# Graphene and Composite Materials

The Graphene Council

Research, Development and Application

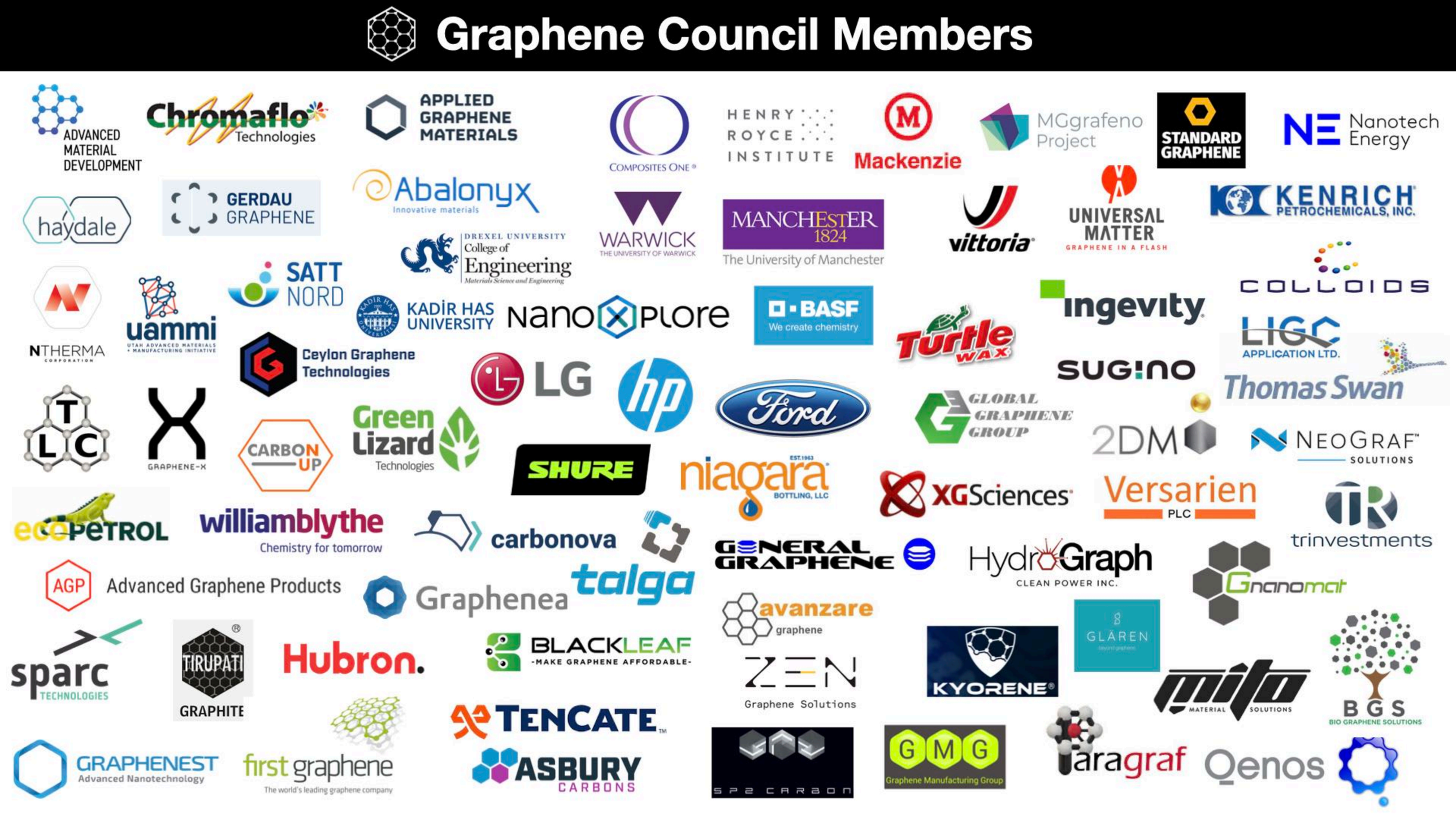
**The purpose of this webinar is to:**

- **Understand the critical supply chain for different types and grades of graphene materials and composites systems.**
- **Become aware of the range of plastics, polymers, and epoxies that graphene may be suitable for to enhance their properties.**
- **Stimulate a discussion about how to address potential obstacles to greater adoption of graphene enhanced composites.**

# The Graphene Council

- The largest and oldest trade body for the graphene sector
- Includes the entire value chain, from raw materials to end-users
- More than 30k material scientists from academia and commerce
- Partnerships with leading industry sectors connecting hundreds of thousands of engineers and product developers, world-wide

# Graphene Council Members

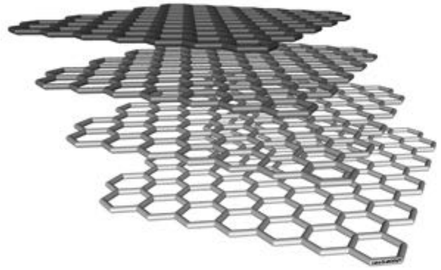


# Types of Graphene Materials Used in Composites

# Forms of Graphene

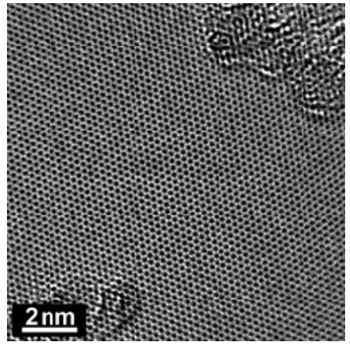
## Definitions

- Graphene is a two dimensional (i.e. one atom thick) planar sheet of $sp^2$-bonded carbon atoms in a dense honeycomb shaped crystal lattice.



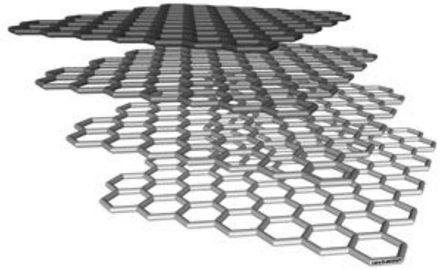
- Graphene has extraordinary material properties including ultimate tensile strength of 130 gigapascals, electron mobility of 15,000 cm2·V−1·s−1, thermal conductivity between 2000–4000 W m−1K−1 and optical transparency of 97.7%. (Eric Pop, 2012) (Sheehy DE, 2009)

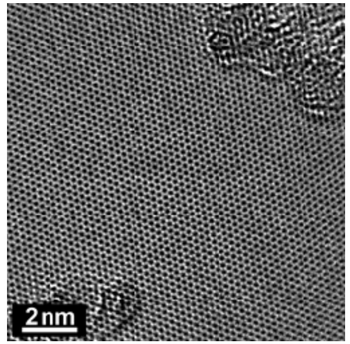
- ISO/TS 80004-13:2017(en) Nanotechnologies — Vocabulary — Part 13: Graphene and related two-dimensional (2D) materials. Recognizes material up to and including 10 carbon layers as “graphene”.



# Superlatives of Graphene

- thinnest imaginable material
- strongest material ever measured (theoretical limit)
- stiffest known material (stiffer than diamond)
- most stretchable crystal (up to 20% elastically)
- record thermal conductivity (outperforming diamond)
- highest current density at room temperature
- highest intrinsic mobility (100 times more than in Si)
- conducts electricity in the limit of no electrons
- lightest charge carriers (zero rest mass)
- impermeable (contains He atoms)





# Graphene Materials

- **A wide range of materials in the commercial market are currently referred to as “graphene”.**

| Number of Carbon Layers | Description |
|---|---|
| 1 | CVD, Mono-layer or “Pristine” Graphene |
| 1 - 3 | Very Few Layer Graphene (vFLG) |
| 2 - 5 | Few Layer Graphene (FLG) |
| 2 - 10 | Multi-Layer Graphene (MLG) |
| > 10 | Exfoliated graphite or “Graphene nanoplatelets” (GNP) |

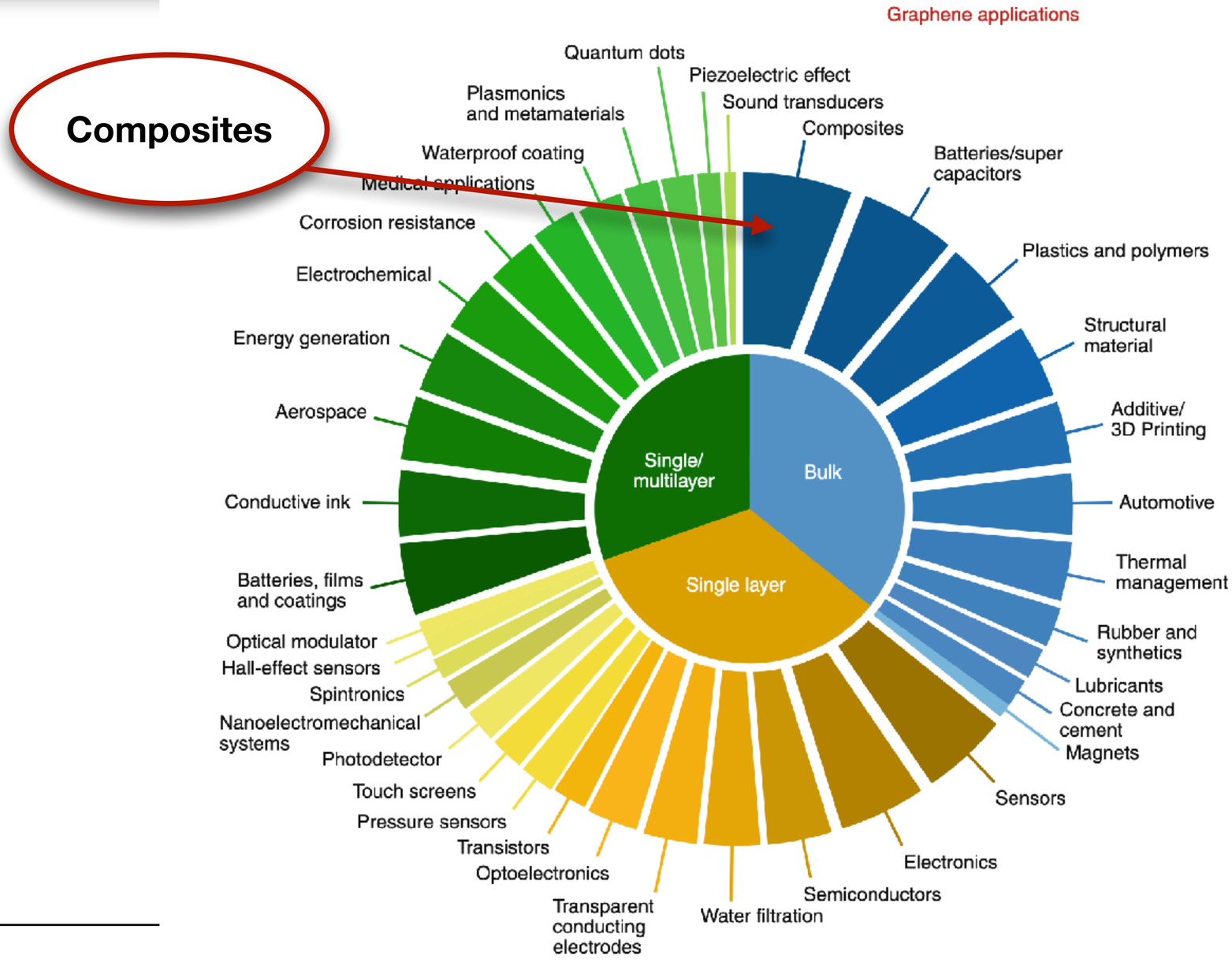
# Forms of Graphene

- **In addition to the number of carbon layers, additional characteristics define the material.**
  - **Graphene Oxide (GO) - a compound of carbon, oxygen and hydrogen (typically approx. 65% carbon / 35% oxygen by weight).**
  - **Reduced Graphene Oxide (rGO) - Graphene Oxide in which removes much of the oxygen content resulting in approximately 95% carbon by weight.**
  - **Graphene Powder, Solution or Paste - Graphene material can be prepared in various physical forms including as a dry (usually black) powder, in solution (e.g. water or alcohol) or in a paste form (often as a dull reddish brown color).**
  - **Graphene Nano Platelets (GNPs) - GNPs typically have thickness of between 1 nm to 3 nm and lateral dimensions ranging from approximately 100 nm to 100 µm.**
  - **Functionalized Graphene - Chemical functionalization (adding specific elements to the surface or edges of the graphene) is important in many applications where untreated graphene would be difficult or impossible to work with.**

# Graphene Applications

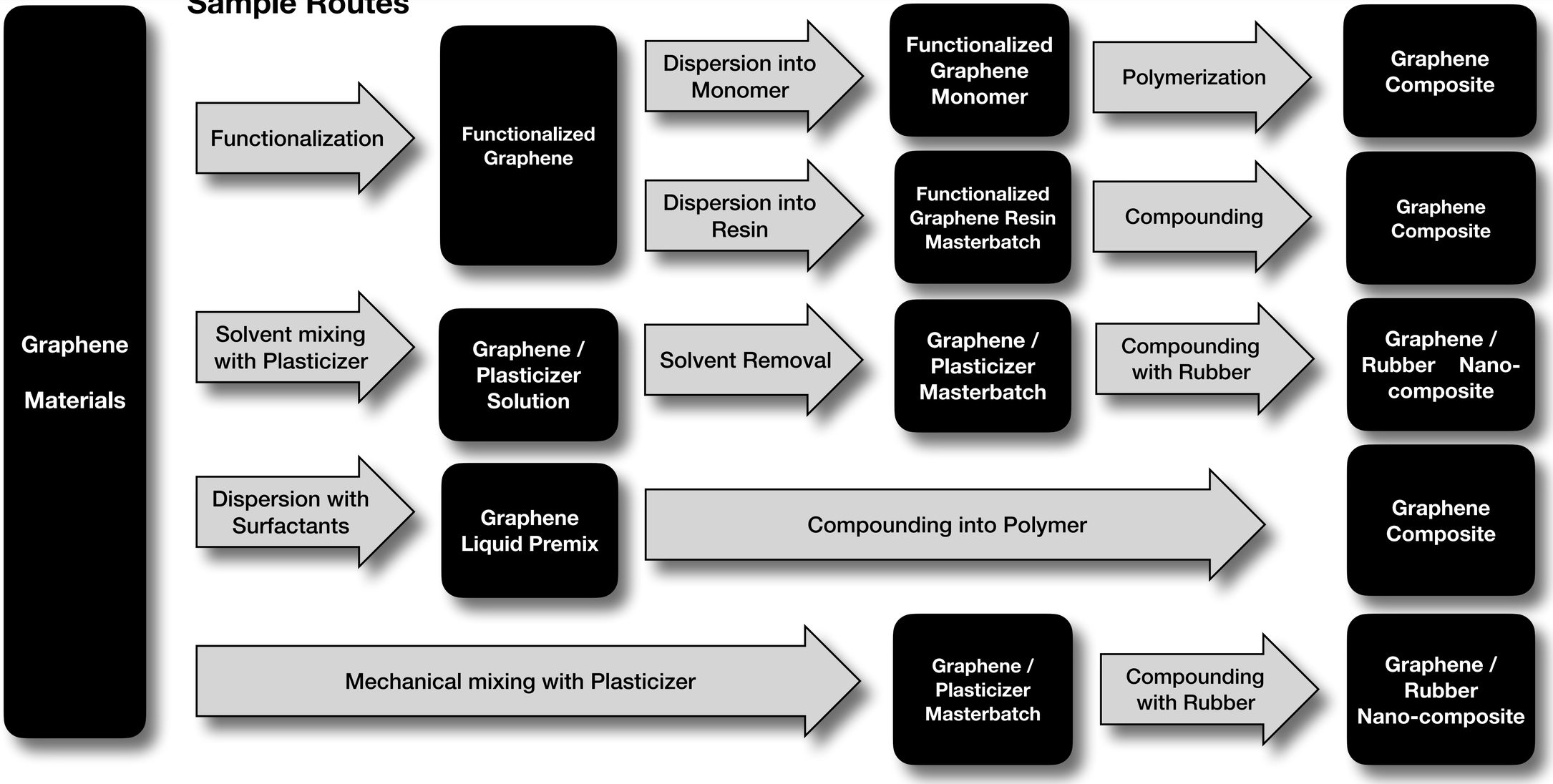
**Of the more than 40 major applications areas for graphene, ‘Composites’ form the largest single application area.**

**The type of graphene most suited for composites will be “bulk” or multi-layer materials**



# Graphene Dispersion Routes

## Sample Routes

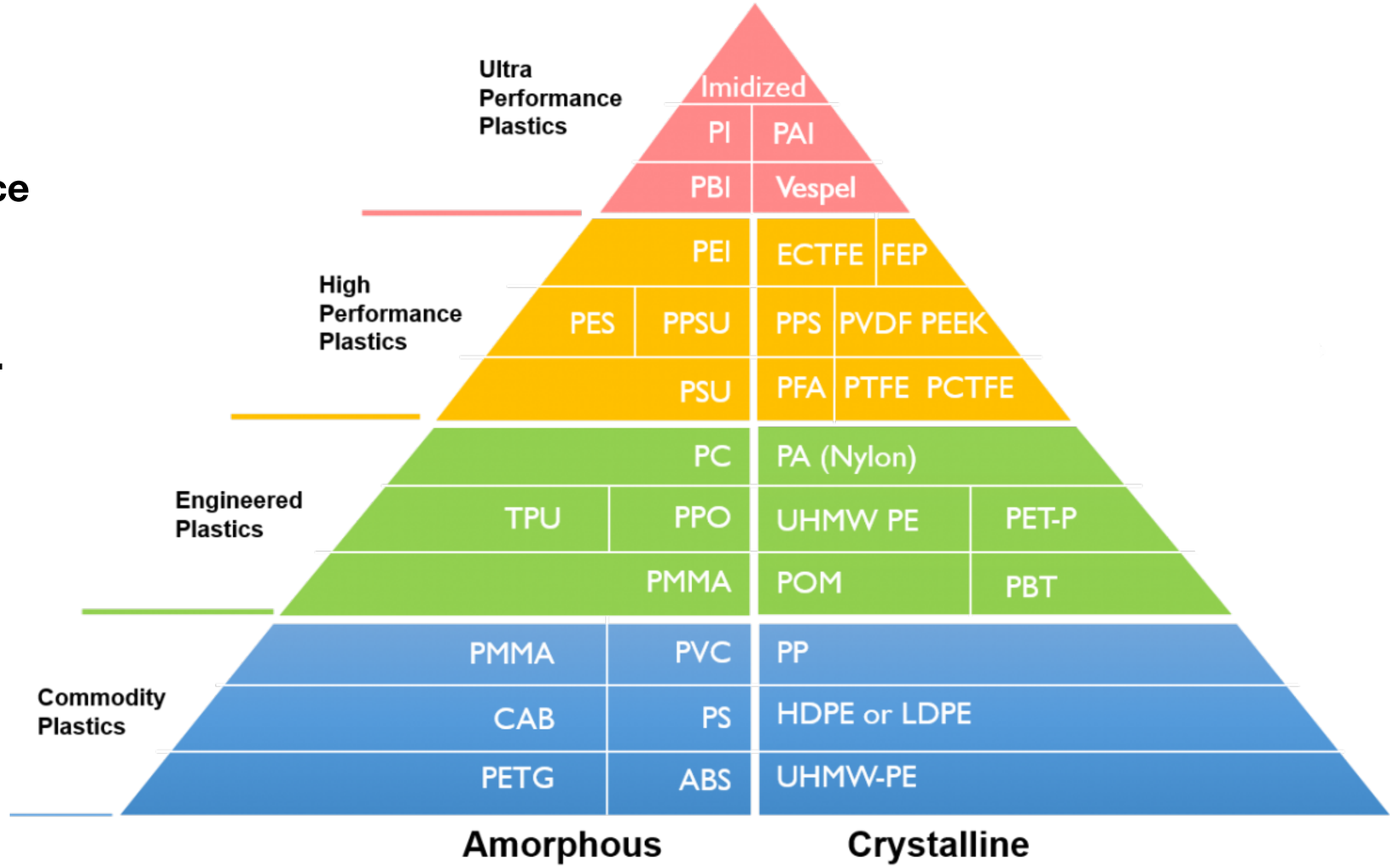



Sources: Fullerex Ltd. and Cealtech Inc.

# Application Areas

## Plastics

**Graphene can be used to enhance performance in a wide range of polymer systems including, Thermosets and Thermoplastics.**



# Composite Applications

Graphene is used to enhance performance in a wide range of applications;

- Aerospace
- Automotive
- Sports Equipment
- Marine
- Rubber
- Plastics
- 3D printing
- Coatings and Barriers
- Polymers and Epoxies
- Carbon Fibre Reinforced Polymer (CFRP)
- Glass Fibre Reinforced Polymer (GFRP)

# Material Performance Characteristics

## Performance Improvement Targets

**Graphene is used to provide enhanced performance metrics;**

- **Electrical Conductivity**
- **Thermal Managment**
- **UV Protection**
- **Longer Wear**
- **Anti-Static**
- **Weight Reduction**
- **Robustness, Stiffness**
- **Mechanical Reinforcement**
- **Impact Performance**
- **Flexibility**
- **Barrier Properties**
- **Sensors (Enabling)**
- **Barrier Properties**
- **Fire Retardation**

MANCHESTER 1824
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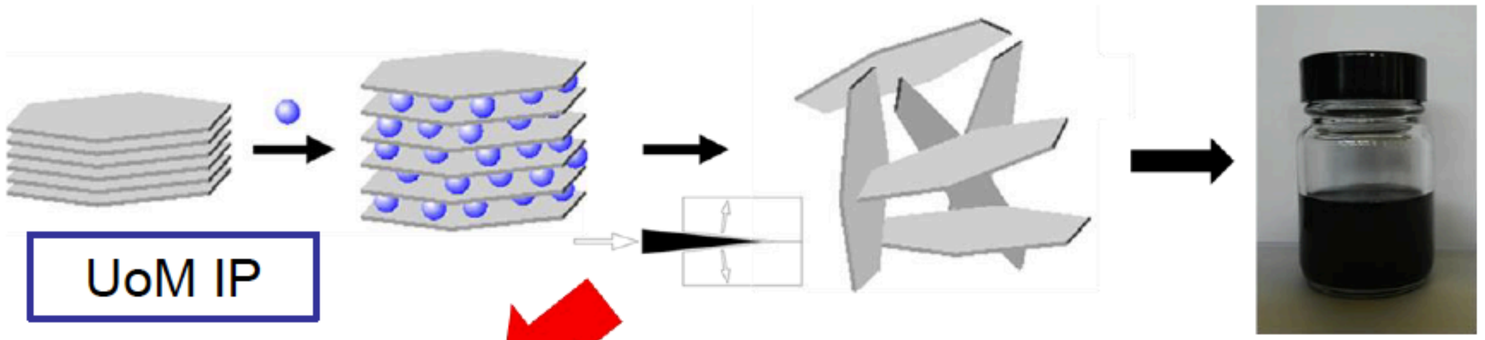
National Graphene Institute

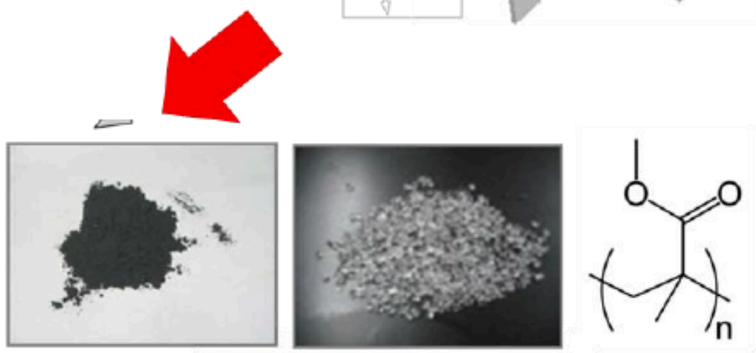
# Injection moulded PMMA–graphene composites

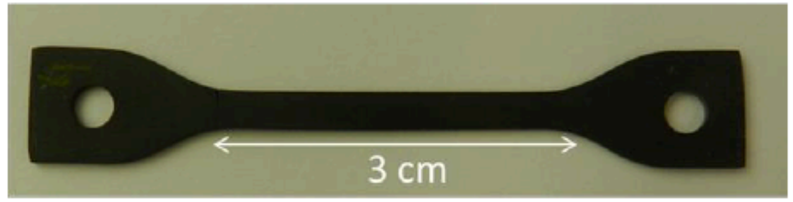
**Graphene can be added to Thermoplastics with a twin screw extruder.**

**Lateral flake size of the graphene can have an impact on viscosity.**

**<5 µm flakes have little impact while >20 µm flakes will increase viscosity**




- Melt processing of composites using standard compounding and injection moulding.

## Application Case Study:

# Automotive

**XG**PU **Foams**

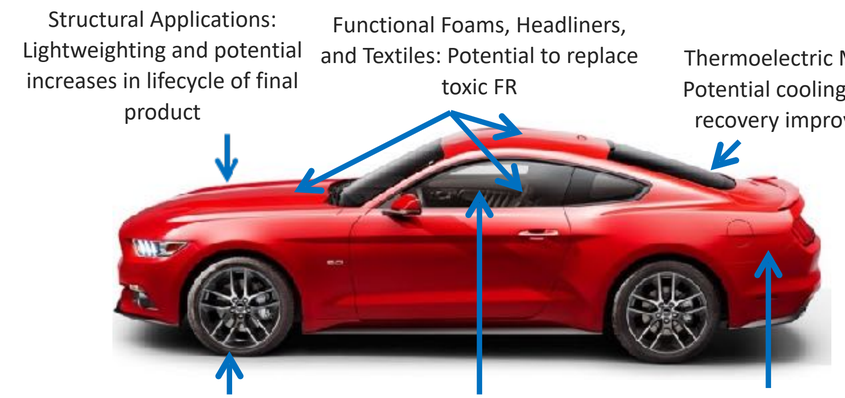
Multiple performance improvements in PU foam application, enabled by the addition of xGnP®

xGSciences + Ford Go Further

## Graphene-Enhanced PU Foams

- **Improved compression strength by 20%**
- **Improved NVH (noise & vibration) by 17%**
- **Improved heat deflection temperature by 30%**

### Parts in Production

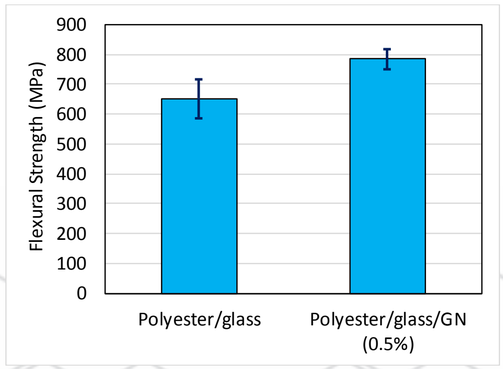



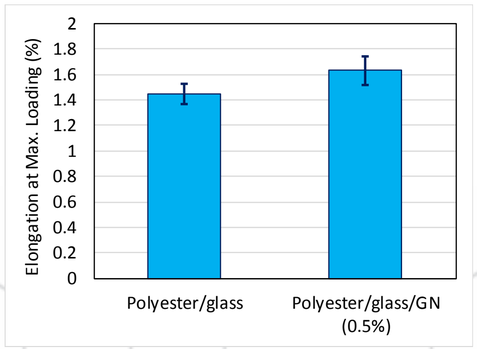
# Graphene Pultrusion: Case Study

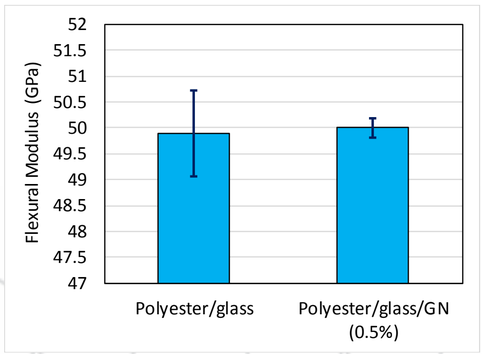
Improvements: >20% in flexural strength and >12% in the elongation only by addition of **0.5% graphene** to polyester/glass rods.

**ASTM D790**

| | Flexural Strength (Mpa) | SD | Elongation at max Loading (%) | SD | Modulus (GPa) | SD |
|---|---|---|---|---|---|---|
| Polyester/glass | 651.22 | 66.06 | 1.45 | 0.08 | 49.9 | 0.83 |
| Polyester/glass/GN (0.5%) | 784.24 | 34.96 | 1.63 | 0.11 | 50 | 0.19 |




**polyester/glass**

**polyester/glass/GN (0.5 wt%)**

Industrial Volume

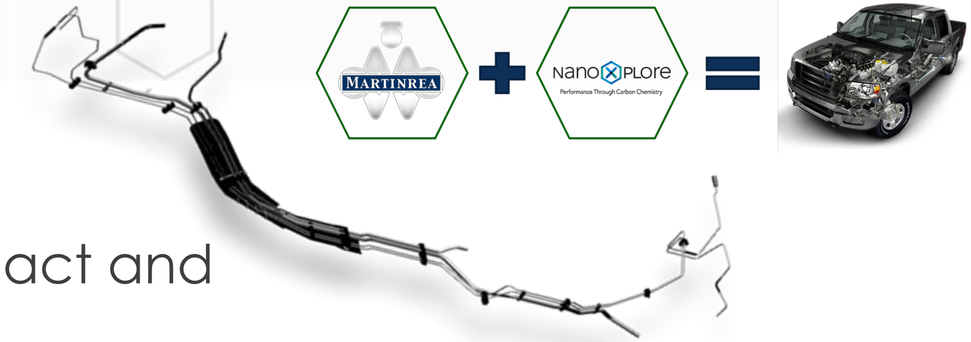
Proprietary Technology

Low-Cost

# Graphene Enhanced Coatings

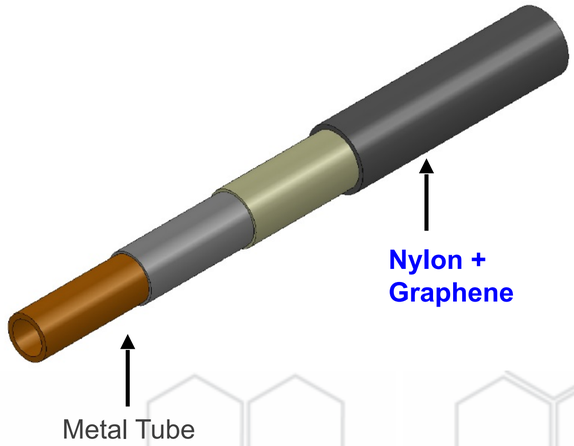
**Abrasion Resistance:**

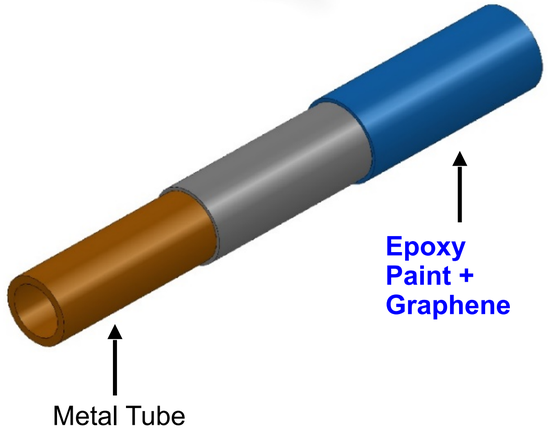
- Nylon / Graphene
- Epoxy / Graphene
- Improve robustness of coating to resist impact and abrasion conditions




**Corrosion Protection:**

- Improving the barrier to salt water solution penetration to base steel
- Prolonged component life




Industrial Volume

Proprietary Technology

Low-Cost

# Graphene Application Examples

## Aecom uses graphene by Versarien to 3D print an arch support structure

Aecom has produced a graphene arch using additive manufacturing techniques intended to reduce the time and cost of installing digital signalling systems and transform the digitization of transport networks.

The 4.5-meter high (approx. 14 feet), lightweight arch is being tested on outdoor track at Network Rail's workforce development center in Bristol, UK.

Aecom has partnered with UK engineering firm Scaled to develop the detailed design and prototypes of the CNCTArch using large-scale 3D-printing techniques. Scaled uses its 3D printer, one of the largest in Europe, to print the product in the new graphene-reinforced polymer, which is supplied by Aecom's materials partner Versarien plc.

# Graphene Application Examples

**Haydale graphene-enhanced prepreg has now been incorporated in the composite tooling and automotive body panels of the new 'BAC Mono R'.**

**Utilisation of graphene-enhanced tooling materials offers the potential for significant improvements in the following aspects:**

- **The coefficient of thermal expansion (CTE) – is more closely matched when using composite tooling. A key issue with the use of metal tooling is a significant mismatch in (CTE)**
- **The need for superior quality – higher dimensional stability tooling is increasing the demand for composite tooling**
- **Current composite tools also suffer from a finite life - wearing of the tool surfaces and microcracking. The use of graphene has the potential to increase the life of the tools.**

**50% improvement in tensile strength and stiffness**

# Graphene Application Examples

GRAPHENE PRODUCT CASE STUDY

dassi

GRAPHENE ENHANCED CFRP FOR A LIGHTER, FASTER RACING BIKE

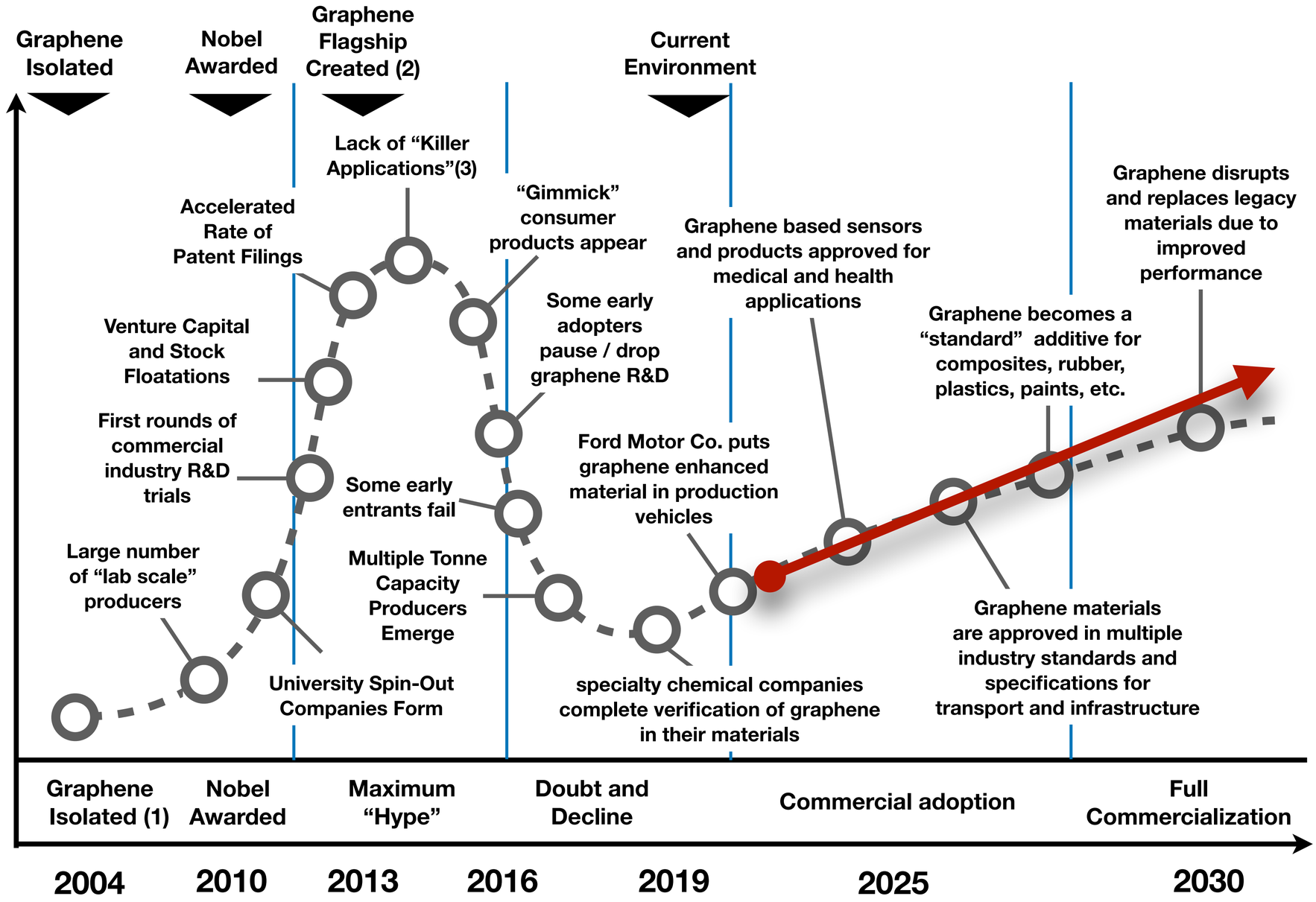
50% ⬆ FRACTURE TOUGHNESS

30% ⬇ LIGHTER

70% ⬆ INTER-LAMINAR SHEAR STRENGTH


*The Dassi Interceptor Graphene weighs just 750g, but records the same stiffness and strength characteristics of a 950g carbon fibre frame*

# The Graphene “Hype Cycle”




1) “Electric Field Effect in Atomically Thin Carbon Films”, K. S. Novoselov et. al, Science, Vol. 306, Issue 5696, pp. 666-669 (2004)

2) The Graphene Flagship is a 10 year, Euro 1 billion program sponsored by the European Union.

3) Focus was on the development of never before possible applications made entirely out of graphene, such as a “space elevator”

**Note:**

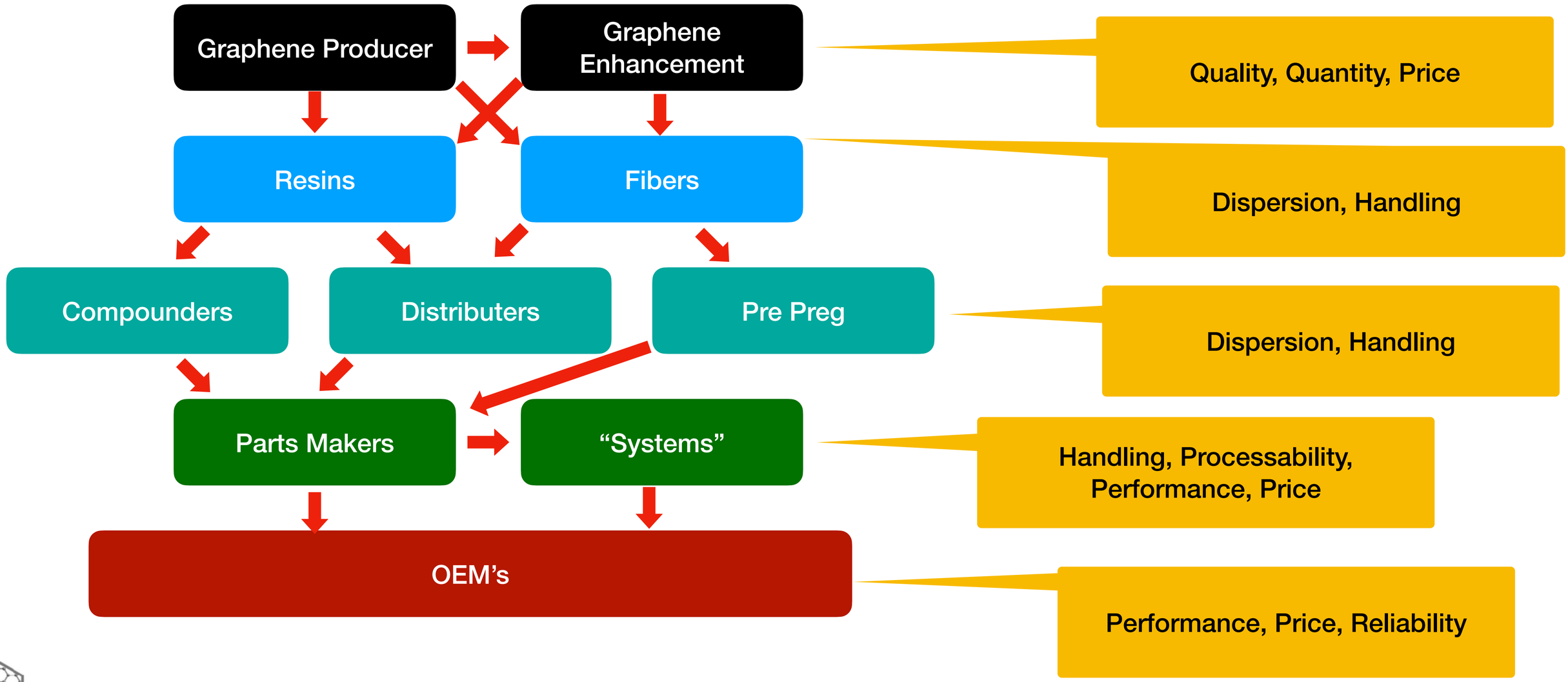
The evolution of a “hype cycle” is not uniform and is a gradual process where stages often overlap.

The dates indicated are based on our observations of the global graphene research and production environment.

Some geographic markets and industry sectors move faster than others and are therefore at different stages accordingly.

Source: The Graphene Council

# Composites Supply Chain



# Graphene Enhanced Composites Testing Project

## Objectives

We are comparing a standard resin system that is commonly used to produce composite parts and that has been enhanced with different forms of graphene in order to measure changes in;

a.) tensile and stiffness,
b.) flex,
c.) impact toughness,
d.) compression strength and
e.) inter-laminar shear.

## Partners

The project is an initiative of The Graphene Council and is enjoys the support and collaboration of ChromaFlo, Composites One, and the American Composites Manufacturers Association (ACMA).

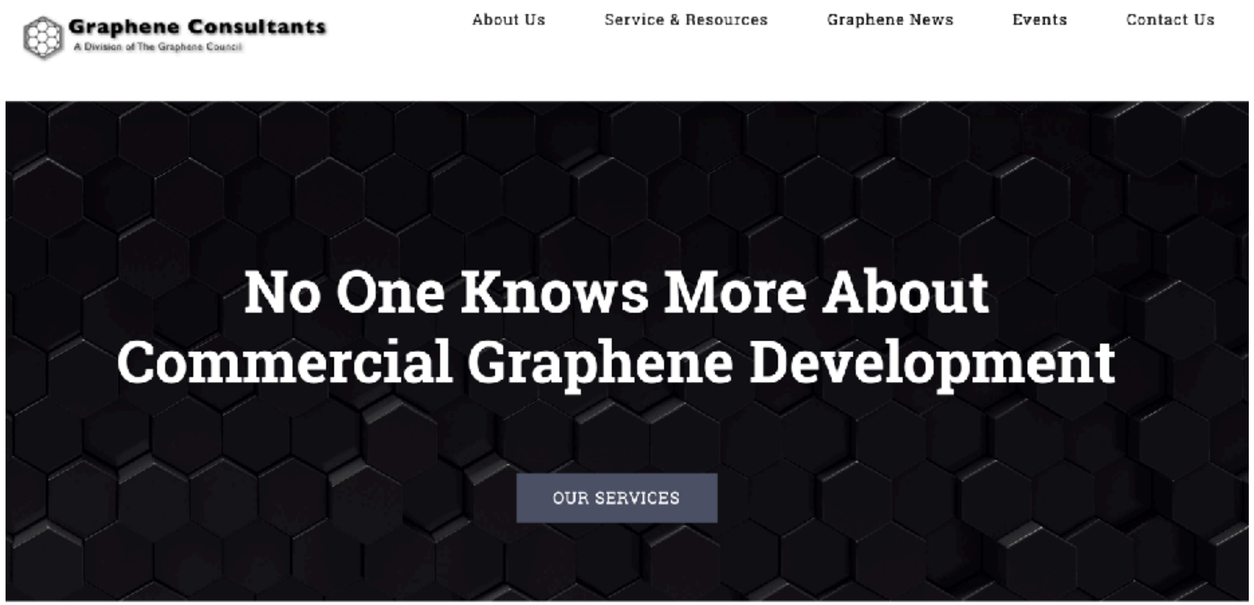
ASTM D790 - FLEX MODULUS

| Graphene Sample | Graphene Specifications | Load Factor 0.0% | | | Load Factor 1.0% | | | Load Factor 0.5% | | | Load Factor 0.1% | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Neat | GF | CF | Neat | GF | CF | Neat | GF | CF | Neat | GF | CF |
| Material A | Graphene Oxide 35%O | | | | | | | | | | | | |
| Material B | GNPs 10-20 layer | | | | | | | | | | | | |
| Material C | FLG functionalized | | | | | | | | | | | | |
| Material D | rGO 5%O | | | | | | | | | | | | |
| Material E | MLG 3-9 layers | | | | | | | | | | | | |

# How The Graphene Council Can Help

The Graphene Council

- Company Membership gives you access to industry intelligence, market reports and supplier / application development matchmaking support.
- Custom advisory services available with graphene experts from academia and industry, world-wide.
- Verified Graphene Producer™ and Verified Graphene Product™ programs.

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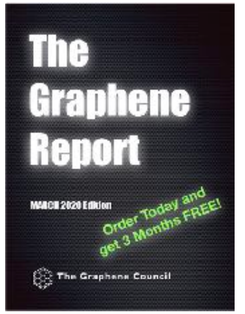
# Join The Graphene Council!


## Valuable Member Benefits

- Weekly Graphene Intelligence - Commercial, Research & Patents
- Global network of 25k+ material scientists and engineers
- Discounts on industry events and trade shows

- **THE GRAPHENE REPORT*** **(more than 600 pages!)**

- Production Methods and Processes
- Characterization techniques
- Types of commercial graphene materials
- Graphene Market Pricing data
- Review of current standardization efforts
- Applications
- Commercial Markets
- Profiles of 200 graphene producers



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