Graphene and Water Treatment

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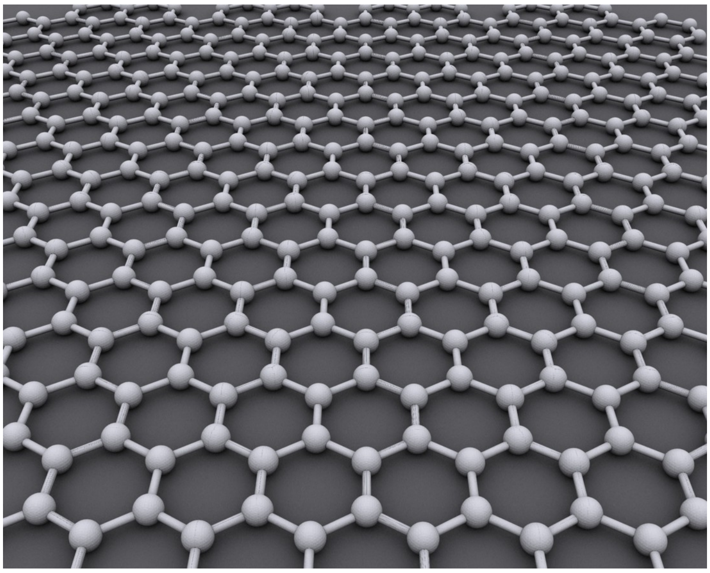

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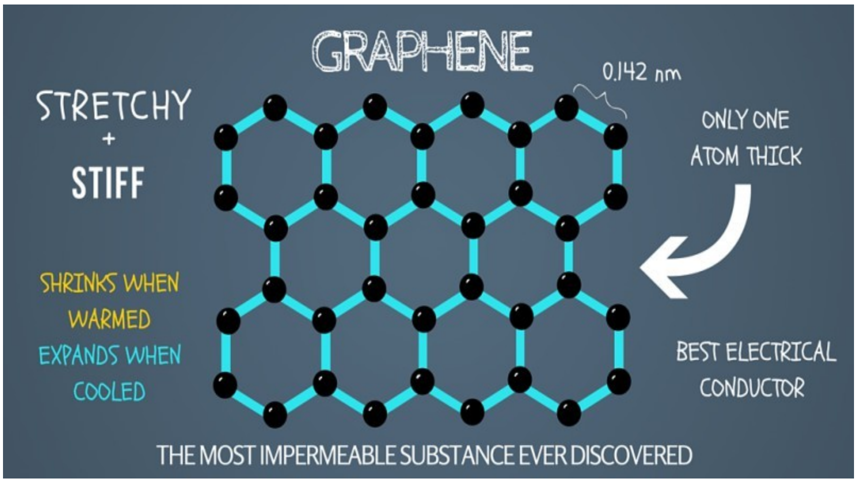
Imagine having smart water supply system with almost eternal service life, resistant to bacteria fouling, corrosion, and with the possibility to detect and degrade instantly any potentially hazardous contaminants. Could you imagine painting the walls of your building with paint and produce energy to power up your washing machine? Could you imagine that this water under movement produces more energy to power up the disinfection and treatment of this effluent and can be reused as potable water? How can these water treatment technologies be accompanied by energy storage and generation? How can water quality sensing be integrated with energy and treatment to have a self-regulated and self-powered system?

Graphene materials may play an important role soon to answer some of these questions…

1. The future is in your hands all the time.

Could you imagine you have been holding the future in your hands all your life? Well, Geim and Novosolev did so and isolated graphene from graphite using a simple tape , for the first time in 2004. Graphite is what pencils are made off and you have been using it all the time. They were awarded with the Nobel Prize for the isolation and characterization of electronic properties of graphene. Is there a Nobel prize in your pen!? Might be. But first, what is Graphene, the material everybody is talking about. Graphene is single layer of carbon atoms in a two-dimensional hexagonal lattice. Stronger than steel and highly flexible one can imagine it as a sheet of paper with a honeycomb structure made of tight carbon atoms. This enables the electrons to move highly fast as they find no resistance. One can image a perfectly smooth highway where you can drive your car without any other cars on the way. Now, if in this highway you place some trees (oxygen functional groups) all around the place and some holes on the floor (vacancies/defects) you will find a cousin of Graphene called Graphene Oxide (GO). Unlike Graphene, GO is an insulator and has a very high resistance for electrons to go through its surface. Despite this drawback, this disadvantage introduces the ability for GO to be suspended in water and to make inks. In this way, one can print, paint or coat GO almost everywhere. It is easier to handle, and it has a much lower price as it can be mass produced from natural graphite by chemical or physical methods in high quantities in comparison with the "*all mighty perfect*" cousin Graphene; and more importantly, GO can be transformed into a conductive material by simple removing its` oxygen functional groups and repairing the holes in its structure by different treatments (chemical, electrochemical in between others). At this moment, our "highway" will be almost without trees (some are impossible to remove) and although you cannot go as fast as on Graphene highway, it still allows you to drive! These properties give rise to the production of a new material called Reduced Graphene Oxide (RGO). This material, due to the re-arranged defects and the precise control of the level of oxygen functional groups, is highly reactive to molecule interactions, conductive and electrochemically active. It has enabled the production of cheap and flexible sensors, batteries (supercapacitors) that can charge and discharge very fast, enhance the functionality of solar cells or even be used for antibacterial applications. Remarkably, RGO can serve as a support network and be doped with other atoms such as boron, nitrogen, fluorine or sulfur (in between others – Graphene family is growing all the time) to give raise to new specific properties for precise applications – the road will be now doped with trees of different species. Given that these 2D family materials with different atomic structures and chemical doping can be processed as inks, we can easily construct 3D matrix structures and thus move from nano to micro and macrostructure scale. From these nanomaterials one can produce foams, sponges, or films, that can be easily handled by human hands but with exceptional properties due to its nano/micro specific structures.

As a short conclusion, depending on the specific application the three aspects mentioned above: 1) possibility to produce inks; 2) possibility of chemical doping; 3) possibility to transform the intrinsic structure into 3D micro or macro devices; opens the door to infinite configurations.



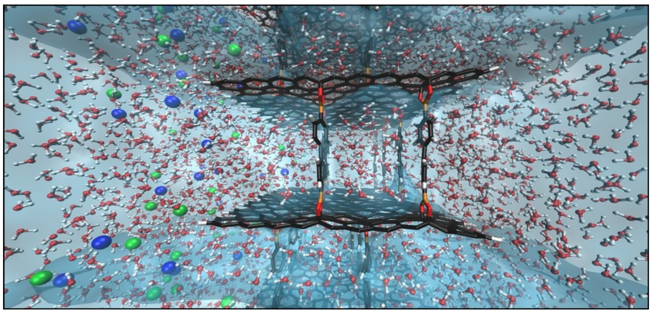
https://www.soumac.co.uk/soumacs-wow-technology-blog-graphene/

2. Graphene-based materials in water treatment.

GO and RGO have been widely explored for water treatment and one of their most investigated applications is in the production of novel filtration membranes. GO and RGO-based membranes have been used either for filtration separation by size of different molecules or for electrochemical degradation of contaminants. RGO like GO has anti-bacterial and anti-fouling properties, and additionally it can be corrosion free and even impermeable to acids depending on its microstructure. GO being suspended in water can be filtered onto a paper and used as a membrane for filtration where the oxygen atoms present produces a distance between the atomic carbon layers. This very precise interlayer distance can be tuned to let some molecules pass through it and others not – depending on the size of each; and have been applied for desalination and contaminant removal. This material has also been used to control water permeability using electricity when placed between two electrodes due to charge managing in the interlayer spacing. Using the same membrane system with RGO as an electrode, enable the degradation of contaminants using electrochemistry once they pass through. Electrochemistry is currently a trending topic for water researchers because it offers great advantages compared to existing technologies. For example, electrochemical systems are chemical-free, and use electrons as the only reagent. They are capable of degrading even the most persistent contaminants, such as poly- and perfluoroalkyl substances. RGO-based foams or other RGO macrostructures that can be atomically doped or not, are an excellent candidate for electrochemical degradation of persistent pollutants in water. Despite the remaining oxygen functional groups and disordered structure that limits the electrical conductivity, RGO foams possess additional catalytic sites to promote the degradation of persistent pollutants, (electro)sorption and removal of heavy metals, and bacteria killing. RGO foams can also be designed to be highly hydrophobic and are applied for the adsorption and removal of oil from water.

Membranes, foams, sponges, doped or not, GO or RGO -based technologies addressed above may change the way water treatment, water reuse and supply is approached considering its versatility, infinite shaping capability and easiness to handle. GO and RGO are the most versatile building blocks for the synthesis of graphene-like coatings, composites and 3D architectures. With market projections for graphene expected to significantly expand in the next 5-10 years, it is reasonable to assume that large-scale production of GO will expand, driving down costs and making it an even more economically viable option for water treatment.

Overcoming the challenge of water scarcity and pollution requires innovative approaches in water resource management, and pioneering water treatment technologies. A more localized management of the water cycle and introduction of distributed treatment systems is increasingly recognized as a promising alternative to the centralized end-of-pipe approach that has been implemented since the mid-19th century. Application of decentralized water treatment and reuse such as rainwater harvesting and greywater reuse represents an opportunity to better adapt to water shortages, unpredictable rainfall, and other consequences of climate change. Smart, low-cost technologies based on GO and RGO-based membranes, foams and sponges, with and without the application of current, can enable a sustainable and safe use of alternative water sources, making us less dependent on the centralized water and energy grid, and minimizing the environmental impact of our water consumption.



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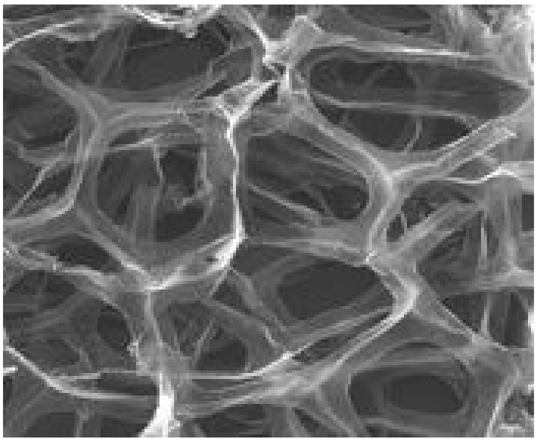
3. **What next?**

In addition to water-based applications, graphene-based materials have been the focus of interest in the field of supercapacitors, solar cells, sensors, energy storage/harvest devices and actuators (shape-shifting materials). RGO-based sensors can, in one printed device (personalized to the proposed structure or environmental reality) simultaneously determine pressure, motion, humidity, temperature, changes in pH, and the presence of bacteria; vital parameters for monitoring of water and wastewater treatment and distribution systems. Monitoring and treatment systems need typically to be powered by electricity, which is where another peculiarity of RGO becomes significant: it can produce small quantities of energy by water motion, humidity gradient and pressure or it can increase existing renewable energy technologies efficiency. The energy produced can be stored in fast charge/discharge supercapacitors, to power-up low energy-dependent devices such as sensors or signaling transmission networks. Energy, sensing, and water treatment added to the mechanical properties of graphene-based materials such as flexibility and strength opens the door to incorporate these in hard to reach systems. Self-powered multi-tasking graphene-based devices for environmental monitoring, and water and wastewater treatment, will be a huge step forward and may play a game-changing role in our slow but inevitable transition towards a more sustainable world. Water research industry has typically been much less inclined towards this kind of disruptive research. emerging academic research or spin-off companies face a long way to make reach the market and substitute existing technologies. Although, the ease of integration, the different functionalities in one single device can be a major force to push this research into day-life applications and as a supplement to nowadays solutions. With the evolution of IoT, 5G and AI, real-time online monitoring will be a step forward to avoid problems like pipe leakage or detection of hazardous compounds that have been spilled into the water system or even bacteria/virus variations on the water streams. Putting all together, one can imagine advanced de-centralized water treatment and monitoring using modular systems that are versatile, can either treat and detect and in the same way be energy efficient or energy independent. Overall, the possibility to apply these systems in different world sights/ realities, either for populations with high economical input or for hard to reach, rural communities will make a progress in water accessibility and re-use.

Although much research is still needed to reach higher energy generation through graphene based devices, and to lower the energy consumption of electrochemical water treatment systems using more efficient electrocatalytic structures, the combination of these properties with the unlimited ability to shape, paint, or pattern these structures in existing or futuristic architectures, will have a huge impact on the way we see water treatment. Design, Architecture, Science coming together with Society imagination and creativity for re-designing how we use water treatment at a personal level with personalized and energy efficient platforms will be a goal to reach. Giving tools to society and making people be the engineers of their own water treatment systems will change our relationship with water and address some of the society´s major challenges related to the environmental footprint of water treatment and management, making our planet more sustainable. Will Graphene perform a game-changing roll in this near future? We cannot predict. But questions and solutions will rise from the infinite possibilities it puts on the table. Thus, society will evolve.



https://www.nature.com/articles/472138c

Can you imagine you can print your own water purification system? You can start doing so.

ACKNOWLEDGMENTS:

- *Authors acknowledge the support from the Economy and Knowledge Department of the Catalan Government through Consolidated Research Group (ICRA-TECH - 2017 SGR 1318)*