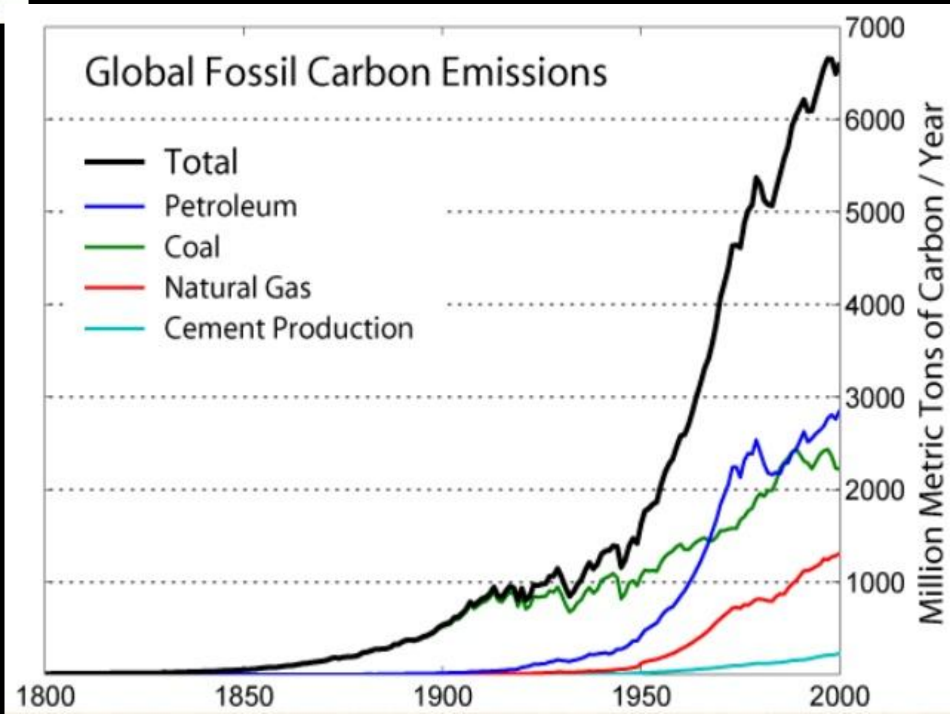


Current scenerio

- The 20th century has seen the rapid increase of population and explosive growth in energy consumption. Currently, over 85% of world energy demand is supplied by fossil fuels.
- Environmental issues due to emissions of pollutants from combustion of fossil fuels have become global problems, including greenhouse gases(GHG) . Increased levels of GHG in the atmosphere is believed to cause global warming.
- Among these GHG, CO2 is the largest contributor due to the amount present in the atmosphere contributing to 60% of global warming . Various options to reduce total CO2 emission into the atmosphere including development of smart technologies to capture CO2 are emerging.

Global CO 2 emission





CO2 adosrption by Graphene

Various CO_2 capture technologies, including absorption, adsorption, cryogenics and membranes etc. are employed. Among these the technology considered nowadays as mature is CO_2 scrubbing using amine solutions. However, high energy requirements for solvent regeneration, extensive corrosion of the equipments and the impact of amine solutions life cycle on the surrounding ecosystems are being of major concern for the use of this technology.

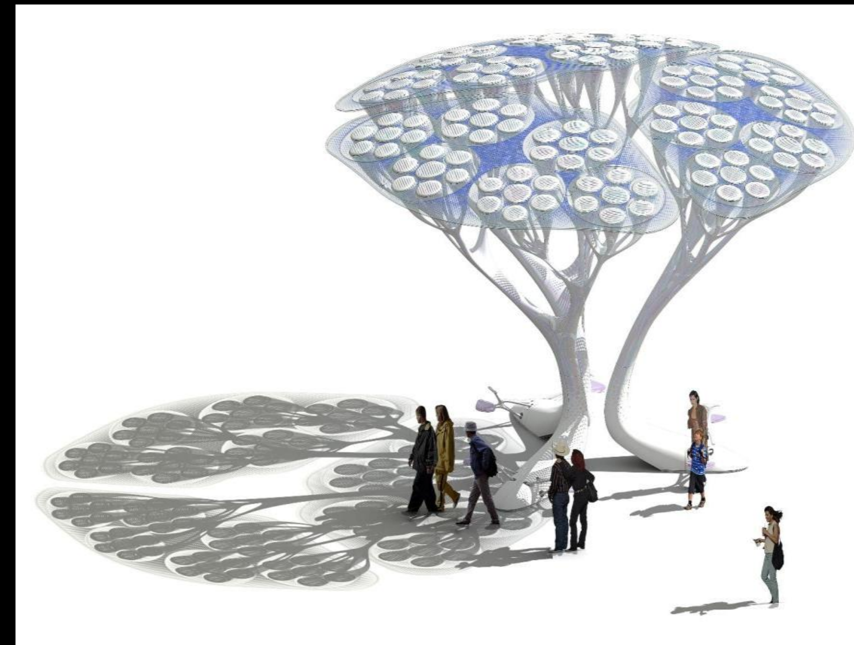
Adsorption is known to be an alternative solution of the above problems associated with CO_2 absorption in amine based solutions. Different porous materials like zeolite-based molecular sieves, activated carbons (ACs), carbon nano tubes (CNTs) have attracted the attention of researchers for CO2 adsorption.

Graphene, as new class of carbon nanomaterials, is found to be opt & economical and has novel properties similar to CNTs. Storage capacity of graphene for different gases is engaraged and CO_2 adsorption capacity is demonstrated at very low temperature (195 K), Therefore, investigation of CO_2 adsorption by graphene at room temperature and moderate pressure for practical application is to be investigated.

Lackner's Artificial Tree to capture CO2

Detailed studies

- Lackner's tree is made from a special resin – a unique plastic that sponges up CO2 from the air in a chemical reaction. When the resin is dry, it "has an exceedingly high affinity to carbon dioxide" – in other words, it absorbs the C02. And when the resin is submerged in water, it releases the carbon dioxide,
- This tree is specialist for carbon dioxide collection, and about 1,000 times faster [than natural trees].
- The first outdoor prototype was installed on the roof at Arizona State University for detailed study--- Lackner
- One hundred million of Lackner's units, each built to remove one metric ton {2,204 pounds} of C02 a day, would be needed to match the amount of carbon dioxide the world currently emits each year. Adding more units would begin to lower the 400 ppm of carbon dioxide already in the atmosphere, a level that is on the rise.
- If these units are built up another 100 million [units], it is possible to bring [carbon dioxide levels] down another 2 ppm, per year," - Wallace Broecker---pioneering climate scientist.
- If this is realistic, [200 million units], one [million] matching what we're producing, and another [million] taking some out. Then to go back to 350 ppm, it would take 50 years.
- Scientists consider 350 ppm of C02 a ceiling to keep climate change under control, according to many experts. Levels of the greenhouse gas started to rise above 300 ppm with the Industrial Revolution.



CO2 trees

Graphene and water treatment

- **Water is an invaluable resource and the intelligent use and maintenance of water supplies is one of the most important and crucial challenges that stand before mankind. New technologies are constantly being sought to lower the cost and footprint of processes that make use of water resources, as potable water (as well as water for agriculture and industry) are always in desperate demand. Much research is focused on graphene for different water treatment uses, and nanotechnology also has great potential for elimination of bacteria and other contaminants.**

Treatment by Graphene

- Wastewater treatments usually consist of three levels: a primary (mechanical) level, in which solids are removed from raw sewage by screening and sedimentation. This level can remove about 50-60% of the solids, and is followed by the second level - secondary (biological) treatment. Here, dissolved organic matter that escaped primary treatment is removed, by microbes that consume it as food and convert it into carbon dioxide, water and energy. The tertiary treatment removes any impurities that are left, producing an effluent of almost drinking-water quality. The technology required for this stage is usually expensive and sophisticated, and demands a steady energy supply and specific chemicals. Disinfection, typically with chlorine, can sometimes be an additional step before discharge of the effluent. It is not always done due to the high price of chlorine, as well as concern over health effects of chlorine residuals.

Wash Water treatment

- **Nanotechnology - the use of nanotechnology to purify drinking water can help remove microbes and bacteria. Many nano-water treatment technologies use composite nanoparticles that emit silver ions to destroy contaminants.**

- **Membrane chemistry - membranes, through which water passes and is filtered and purified. The pores of membranes used in ultrafiltration can be remarkably fine. This technology exists, and efforts are constantly being made to make it more dependable, cost-efficient and common. Membranes' selective separation grants filtration abilities that can pose as alternatives to processes like flocculation, adsorption and more.**

- **Seawater desalination - processes that extract salt from saline water, to produce fresh water suitable for drinking or irrigation. While this technology is in use and also holds much promise for growing in the future, it is still expensive, with reverse osmosis technology consuming a vast amount of energy (the desalination core process is based on reverse osmosis membrane technology).**

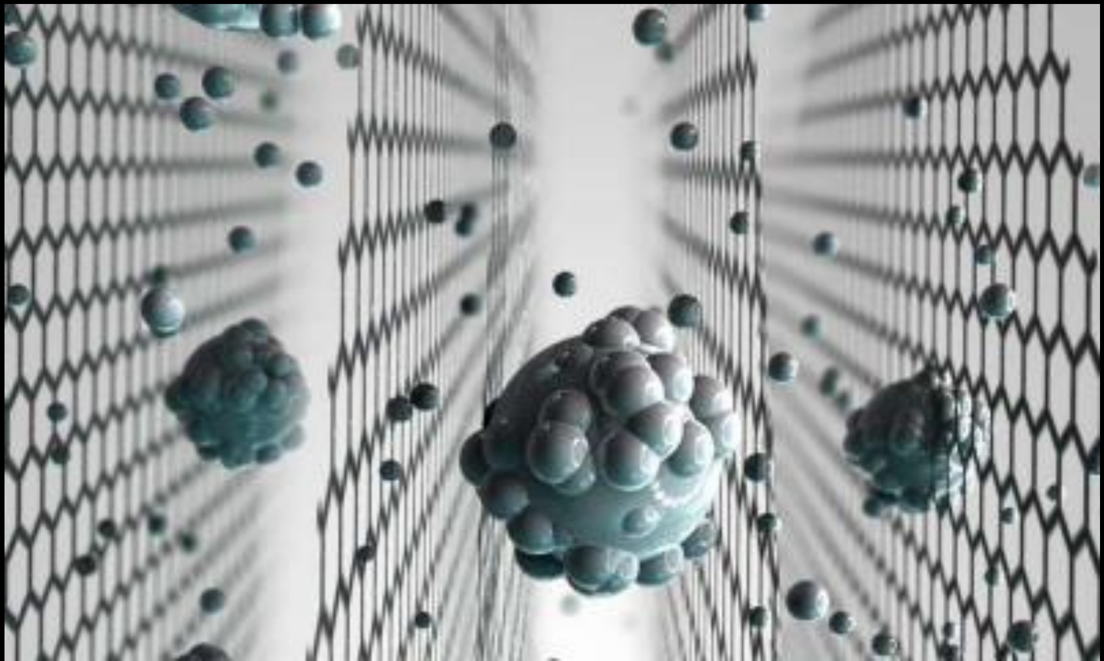
- **Innovative wastewater processing - new technologies aim to transform wastewater into a resource for energy generation as well as drinking water. Modular hybrid activated sludge digesters, for example, can remove nutrients for use as fertilizers, decreasing almost by half the amount of energy traditionally required for this treatment in the process.**

Graphene and water treatment

- Among graphene's host of remarkable traits, its hydrophobia is probably one of the traits most useful for water treatment. Graphene naturally repels water, but when narrow pores are made in it, rapid water permeation is allowed. This sparked ideas regarding the use of graphene for water filtration and desalination, especially once the technology for making these micro-pores has been achieved. Graphene sheets (perforated with miniature holes) are studied as a method of water filtration, because they are able to let water molecules pass but block the passage of contaminants and substances. Graphene's small weight and size can contribute to making a lightweight, energy-efficient and environmentally friendly generation of water filters and desalinators.
- It has been discovered that thin membranes made from graphene oxide are impermeable to all gases and vapors, besides water, and further research revealed that an accurate mesh can be made to allow ultrafast separation of atomic species that are very similar in size - enabling super-efficient filtering. This opens the door to the possibility of using seawater as a drinking water resource, in a fast and relatively simple way.

Scientists at The University of Manchester have made a breakthrough in the field of graphene oxide membranes for water desalination.This research at The University of Manchester found that when immersed in water, graphene oxide membranes become slightly swollen and smaller salts flow through the membrane along with water, but larger ions or molecules are blocked. Now, the team has devised a strategy to avoid the swelling of the membrane when exposed to water. The pore size in the membrane can be precisely controlled which can sieve common salts out of salty water and make it safe to drink.

When the common salts are dissolved in water, they form a 'shell' of water molecules around the salt molecules. This allows the tiny capillaries of the graphene oxide membranes to block the salt from flowing along with the water. Water molecules are able to pass through the membrane barrier and flow anomalously fast which is ideal for application of these membranes for desalination.

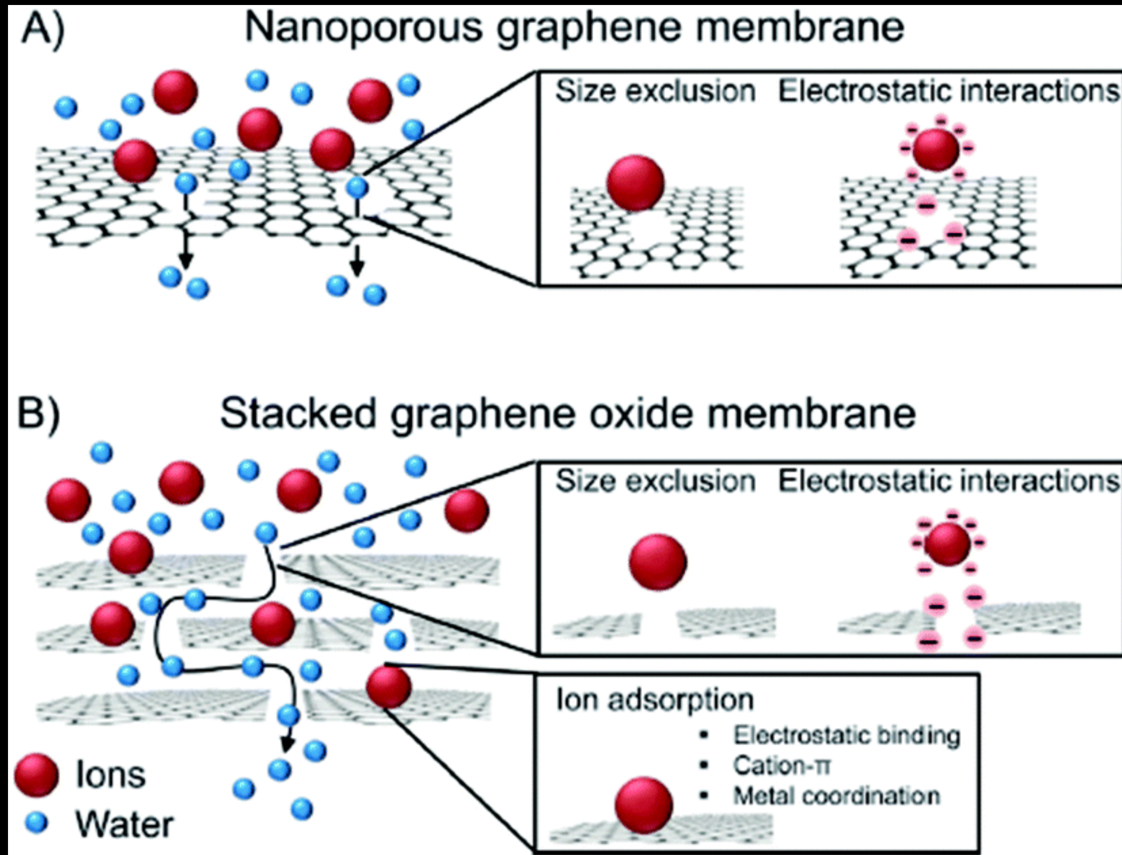


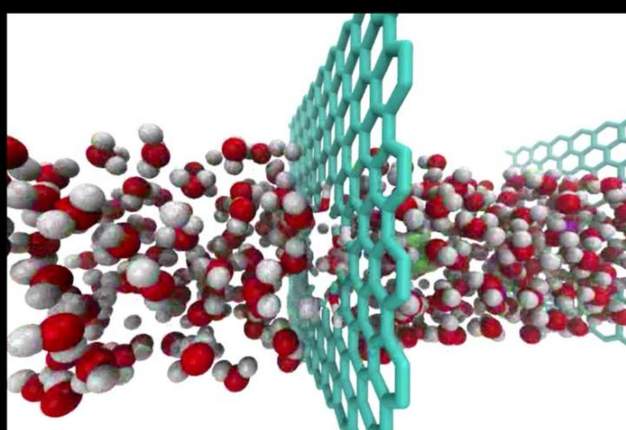
Recent commercial activity in the field of graphene water treatments

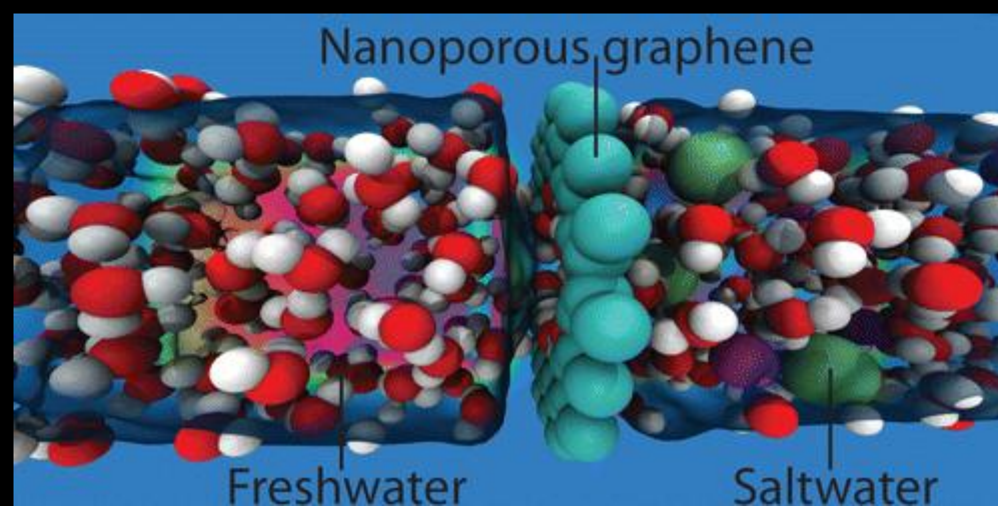
- **In November 2014, the Malaysian based Graphene Nanochem that is traded in the AIM –London stock exchaange signed an agreement with Singapore based HMW to develop anf commercialise Platclean V1 system - a graphene-enhanced water treatment system for the oil and gas industry. In August 2014, the U.S based Biogenic Reagents announced starting a commercial production of graphene-carbon compound based Ultra-Adsorptive Carbon productGrs to replace traditional activated carbon products for air and water purification.**
- **In March 2013,Lockheed Martin announced the evelopment of new graphene based water desalination technology, with hopes to commercialize it by 2014-2015. Their system is said to be energy-efficient and include graphene filters with nanoholes to screen salt from water.**

Latest news on Graphene in water treatment

- **Scientists from China create graphene aerogel that converts sulight into heat to produce water vapour at room temperatureMay 21, 2017Researchers at the Chinese Hubei University have designed a graphene aerogel film capable of producing water vapor at room temperature using only sunlight. The aerogel floats on the surface, where it heats up only a small part of the water column, 'while the temperature of the bulk water is far below the boiling point', the team explains.**
- **This sunlight-harvesting graphene film could convert sea or wastewater into drinking water in places where fuel or access to electricity is limited. Desalinating Seawater to make it drinkable usually means boiling it, and then collecting and condensing the steam. Heating water to its boiling point, however, requires quite a lot of energy, which is not always easy to come by. There are solar stills that desalinate water using only sunlight, but they're slow and not always efficient enough to provide sufficient drinking water for a person's daily needs.**


A)
Nanoporous graphene membrane
Size exclusion
Electrostatic interactions
B)
Stacked graphene oxide membrane
Size exclusion
Electrostatic interactions
Ion adsorption
• Electrostatic binding
• Cation-π
• Metal coordination
Ions
Water




Nanoporous graphene
Freshwater
Saltwater

Graphene membrane for wash water

- Apr 05, 2017Scientists at The University of Manchester have made a breakthrough in the field of graphene oxide membranes for water desalination. Previous research at The University of Manchester found that when immersed in water, G O membranes become slightly swollen and smaller salts flow through the membrane along with water, but larger ions or molecules are blocked. Now, the team has devised a strategy to avoid the swelling of the membrane when exposed to water. The pore size in the membrane can be precisely controlled which can sieve common salts out of salty water and make it safe to drink.
- When the common salts are dissolved in water, they form a 'shell' of water molecules around the salt molecules. This allows the tiny capillaries of the graphene oxide membranes to block the salt from flowing along with the water. Water molecules are able to pass through the membrane barrier and flow anomalously fast which is ideal for application of these membranes for desalination

Corrosion

- Corrosion is known as physico-chemical interaction between a metal and its environment causing deterioration in properties of the metal. This leads to impairment of the function of metal, the environment or the technical system of which these form a part.

- Most of the degradation of engineering components by corrosion is at the surface due to the immediate interaction of the corrosive environment with material.

Harmful effects

- Reduction of metal thickness that leads to loss of mechanical strength and structural failure
- Hazards or injuries to people arising from structural failures
- Loss of time in profit-making industrial equipments
- Reduced value of goods --deterioration of appearance
- Contamination of fluids in vessels or pipes
- Perforation of vessels
- Loss of technically important surface properties of a metallic component
- Mechanical damage to pumps, valves or even blockage

Table of Electrode Potentials

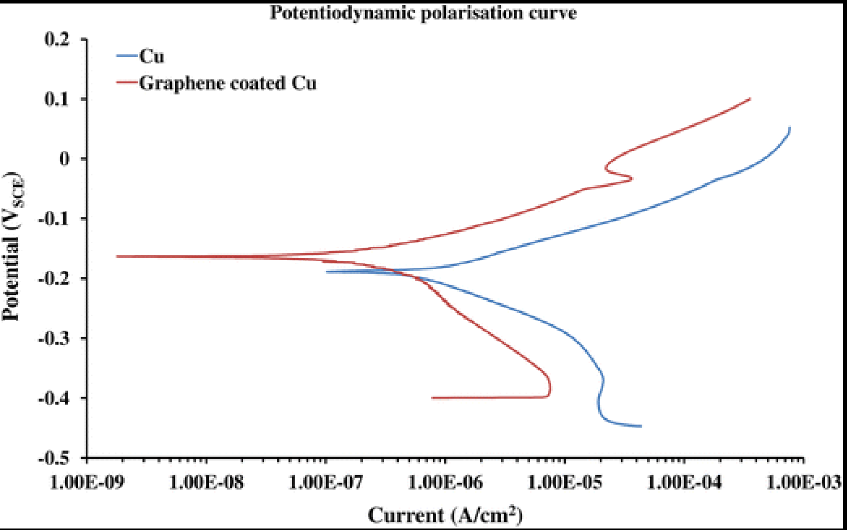
Metal	*Electrode Potential (V)*
Magnesium	-2.40 (Anodic – more basic)
Aluminium	-1.76 CORRODED END
Zinc	-0.76
Chromium	-0.65
Iron	-0.44
Nickel	-0.23
Tin	-0.14
Lead	-0.12
Hydrogen (REF)	0.00
Copper	+0.34
Silver	+0.80 PROTECTED END
Gold	+1.40 (Cathodic – more noble)

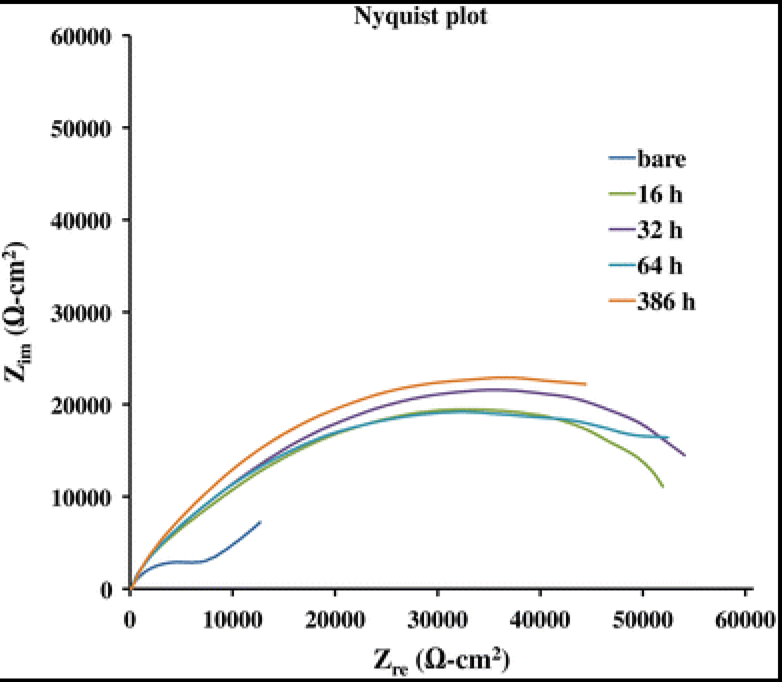
Reinforcement Corrosion

- Corrosion of steel reinforcement leads to expansion as corrosion products develop.
- Expansion leads to tension between the reinforcement & the concrete cover.
- Spalling of concrete cover.

Graphene for corrosion

- The nature of graphene films profoundly influences the corrosion resistance of the graphene-coated metals. The corrosion resistance of graphene-coated Nickel, produced by two different routes. The coatings developed by the chemical vapor deposition (CVD) process provided improvement by **20 times** whereas those developed by mechanically transferring two or four layers of graphene onto Nickel resulted in a maximum improvement by only four times
- It is extremely important to reiterate that during CVD, graphene film on Ni develops by the combined mechanism of a surface catalysis and greater solubility of carbon in Nickel at raised temperature and the rejection of carbon from the metal matrix with cooling to allow the formation a thin surface layer of graphene. The graphene coating thus developed has a good correlation and adhesion with the substrate and has a good surface coverage, which explains the superior corrosion resistance due to such graphene. The remarkable corrosion resistance has observed also in the commercially available graphene-coated nickel. But, the graphene coatings developed by mechanically transferring layers of graphene onto Nickel apparently had channels/discontinuities that allowed ion transport and, hence, provided only up to four times improvement in corrosion resistance





Graphene for corrosion

The methods reported so far for synthesizing CVD graphene have been successful on metals having face-centered cubic (fcc) or hexagonal close-packed (hcp) crystal structures. Hydrocarbons such as methane and ethylene have been used as precursors at decomposition temperatures of about 1000°C.

Generally a multilayer graphene will be formed instead of the single-layer graphene. Complications can arise also when metal substrates of larger thicknesses are used.

The thinnest known corrosion-protecting coating, such like this coatings on copper and nickel can considerably improve their corrosion resistance (by up to 1.5 orders of magnitude) in common electrolytes.

Graphene in construction

- UK companies are now developing commercial applications of graphene for civil engineering. For example, Graphitene Ltd is currently developing thermally conductive cement grout materials containing graphene for geothermal wells, as well as cements with graphene admixtures that are mechanically stronger.
- The company is also working on improving asphalt with graphene, both for more thermally resistant and durable roads, with increased elastic recovery and reduced cracking, and for fire-resistant bitumen roof materials.
- Meanwhile, Haydale Composite Solutions Ltd has announced production of graphene-enhanced, electrically-conductive, carbon fibre reinforced, composite materials with improved resistance to damage from lightning strikes. This has already been incorporated into an aileron designed by Airbus and could soon be used for wind-turbine blades.

Weatherproofing and packaging

- The same technique could also be applied to brick and stone, to weatherproof houses, or even to food packaging to stop the transfer of water and oxygen molecules which causes food to go off.
- Further benefits come from incorporating graphene-based composites in major components in industries such as construction, transport or aerospace. Due to ongoing research alongside commercial collaborators, scientists at The University of Manchester are moving toward a realistic future where potential is becoming reality.

Graphene for sports

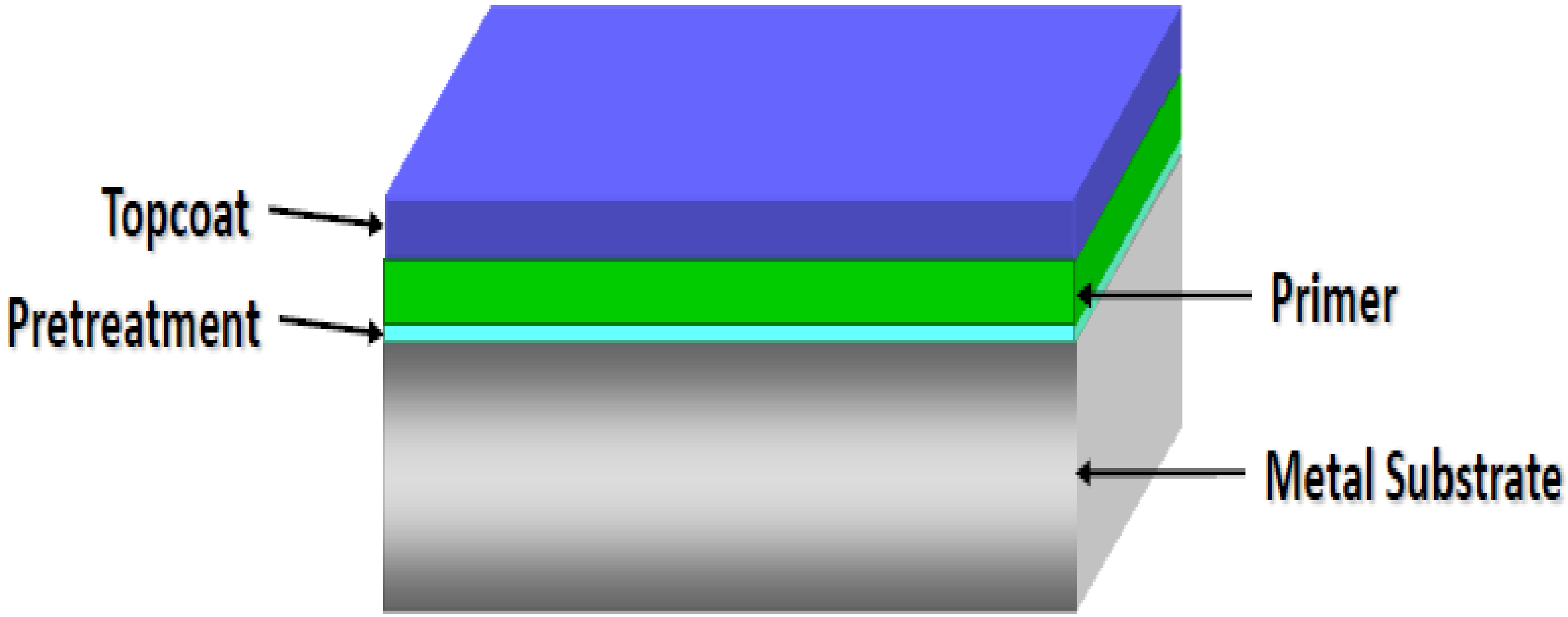
Sporting goods are often the first to take up on new materials development which has already been the case with the successful graphene-enhanced tennis racket from Head.

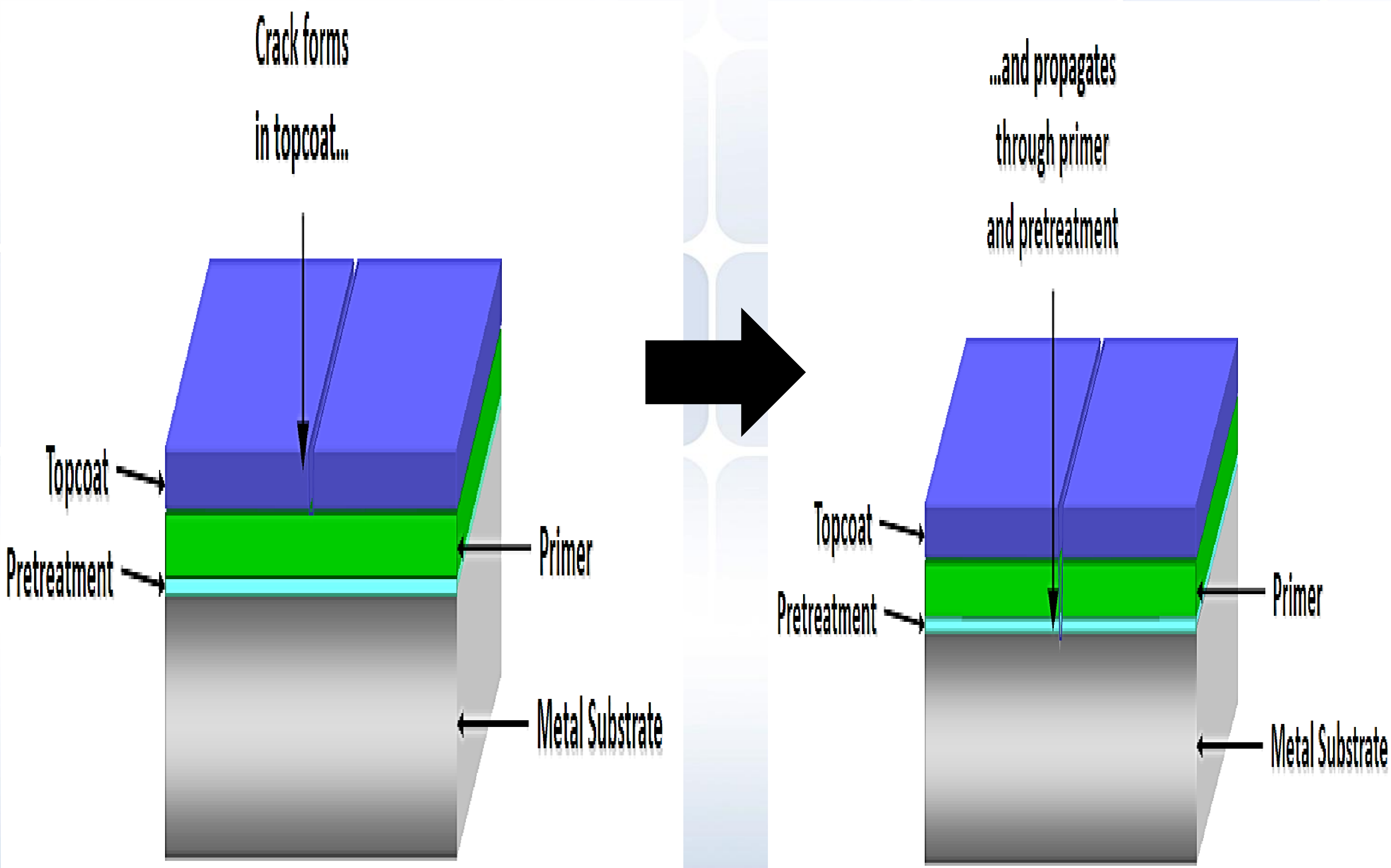
Graphene-based composites and coatings could be further involved in enhancing sports equipment in skiing, cycling, and even Formula 1 in the near future.

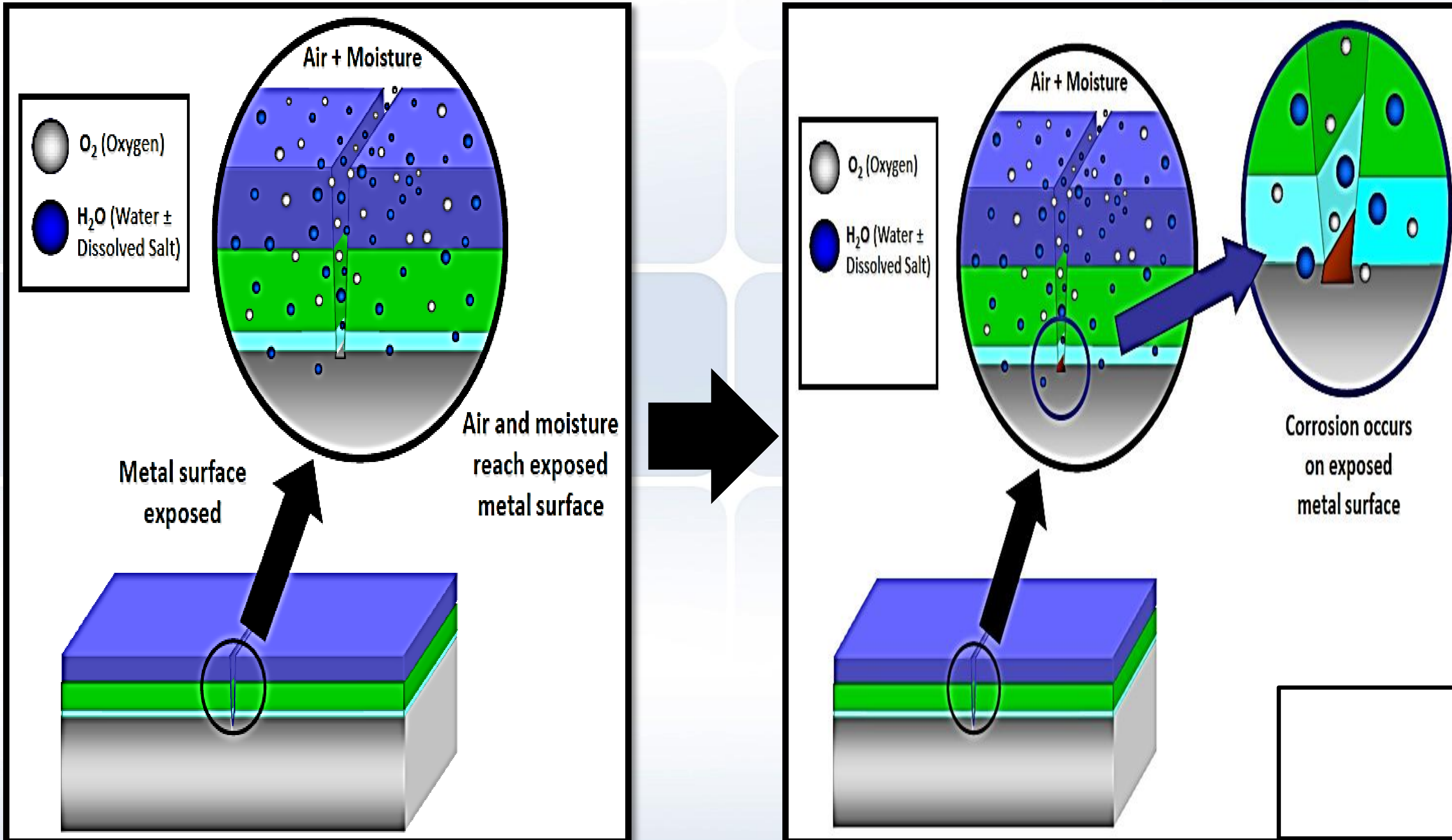
Paints

- **Pigment – Pigment are used decoratively as colorant or functional as anticorrosion or magnetic pigment.**
- **Binder – The binder bonds the pigment particles to each other and to the substrate.**
- **Additives - Substances added in small proportion to coating composition to modify or improved properties**
- **Fillers - Mostly used to extend the volume (low price), to confer or to improve technical properties.**
- **Solvent – Liquid consists of several components and dissolved binders without chemical reaction.**

Conventional Coating System



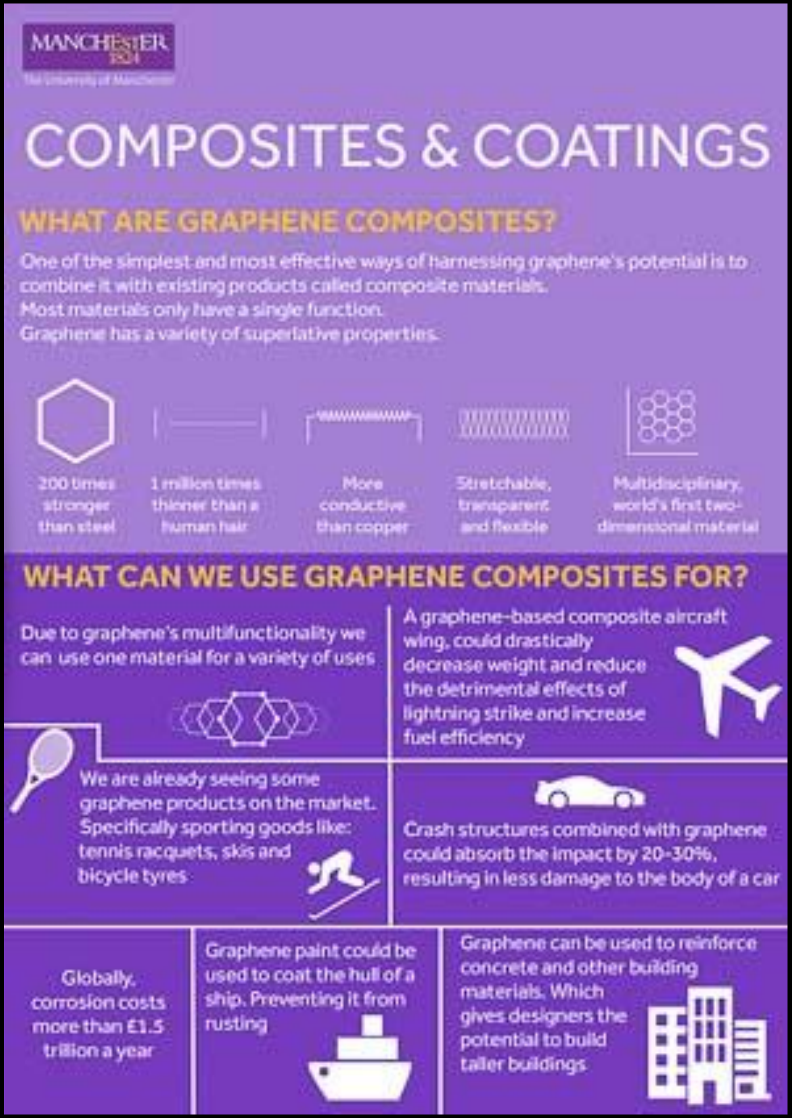

Crack forms
in topcoat...
Topcoat
Pretreatment
Primer
Metal Substrate
...and propagates
through primer
and pretreatment
Topcoat
Pretreatment
Primer
Metal Substrate



O_2 (Oxygen)
H_2O (Water ± Dissolved Salt)
Air + Moisture
Metal surface exposed
Air and moisture reach exposed metal surface
O_2 (Oxygen)
H_2O (Water ± Dissolved Salt)
Air + Moisture
Corrosion occurs on exposed metal surface

Graphene in coatings

Researchers at The University of Manchester have already shown the potential of a rust-free future. By combining graphene with paint, a unique graphene coating is formed which could signal the end of the deterioration of ships and cars through rust.



Surface treatment – Non automotive applications

Advanced Technologies

Cold Extrusion
Phosphate+Soap

Wire Drawing
Phosphate+Soap

Screws and Bolts
Phosphate+Oil

HVAC
Zinc phosphate

Architectural Al
Cr-free Al Treatment

Pipe Coating
Zinc phosphate

Appliances
Zinc Phosphate

Housings
Zinc Phosphate

Containers
Cr-free Al Treatment

Systems Technologies

Coil
Cleaner, Zn Phosphate
Organic Coatings

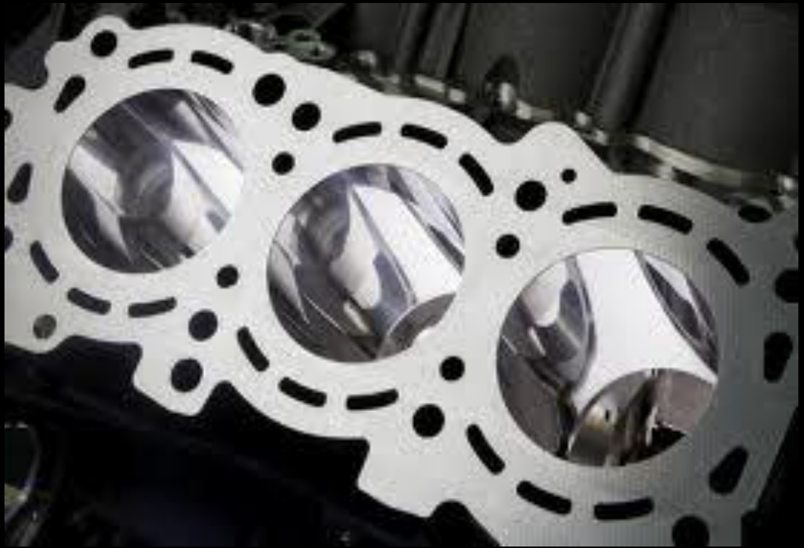
Airlines
Paint Stripper/Cleaner

Manufacture
Sealants / CIC's

Turbines
Cleaners / NDT

Off-Shore
NDT Inspection

Organic Coating

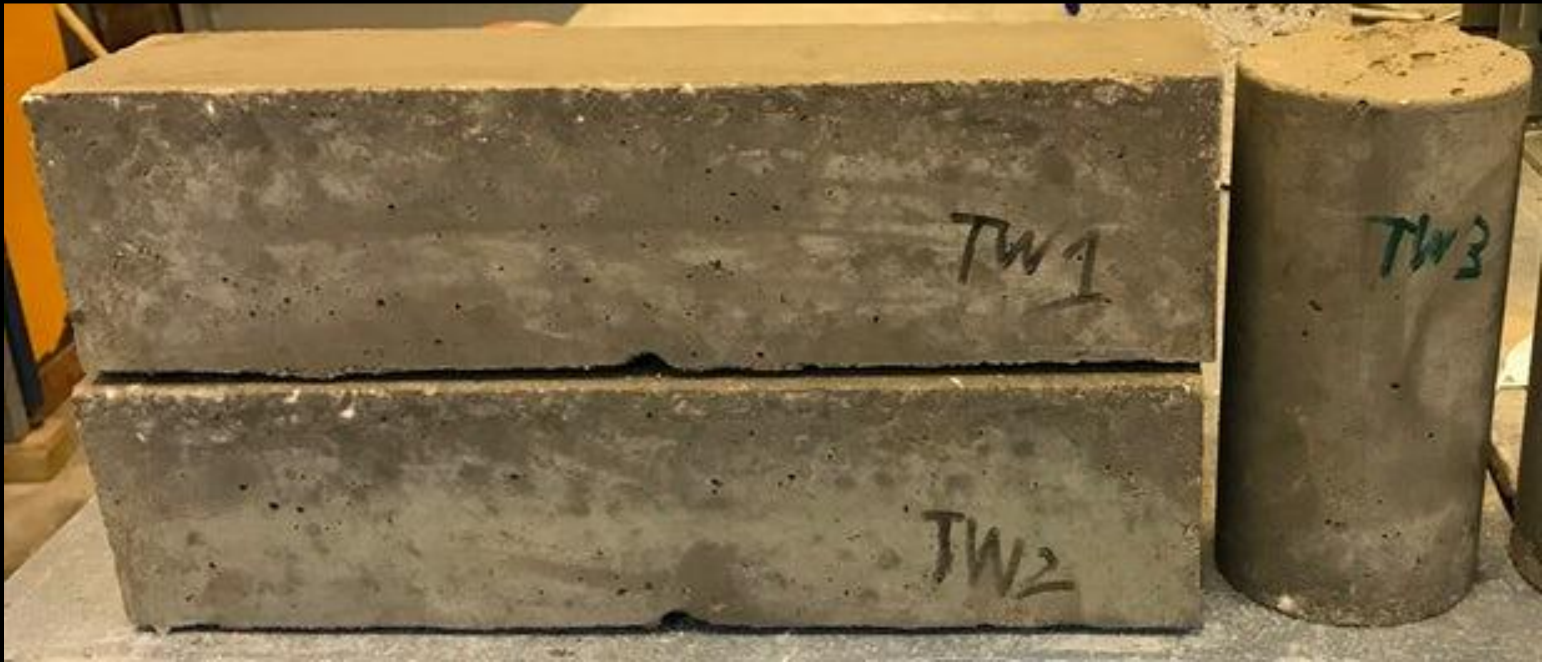


Graphene in concrete

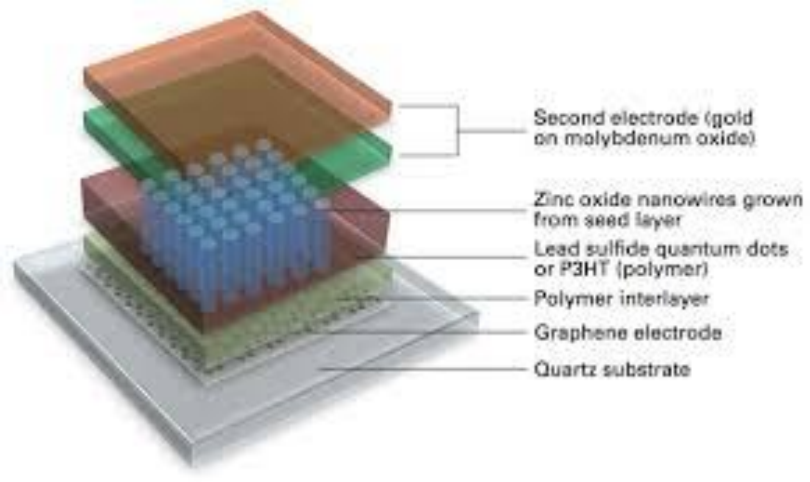
- To make the concrete, a team from Britain's University of Exeter devised a technique of suspending flakes of graphene in water, then mixing that water with traditional concrete ingredients such as cement and aggregate. The process is reportedly inexpensive, and compatible with modern, large-scale manufacturing requirements.
- When tested, the graphene-enhanced concrete was found to have a **146-percent increase in compressive strength** as compared to regular concrete, a 79.5-percent increase in flexural strength, and a decrease in water permeability of almost 400 percent. The material meets British and European standards for construction.

Graphene in Concrete

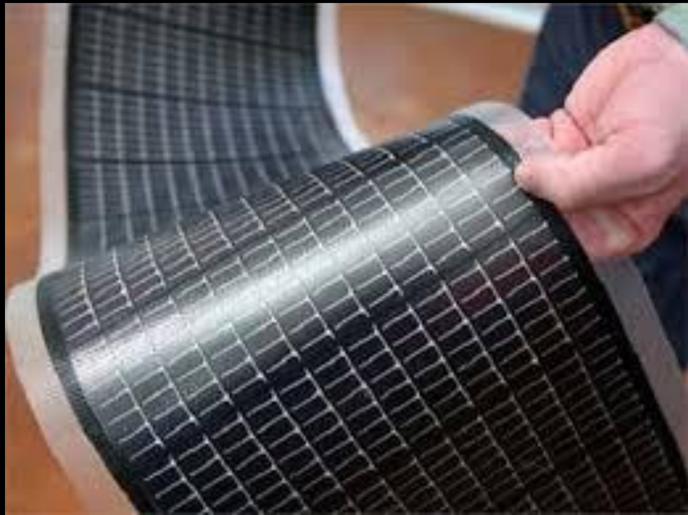
Additionally, the inclusion of graphene in the concrete reportedly allows for a reduction of about 30 percent of other materials used, including cement. The scientists state that this factor should result in a 446 kg/tonne reduction in emitted CO2.



Graphene in Traction sector



Graphene in Solar cells



Thanks