HYDROGRAPH

FRACTAL GRAPHENE™

How HydroGraph's Unique Graphene Delivers Unprecedented Performance At Minimal Addition Rates

Tom Eldridge
Director of Business Development

Contents

HYDROGRAPH

Executive Summary

HYDROGRAPH

Executive Summary

The industrial materials landscape is on the cusp of a significant transformation with the emergence of Fractal Graphene™. This white paper examines HydroGraph's breakthrough in graphene production—a clean, consistent, and scalable process that yields high-purity graphene with unique fractal morphology.

Unlike conventional graphene production methods that struggle with purity, consistency, and environmental impact, HydroGraph's chamber explosion synthesis delivers exceptional quality material with remarkable performance across multiple industries. The combination of high purity, nanosized lateral dimensions, and fractal aggregate structure of this graphene enables unprecedented performance improvements at addition rates 10–100 times lower than conventional graphene products, fundamentally transforming the value proposition and economic viability of graphene technology.

For forward-thinking businesses seeking competitive advantage through advanced materials, Fractal Graphene™ represents an opportunity to enhance product performance, reduce material usage, lower costs, and minimize environmental footprint with minimal addition rates from as little as 0.001% by weight. HydroGraph's Fractal Graphene™ finally delivers on the long-awaited promise of graphene as a transformative material for industry.

Introduction

HYDROGRAPH

Introduction

The Graphene Promise vs. Reality

Since its discovery in 2004, graphene has been heralded as a "wonder material" with transformative potential across industries due to its extraordinary physical properties.

Graphene is a single layer or collection of weakly associated single layers of sp^2 bonded carbon atoms arranged in a two-dimensional hexagonal lattice. These unique structural characteristics create a material with exceptional electrical conductivity, mechanical strength, thermal conductivity, and barrier properties.

However, two decades after its discovery, graphene's commercial adoption has been limited by a fundamental problem: **the value proposition has not been compelling enough.**

HYDROGRAPH

Key Barriers

The key barriers to widespread industrial adoption of graphene include:

Low purity

Most products fail to meet ISO standards for what actually constitutes "graphene". Furthermore, defects and contaminants introduced during conventional production processes compromise material properties and performance.

Inconsistent quality

Many commercial production methods yield inconsistent product batch to batch, with materials often deviating from declared specifications, leading to unreliable results in the end-application.

Poor performance-to-cost ratio

The cost of incorporating graphene hasn't been offset by proportional performance improvements, largely due to quality and consistency issues.

Sustainability issues

Many production methods have significant environmental footprints due to high energy consumption and the use of harsh chemicals.

Application challenges

Difficulty in achieving uniform dispersion and delivering reliable results in real-world applications.

These limitations have created a market where graphene's potential remains largely unfulfilled for most applications. Industries need a breakthrough that delivers consistent, high-performance graphene with a clear return on investment to justify adoption.

HydroGraph's Revolutionary Approach

HYDROGRAPH

HydroGraph's Revolutionary Approach

Chamber Explosion Synthesis

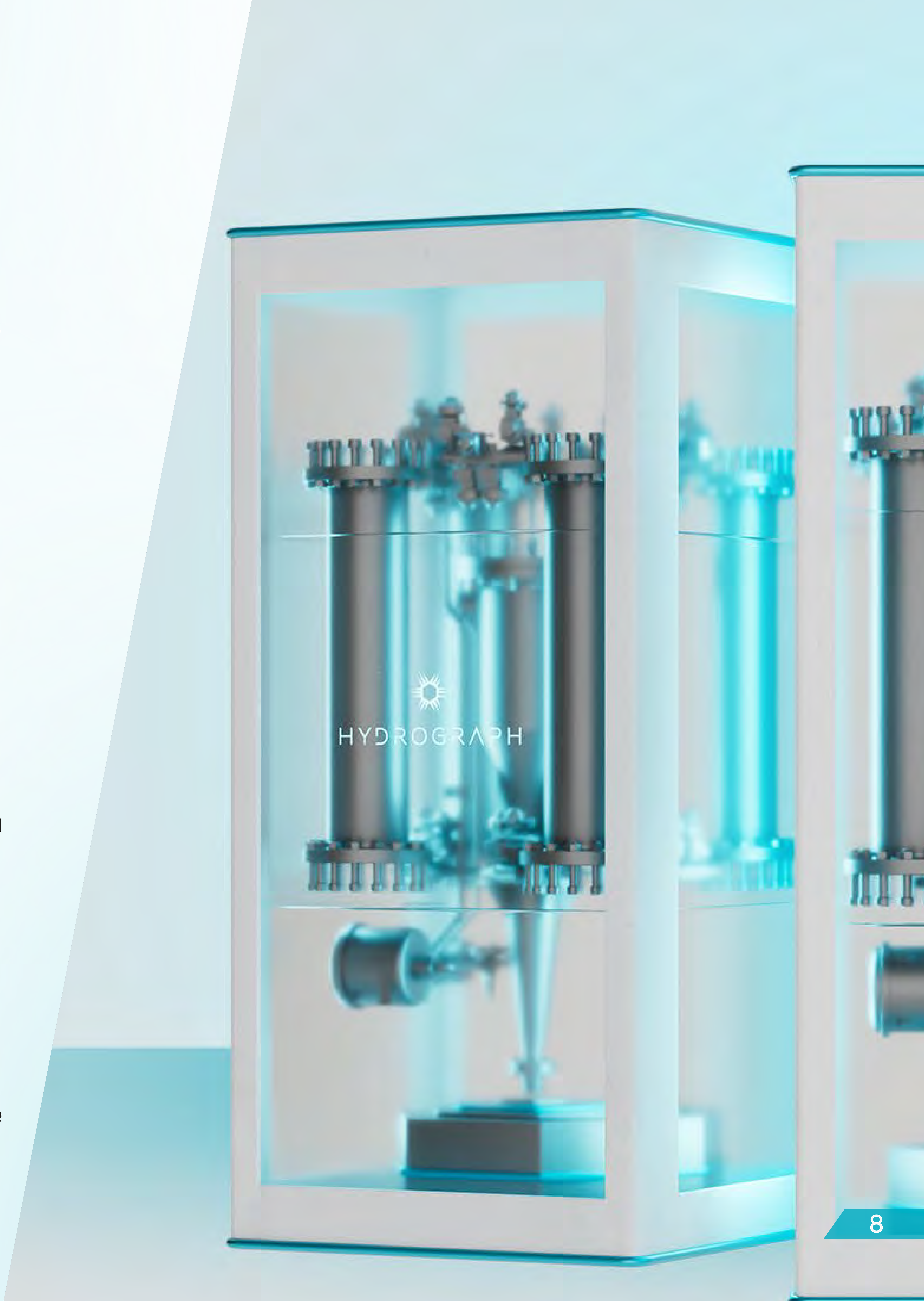
HydroGraph has developed a fundamentally different approach to graphene production through chamber explosion synthesis. This process represents a paradigm shift in graphene manufacturing with several key advantages:

The Process

The chamber explosion method employs a deceptively simple process:

1. A fuel-rich mixture of acetylene and oxygen is fed into a multi-liter, constant-volume metal chamber.
2. Once filled to one bar absolute pressure, an electrical spark ignites the mixture.
3. The resulting exothermic reaction creates a graphene aerosol with syngas (hydrogen and carbon monoxide) as a byproduct.
4. Within seconds, the graphene aerosol is collected in a hopper.

This process is exothermic, meaning the precursor materials bring the energy necessary to convert themselves to graphene—a stark contrast to the energy-intensive methods typically used in graphene production.



The Science Behind the Process

The chamber explosion process can be understood in three distinct phases:.

1 Chemical Reaction	Fuel-rich oxygen/acetylene mixtures react following the equation: $xC_2H_2 + yO_2 \rightarrow 2(x - y)C + 2yCO + xH_2$ This creates carbonaceous soot in less than a millisecond.
2 High-Temperature Transformation	The closed chamber reaches temperatures of approximately 2500K. This extreme heat crystallizes amorphous soot into multi-layer graphene. The high temperature purifies the material by driving off volatile compounds.
3 Fractal Aggregation	Small graphene particles diffuse via Brownian motion, randomly collide, and stick together. This forms ramified aggregates with a self-similar, fractal structure. The resulting material has a unique fractal dimension of 1.8 at the smaller scale and 2.5 at the larger scale.

The entire process occurs in seconds, with the high-purity Fractal Graphene™ ready for collection almost immediately.

HydroGraph has successfully scaled this breakthrough process to commercial production levels, with manufacturing operations certified according to ISO 9001 quality management standards, ensuring consistent product quality and reliable supply for industrial customers.

Fractal Graphene™ Aggregate

HydroGraph produces two primary types of Fractal Graphene™ aggregate with distinct properties:

FGA-1

Very dark, black, hydrophobic powder

Bulk mass density: 70-100 mg/cc

BET specific surface area: 150 m^2/g

Lateral dimensions: 20-50 nm

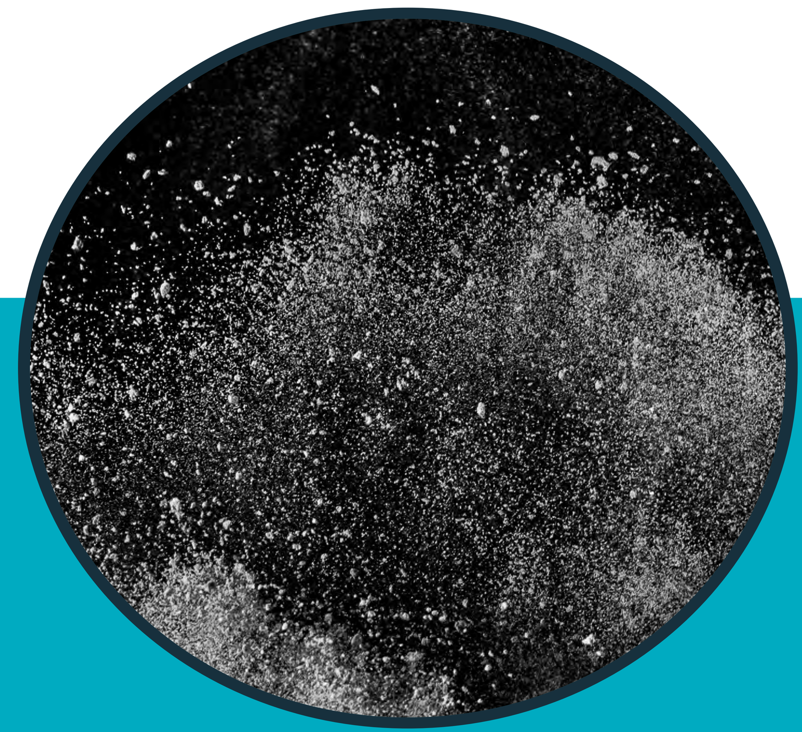
Thickness: 2-3 nm (average 6 graphene layers)

Composed of fractal aggregates of monomers(primary particles)

99.8% carbon, 0.2% oxygen with no PAHs

100% sp^2 carbon structure

No volatiles up to 700°C



FGA-2

Grey, hydrophobic powder

Bulk mass density: 130-200 mg/cc

BET specific surface area: 25 m^2/g

Lateral dimensions: 75-200 nm

Thickness: ~10 nm (average 32 graphene layers)

Composed of fractal aggregates of monomers (primary particles)

98.6% carbon, 1.35% oxygen with trace hydrogen, with no PAHs

80% sp^2 carbon structure

No volatiles up to 700°C

Reactive Graphene Aggregate

HydroGraph has also developed a precisely functionalized variant called Reactive Graphene Aggregate. The RGA-COOH-1 product is functionalised specifically with carboxylic groups to facilitate covalent bonding with the matrix materials it can be incorporated into. Other functionalities can also be developed and produced on request.

RGA-COOH-1

- Dark, black, hydrophilic powder
- BET specific surface area: 165 m^2/g
- Lateral dimensions: 10-50 nm
- Thickness: 2-3 nm (average 5 graphene layers)
- Composed of fractal aggregates of monomers (primary particles)
- 96.3% carbon, 2.1% oxygen, 1.6% hydrogen, no PAHs
- Surface decorated with carboxylic acid (-COOH) functional groups
- Enables rational organic and materials chemistry for covalent bonding

Comparing Fractal Graphene™ Quality to Conventional Graphenes

HydroGraph's Fractal Graphene™ addresses persistent quality challenges that plague other commercial graphene production methods:

Production Method	Common Issues	HydroGraph FGA
Liquid Phase Exfoliation (LPE)	Residual surfactants, edge oxidation from sonication	Ultra-pure carbon content (99.8%), completely crystalline with Sp^2 structure intact. Controlled gas-phase process, no metallic impurities, no intercalated ions, no residual surfactant chemistry, minimal oxygen presence (0.2%). Uniform dimensions, tight tolerances with control and customisability on morphology
Reduced Graphene Oxide (rGO)	5-15% oxygen content, irreparable structural defects	
Mechanical Exfoliation (Ball Milling & Shear Mixing)	Thick graphite-like material, wide distribution of particle dimensions, edge oxidation, and metal contamination	
Electrochemical Exfoliation	Residual intercalated electrolyte ions, edge oxidation	
Reactive Thermal Expansion	Thick graphite-like material, wide distribution of particle dimensions, non-uniform defect content, oxygen containing groups and edge defects	

The presence of unintended functional chemistry, metallic impurities, residual surfactant, and unwanted structural defects is a severely limiting factor when it comes to the commercially available graphene products that have existed in the market for the last several years. In some cases of course, functional groups and defects might be desirable for specific applications, but these ought to be precisely controlled and engineered, so that the product can be tailored to the application, and not inherently arising from the production method.

The Fractal Advantage

What truly sets HydroGraph's graphene apart is its unique fractal aggregate structure, which no other commercial graphene possesses. This structure provides several critical advantages:

1 Exceptional Dispersion

The nanoscale, fractal nature facilitates uniform distribution throughout host materials.

2 Lower Percolation Threshold

Fractal structure creates efficient networks at ultra-low concentrations.

3 Superior Interfacial Bonding

Expanded surface area maximizes interaction with matrix materials.

4 Lack of Pores

Unlike other graphenes, FGA has a non-porous structure that optimizes its performance.

5 Nano-Scale Dimensions

FGA-1 particles are significantly smaller (20–50 nm) and far more uniform than other commercial graphenes (typically 0.5–100 μm)

These advantages translate into higher performance in end-applications, with much lower concentrations of Fractal Graphene™ being required compared to conventional graphene nanoplatelets (GNP). In many cases, Fractal Graphene™ can be incorporated at addition rates of 10 to 100 times less than other graphene materials, for the same or better effect. This totally transforms the value proposition for graphene into an economically viable and indeed commercially attractive technology solution.

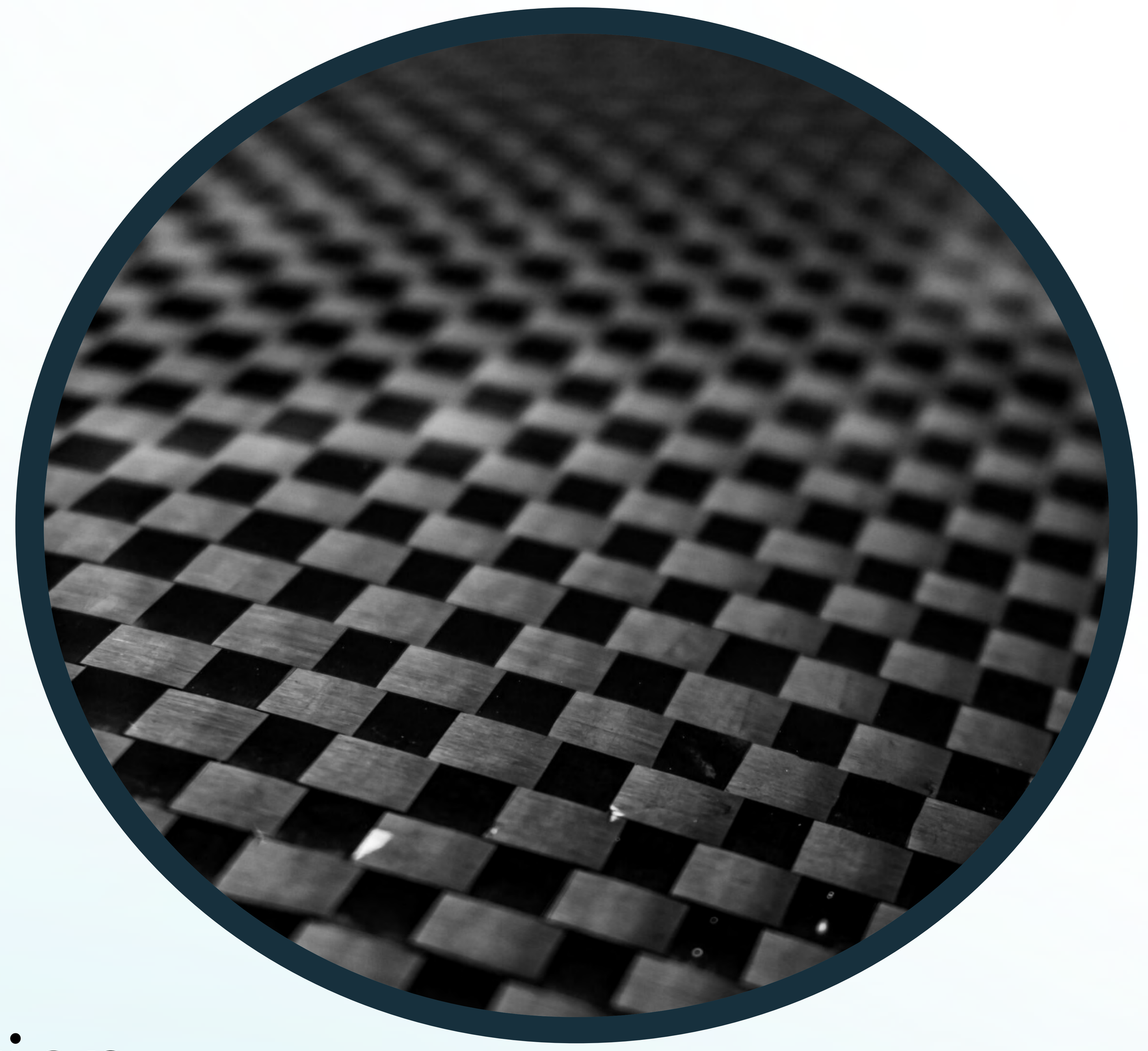
Performance Across Industrial Applications

HYDROGRAPH

Performances Across Industrial Applications

HydroGraph's Fractal Graphene™ delivers remarkable performance improvements across multiple applications, often at ultra-low concentrations from as little as 0.001% by weight. Key applications include:

Thermoset Resins



- Addition of just 0.05 wt% FGA-1 to generic-grade epoxy resins resulted in:
  - 23.5% increase in stiffness.
  - 32.3% improvement in strength at break.
  - 51% enhancement in elongation at break.
- Unique ability to simultaneously improve stiffness, strength, and elongation.
- Ideal for high-performance applications in aerospace, automotive, and construction.

Conventional GNP equivalent: 0.5-5.0 wt%.

For similar mechanical property improvements in epoxy resins, conventional graphene nanoplatelets typically require loadings of 0.5-5.0 wt%. Research shows that 1 wt% conventional GNP in ductile epoxy increases tensile strength by 41% and tensile modulus by 19% when properly dispersed, but often fails to simultaneously improve stiffness, strength, and elongation as Fractal Graphene™ does.[1]

Performances Across Industrial Applications

Thermoplastics

- Ultra-low 0.0015 wt% FGA-1 in blow-molded PET bottles produced:
  - 23% increase in top load compression strength.
  - 83% reduction in water vapor transmission rate.

- For polyethylene with 0.01 wt% FGA-1:
  - 30% improvement in strength at break.
  - 69% increase in elongation at break.
  - 60% enhancement in tensile toughness
  - Nano-fiber pull-out observed in fracture morphology, indicating significant energy absorption and crack propagation resistance.

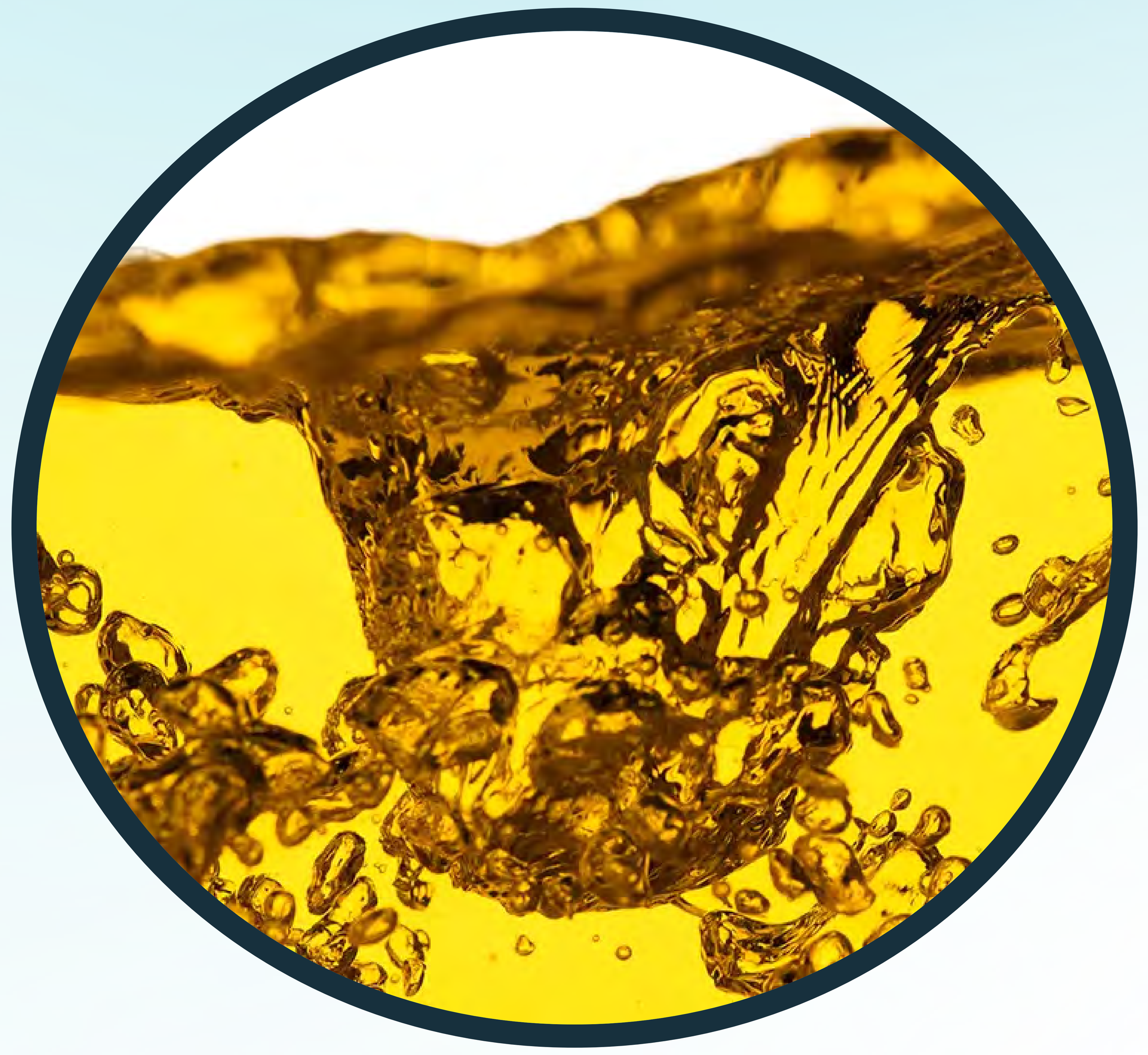
Conventional GNP equivalent: 1.0-3.0 wt%.

To achieve similar barrier and mechanical properties in thermoplastics, conventional GNPs typically require concentrations of 1.0-3.0 wt%. Research on PET with conventional graphene nanoplatelets demonstrated that 2 wt% GNPs are needed to achieve comparable reductions in gas transmission with approximately 24% increase in tensile strength.[2]

Performances Across Industrial Applications

Lubricants

- Addition of 0.01 mg/mL FGA-2 to base oil:
  - Maintained low friction factor 24 times longer than base oil alone.
  - 55% reduction in friction factor.
  - 70% decrease in wear.
- Significant potential to extend component lifespan, reduce energy losses, and enhance efficiency.



Conventional GNP equivalent: 0.25-1.0 mg/mL.

For comparable tribological improvements, conventional graphene products typically require concentrations of 0.25-1.0 mg/mL in lubricating oils. Studies found that tribological properties deteriorate when conventional GNP concentration exceeds 0.1%, with wear, seizure load, and friction coefficient rapidly increasing beyond this threshold. Research has shown maximum friction and worn area reductions of only 20-36% with conventional GNPs at concentrations much higher than required with Fractal Graphene™.[3]

Performances Across Industrial Applications

Energy Storage

- In lead-acid batteries, a 60:40 blend of FGA-1 and reduced graphene oxide showed 47% increase in charge acceptance over acetylene black.

- In supercapacitors, hybrid electrode material incorporating a tiny addition of FGA-1 demonstrated 4x increase in device capacitance compared to high-surface-area activated carbon[4].

Conventional GNP equivalent: 3-10 wt%.

For similar energy storage performance enhancements, conventional graphene materials typically require loadings of 3-10 wt% in electrode materials. Studies on lead-acid batteries show that conventional graphene additives require concentrations above 5 wt% to achieve meaningful improvements in charge acceptance.

Construction

Ultra-low dosages (≤0.04% by mass of cement) of FGA-1 and RGA-1 in cementitious materials:

- Enhanced early-age compressive strength by over 70%.
- Improved later-age strength by 20%.
- Reduced porosity by more than 50%.
- Accelerated hydration and improved rheological properties.

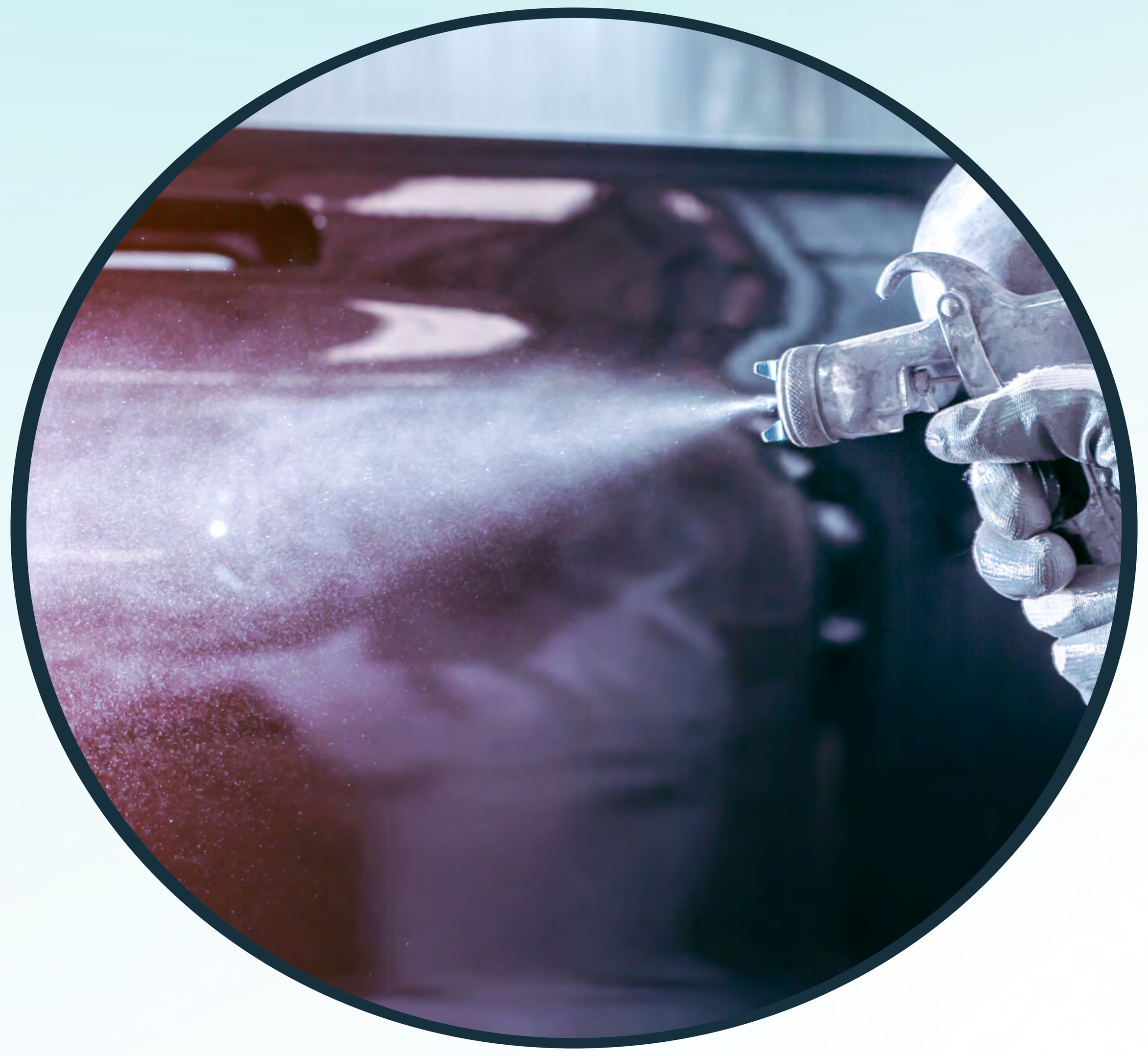
Conventional GNP equivalent: 0.05-0.5% by mass of cement.

Conventional graphene nanoplatelets in cementitious materials typically require 0.05-0.5% by mass of cement to achieve notable improvements in mechanical properties and durability. Research shows conventional GNPs can decrease total porosity from 18.35% to 17.01% at 0.05 wt%, while flexural strength increases by 15-24% with the same loading, but compressive strength increases by only 3-8%, significantly less than the improvements seen with Fractal Graphene™.[6]

Performances Across Industrial Applications

Coatings

• Water-based protective coatings with FGA-1 on copper last more than twice as long as commercial paints in salt spray tests.



In polyurethane-based coatings with 0.5 wt% FGA-1:

- 95% gloss retention after 1000 hours of UVA exposure (vs. 88.4% in controls).
- Minimal color change.
- Fewer defects and superior wear resistance.

Conventional GNP equivalent: 1.0-5.0 wt%.

For comparable protective and UV-resistant coating performance, conventional graphene nanoplatelets typically require loadings of 1.0-5.0 wt%. Research on protective coatings shows that conventional graphene materials are typically incorporated at 2-3 wt% to achieve meaningful improvements in durability and UV resistance, significantly higher than the loading required with Fractal Graphene™.

Comparative Loading Levels

This table summarises how HydroGraph's Fractal Graphene™ achieves equivalent or superior performance at significantly lower loading levels than conventional graphene nanoplatelets across all applications.

Application	Property Enhancement	HydroGraph Fractal Graphene™	Conventional GNPs	Loading Effectiveness
Thermoset Resins	Improved stiffness, strength, and elongation simultaneously	0.05 wt% FGA-1	0.5-5.0 wt%	10-100x more effective
Thermoplastics (PET)	Enhanced compression strength and barrier properties	0.0015 wt% FGA-1	1.0-3.0 wt%	667-2000x more effective
Thermoplastics (PE)	Superior strength, elongation, and toughness	0.01 wt% FGA-1	1.0-3.0 wt%	100-300x more effective
Lubricant	Reduced friction and wear, extended lubrication life	0.01 mg/mL FGA-2	0.25-1.0 mg/mL	25-100x more effective
Energy Storage	Enhanced charge acceptance and capacitance	60:40 blend of FGA-1/rGO	3.0-10.0 wt%	30-100x more effective
Construction Materials	Increased strength and reduced porosity	≤0.04% by mass of cement	0.05-0.5% by mass	1.25-12.5x more effective
Coatings	Improved UV resistance and corrosion protection	0.5 wt% FGA-1	1.0-5.0 wt%	2-10x more effective

Sustainability Advantage

HydroGraph's process stands out for its environmental benefits:

- **Lowest carbon footprint:** Exothermic process requires minimal energy input, the lowest of any graphene production process, resulting in the lowest carbon footprint of any graphene production process.
- **Reduced material usage:** Lighter, stronger materials obtained as a result of incorporating Fractal Graphene™ reduce the total amount of materials used in the manufacture of parts, resulting in more responsible products that are more resource efficient.
- **Clean production:** Simple precursors and production process with minimal waste and no harsh chemicals involved.
- **Enhanced recyclability:** Can replace conventional additives that hinder recycling, as the addition rate of Fractal Graphene™ is many orders of magnitude lower (as low as 0.001%) than macroscopic additives.
- **Reduced end-product emissions:** Lighter, stronger and more durable products manufactured by adding Fractal Graphene™ enable lower consumption of materials, and lower fuel consumption in transportation, resulting in reduction in embedded CO2 throughout the product lifecycle.

Commercial Approach and Vision

HydroGraph approaches customer collaboration through a structured, consultative process:

1. Discovery: Understanding customer needs and objectives.
2. Review: Establishing criteria for success.
3. Validation: Demonstrating clear value through supported technology evaluation.
4. Negotiation: Developing commercial terms and supply agreements.

Depending on customer requirements, HydroGraph offers:

- Graphene powder supply
- Custom dispersions and intermediates
- Application development expertise

HydroGraph's vision centers on driving material change through widespread industrial adoption across sectors where its ultra-pure, consistent product provides clear performance enhancements. The company sees graphene evolving from a niche material to an essential industrial additive, with HydroGraph's Fractal Graphene™ becoming the industry gold standard.

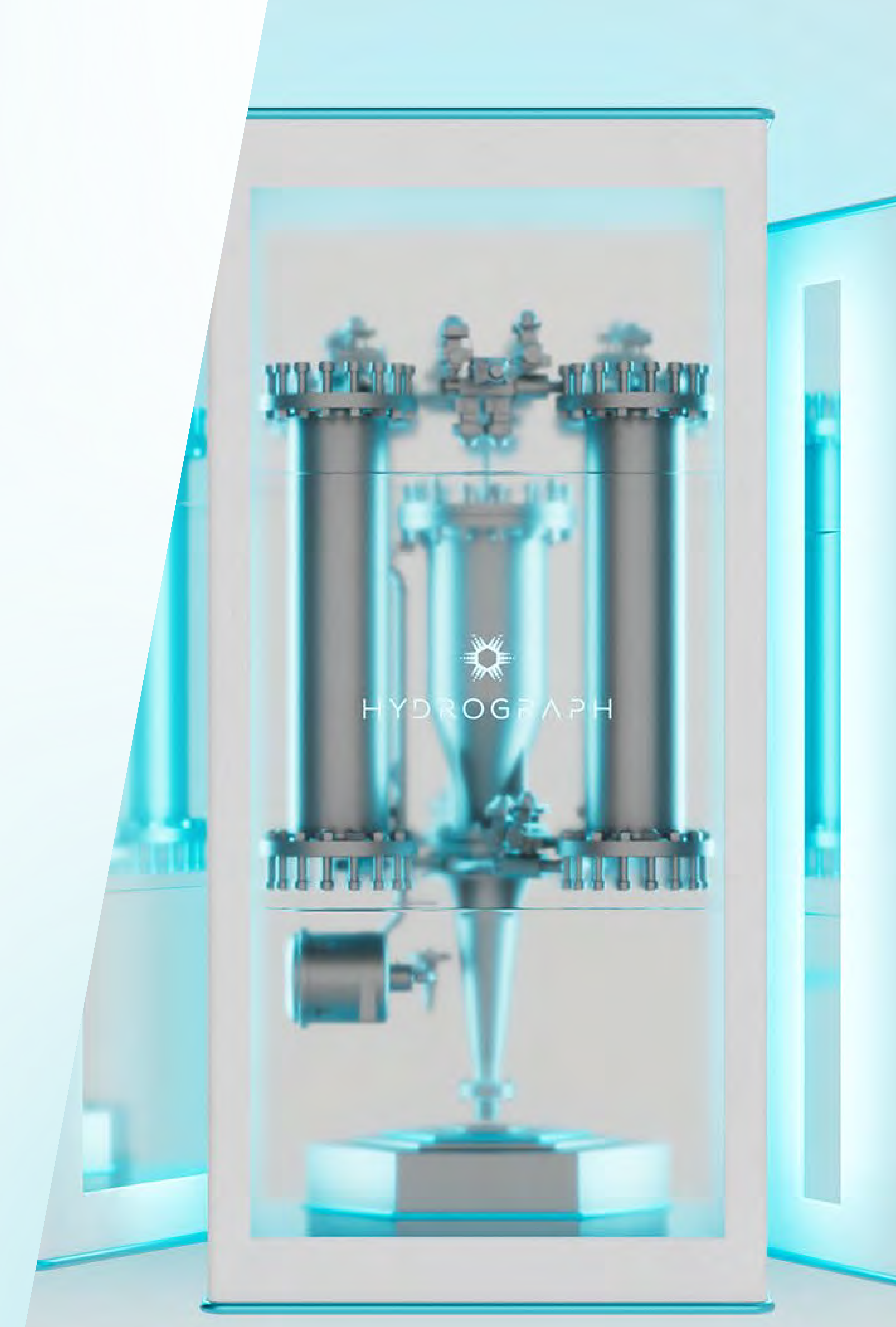
The Fractal Future

HydroGraph's Fractal Graphene™ aggregate represents a significant breakthrough in advanced materials—a graphene that's pure, consistent, sustainably produced, and delivers exceptional performance at ultra-low concentrations. For forward-thinking businesses willing to innovate, FGA offers immediate opportunities to:

- Enhance product performance .
- Reduce material and energy consumption.
- Lower environmental impact.
- Save costs.

The fractal structure—unique to HydroGraph's graphene—provides performance advantages that cannot be replicated by conventional graphenes. As industries increasingly seek sustainability by doing more with less, Fractal Graphene™ stands ready to transform the way products are formulated and manufactured.

Contact HydroGraph today to discuss how Fractal Graphene™ can enhance your products and processes.



References

- [1] Tensile properties of graphene nanoplatelets/epoxy composites fabricated by various dispersion techniques. Construction and Building Materials, 2019.
- [2] Improvement of Gas Barrier Properties of Polyethylene Terephtalate (PET) by Graphene Nanoplatelets (GNP). ResearchGate, 2019.
- [3] Comparison between thermophysical and tribological properties of two engine lubricant additives: electrochemically exfoliated graphene and molybdenum disulfide nanoplatelets. PubMed, 2020.
- [4] Dissanayake et al., Enhanced Performance of a Supercapacitor by Addition of Turbostratic Fractal Graphene to an Activated Carbon Electrode. Graphene Innovation and Technology, 2025.
- [5] Surehali et al., Rheology and early-age structure development in binary and ternary blends modified with novel graphene types. Cement and Concrete Composites, 2025.
- [6] Investigation of the Mechanical Properties and Microstructure of Graphene Nanoplatelet-Cement Composite. PMC, 2017.

Thank You

For more information, please contact:

Tom Eldridge
HydroGraph Director of Business Development

- tom.eldridge@hydrograph.com
- +44 (0) 77 2371 2956