



The Role of Functionalisation in the Graphene Supply Chain

HVM Graphene 2014, Oxford
15/05/2014

Haydale evolution



Haydale set up 2003

Innovative Carbon Ltd. (ICL) purchased Haydale in May 2010

- Invested £5m to January 2014 to support expansion and growth
- Process patent applications in 2009-2012. International phase started
- Significant work on CNTs
- Added mined graphite in November 2011
 - Production of Graphene Nano Platelets (“GNPs”)
- New bespoke facility for processing nano materials opened in May 2011
- Market testing on UK conductive Graphene based ink in June 2013
 - No metal additives, 20 ohms/sq, coverage 550 cm²/gm
- Current functionalisation of nano particles: up to 1 tonne
- Functionalisation process positively reported on by NPL
- ISO 9001 accreditation Jan 2014
- Launched IPO 14th April



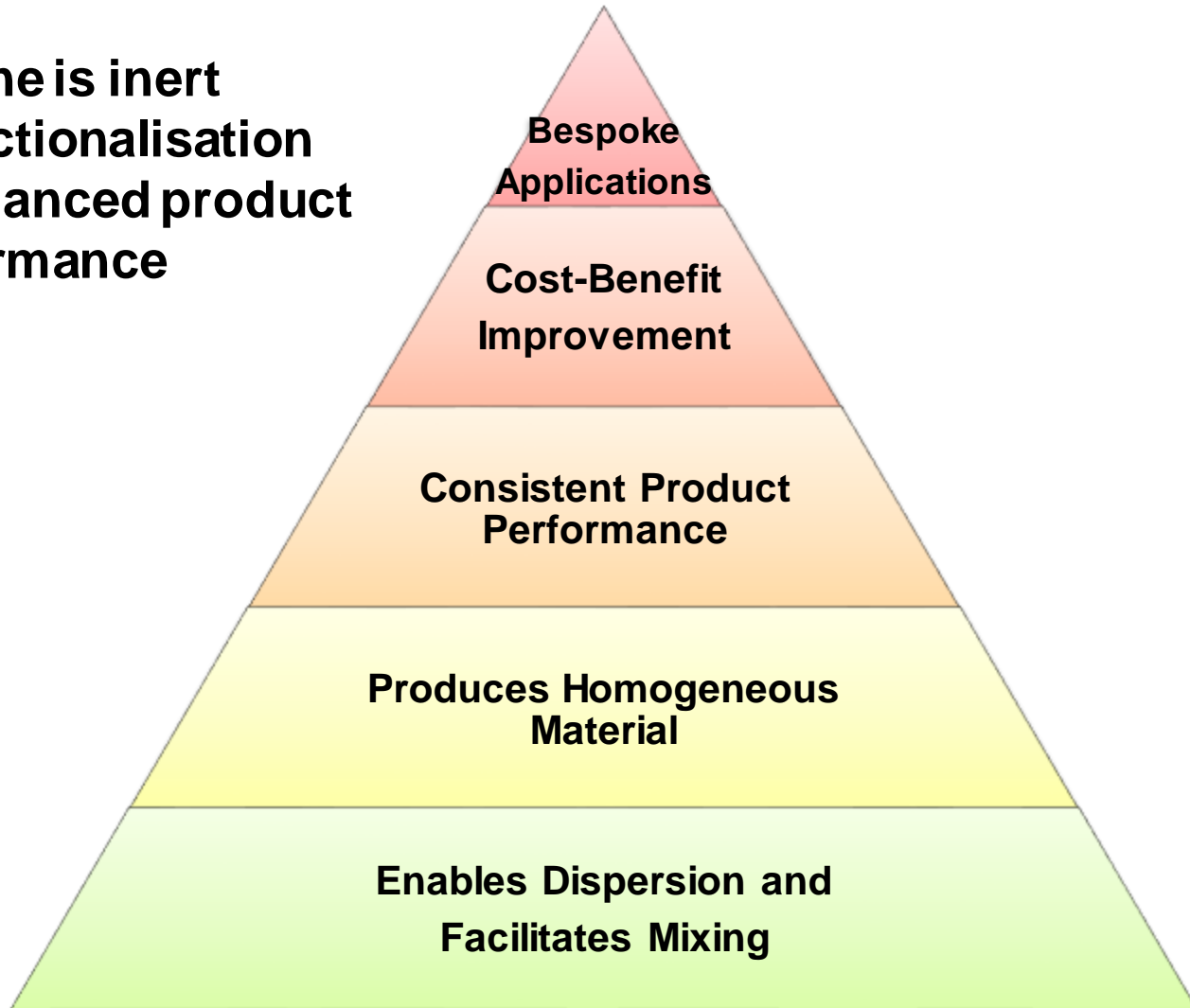
Issues

- Graphene is inert until functionalised
- Graphene supply quality is inconsistent
- Graphene needs to be an affordable price
- Need standardised classification of materials

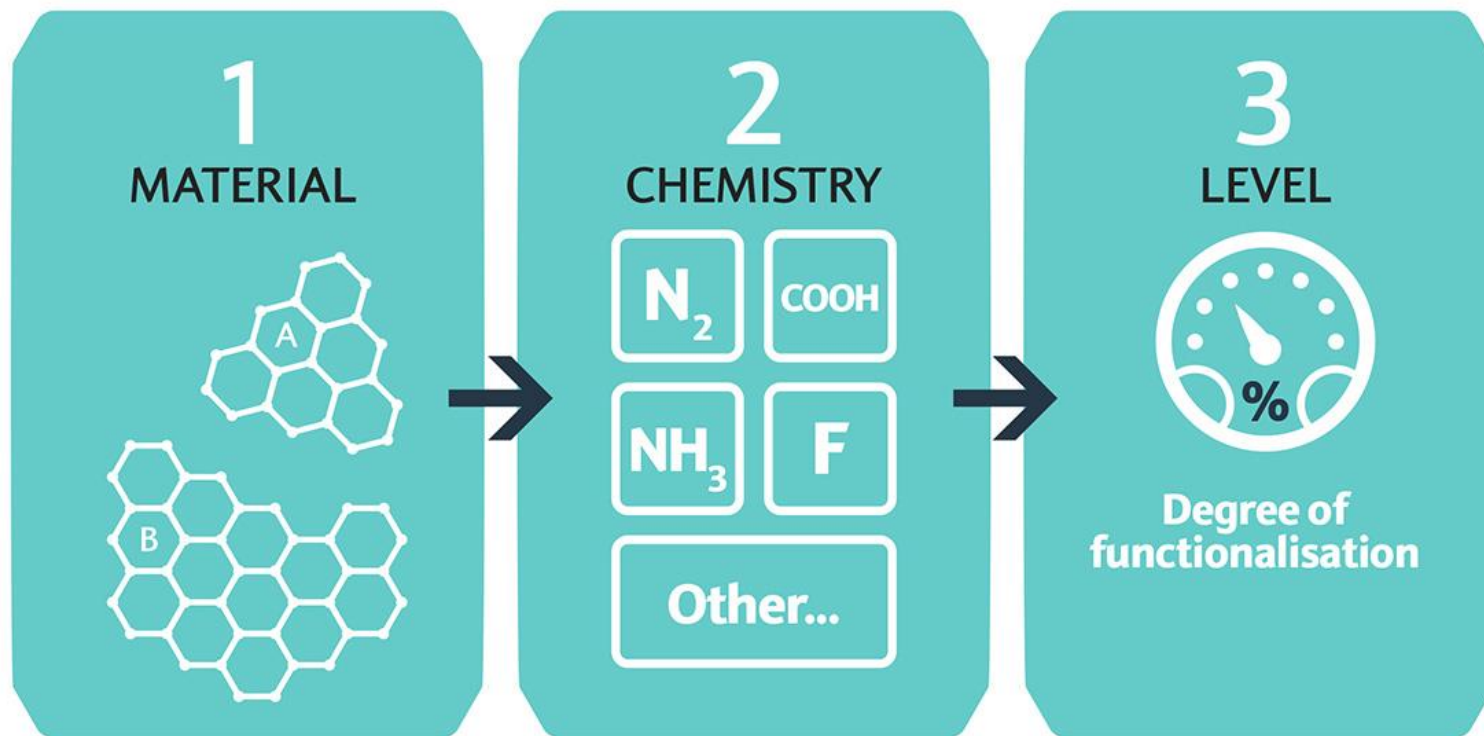
Why Functionalise ?



**Graphene is inert
Correct functionalisation
produces enhanced product
performance**

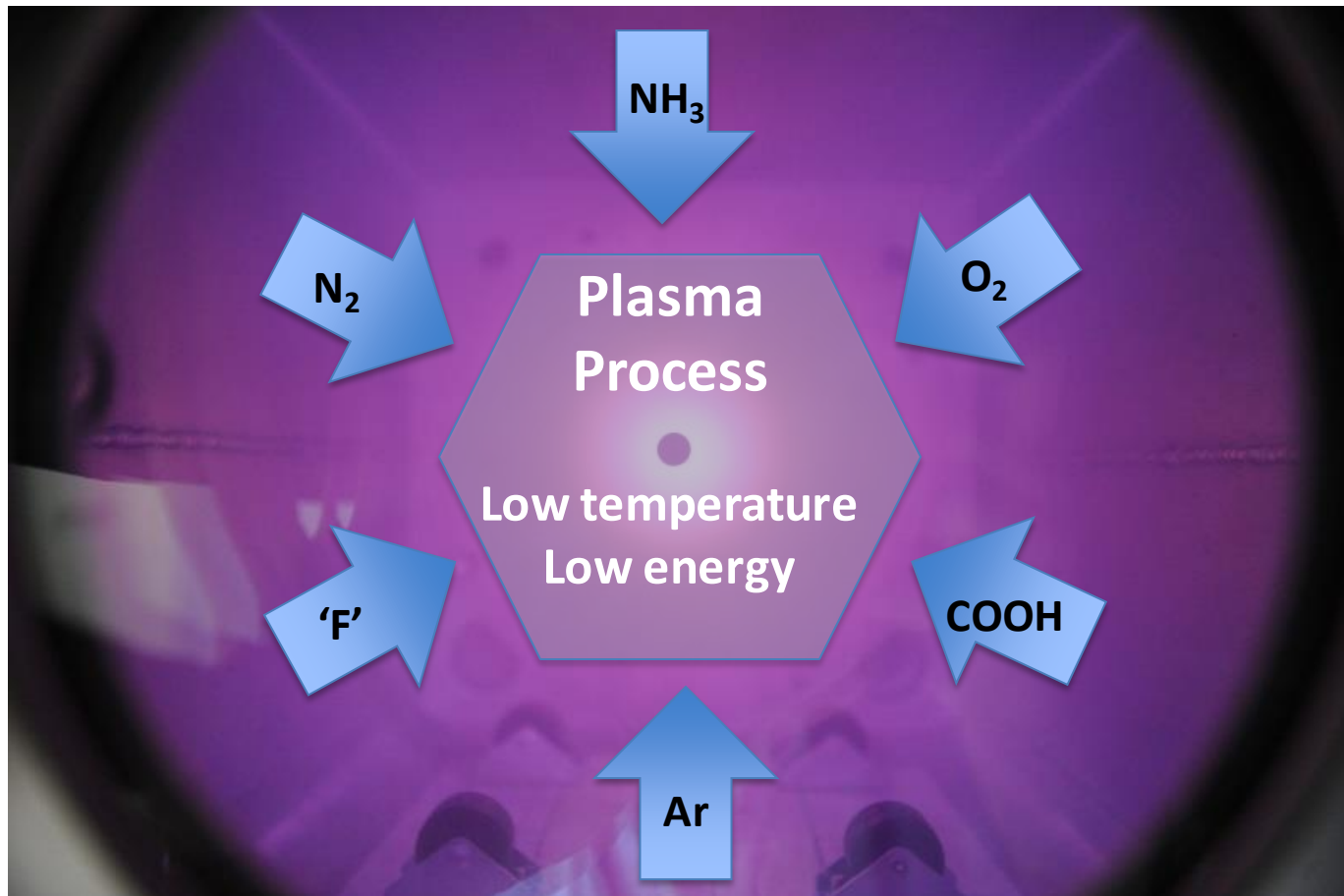


The Haydale approach



3 Levels of Customisation

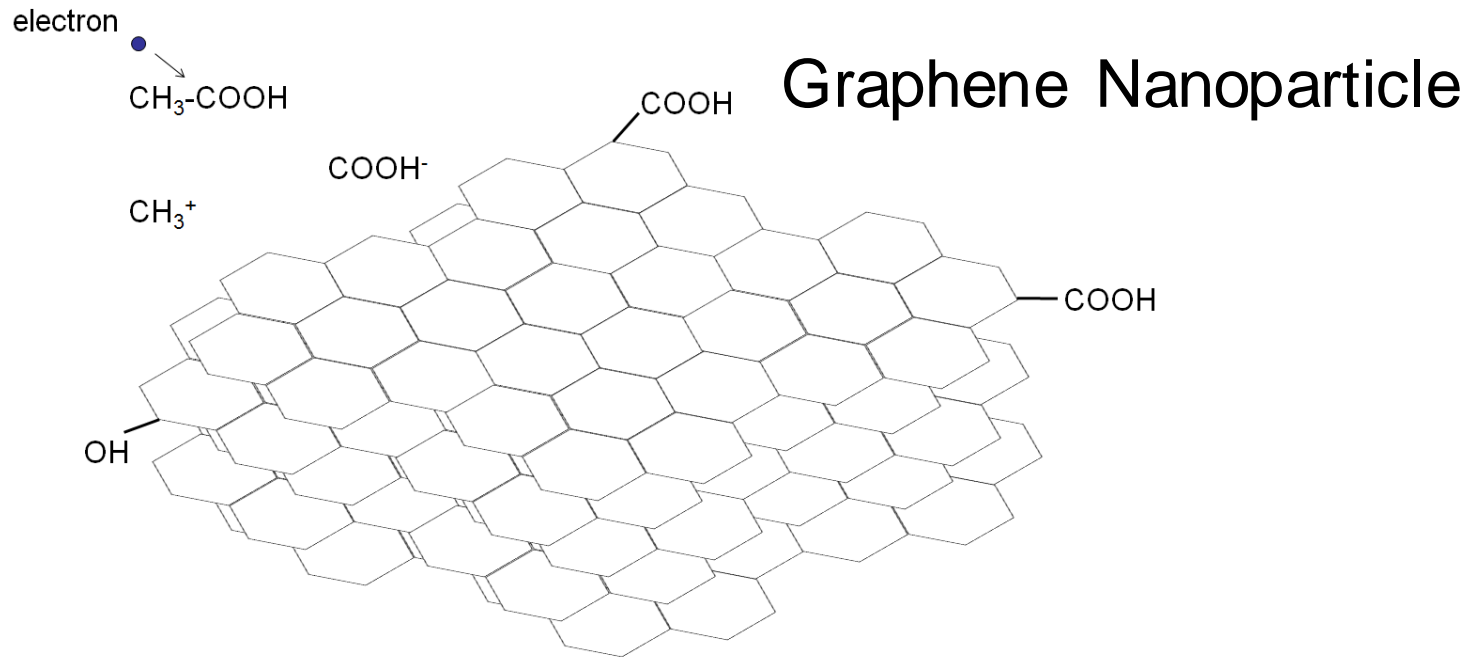
HDPlas™ : standard functionalisation processes



Haydale split plasma processing



- **Low pressure, low temperature gas plasma**
- **Controlled gas and vapour mixtures for bespoke functionalisation**
- **Plasma interacts with the CNT / GNP surface, attaching “free radicals”**



High-energy electrons generated in the plasma can “split” or disassociate molecules into their component parts. These charged particles readily bond with a surface.

Haydale Process Benefits



- No acid processing
- No toxic waste stream
- No post processing drying
- Low temperature processing
- Bespoke materials
- Controlled functionalisation of nano materials
- No catastrophic microstructural damage
- A scalable production route

Functionalisation verified by National Physical Laboratory

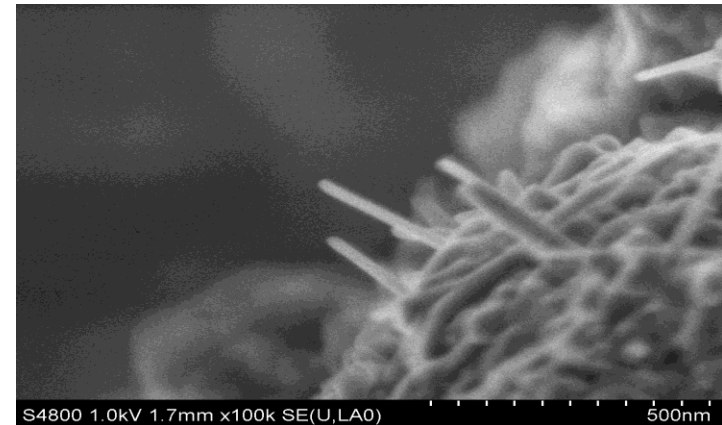
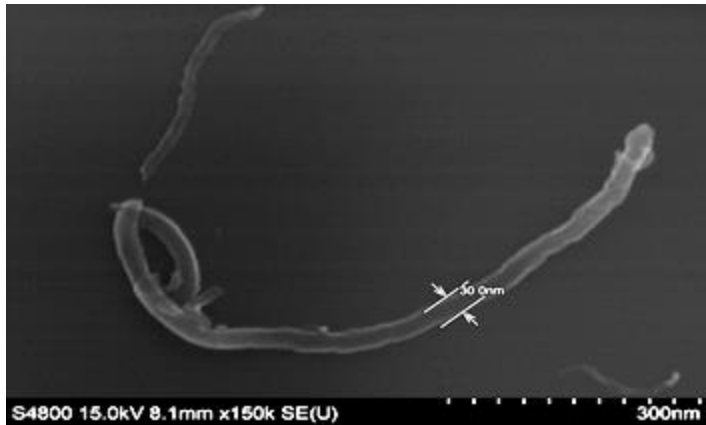
De-agglomeration



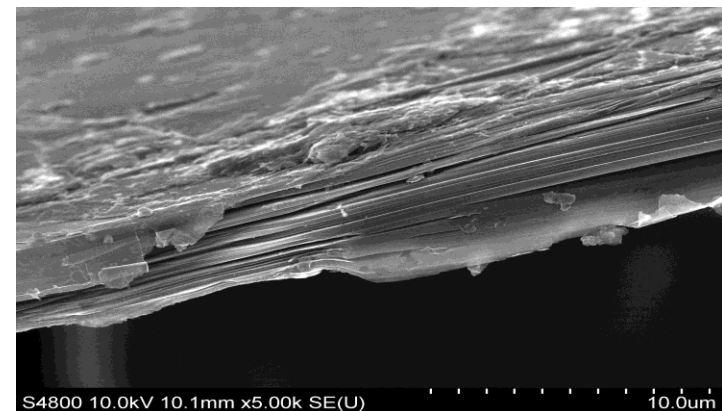
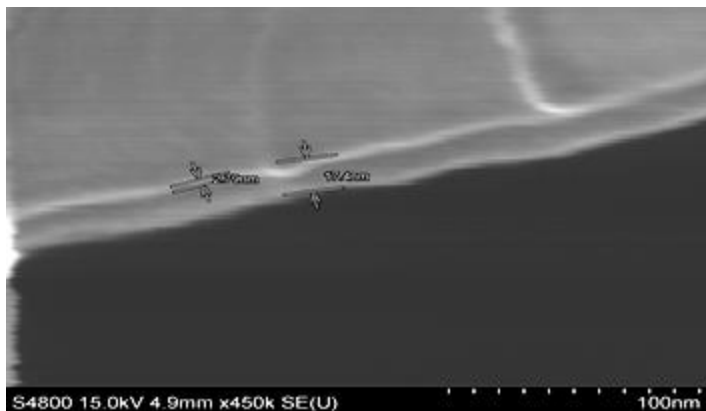
HDPlas™

Industrial

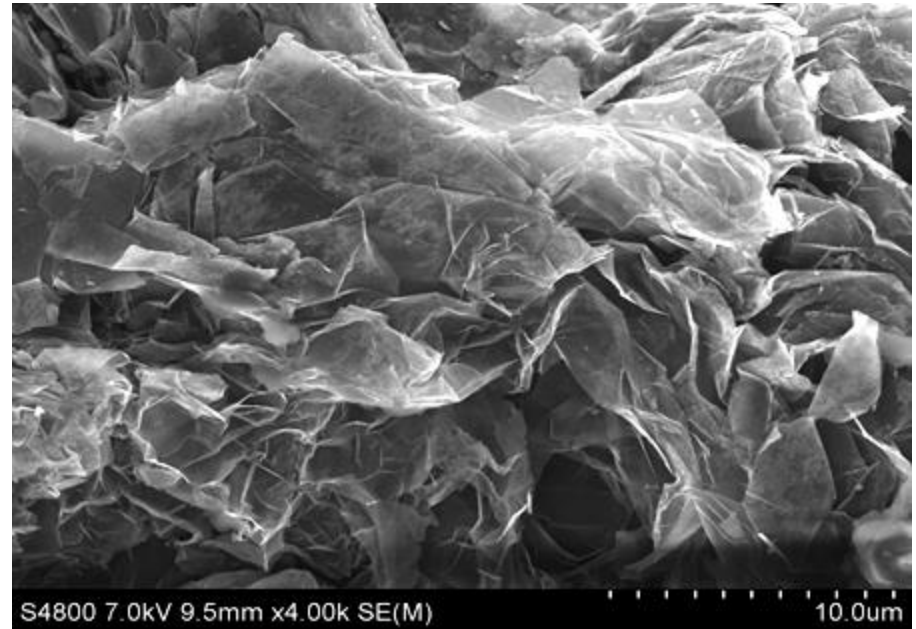
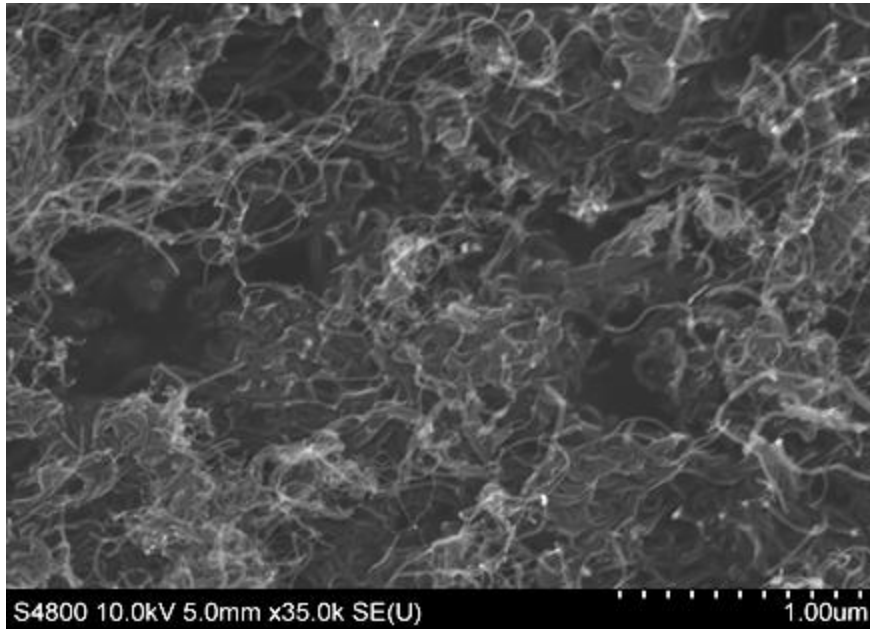
CNTs



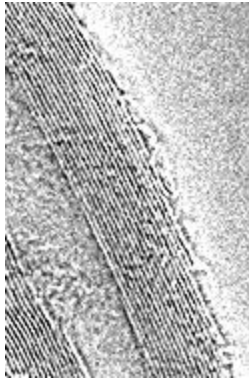
GNPs



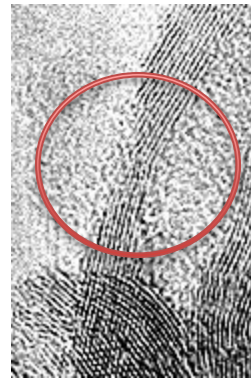
Exfoliating Clean Undamaged CNTs and Graphenes by Split Plasma



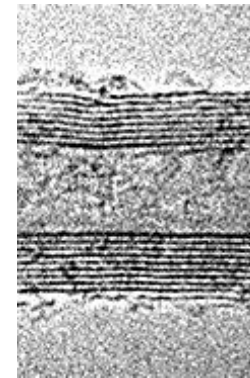
TEM images of MWCNT



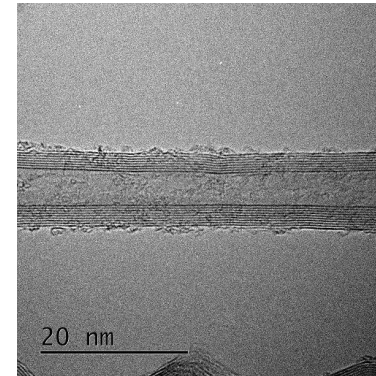
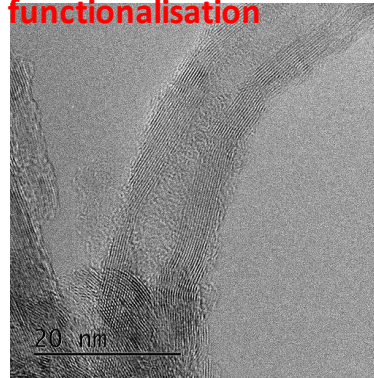
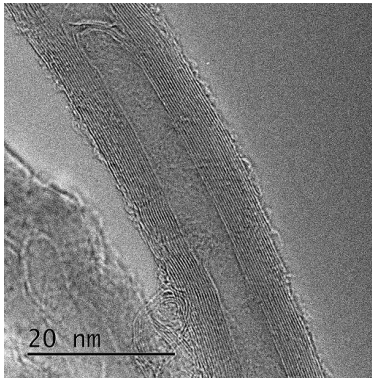
As manufactured MWCNT



After acid
functionalisation



After plasma processing

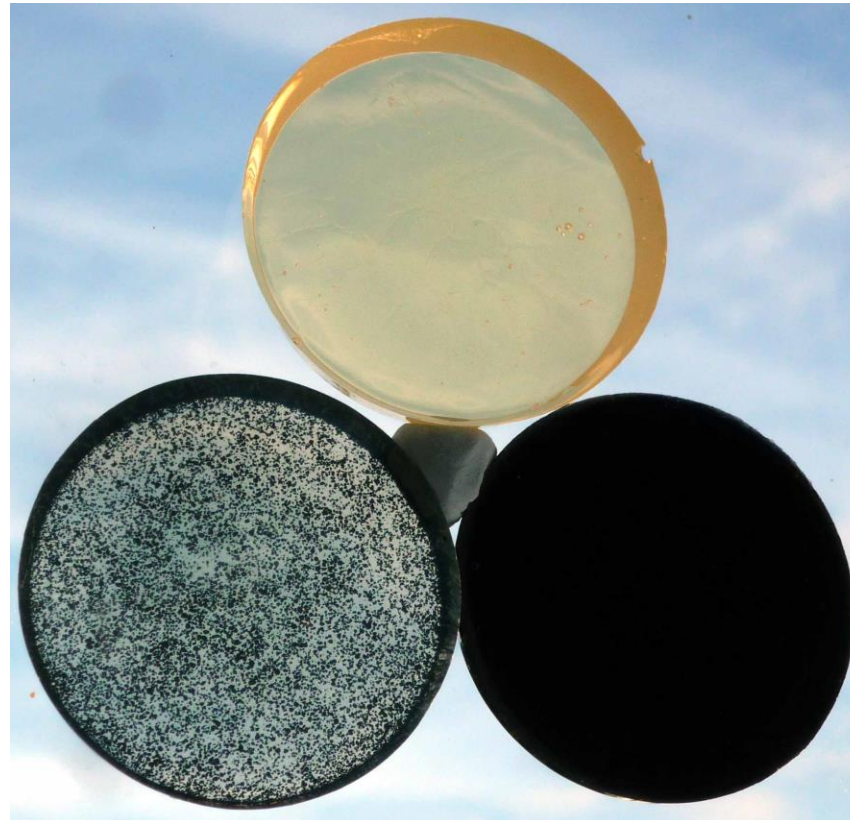


Dispersion in Liquids



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Dispersion in Resins



**0.5 wt% NON
Functionalised
CNT in epoxy
resin**

Epoxy (no filler)

**0.5 wt%
Functionalised
HDPlas CNTs in
epoxy resin**

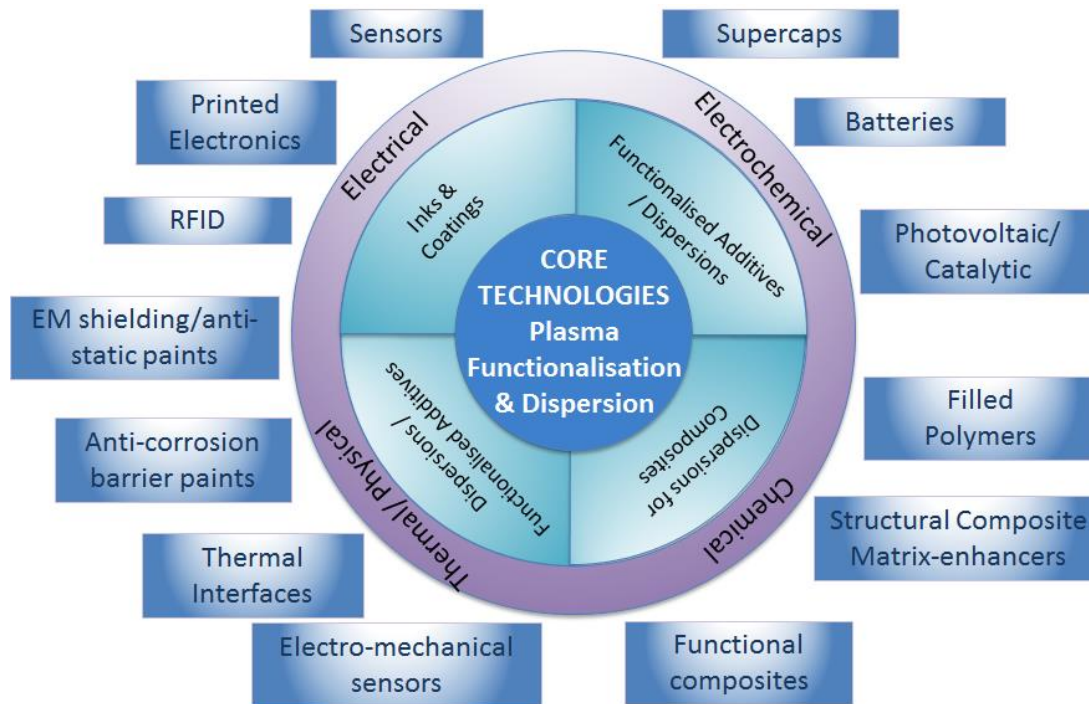
Customer comment about HDPIas™ GNP material



“Our tensile strength and modulus results have been outstanding and increases as a function of loading have shown continuous increases of over 100% at relatively higher loading levels.

Your split plasma method is very efficient with regards to uniformity”.

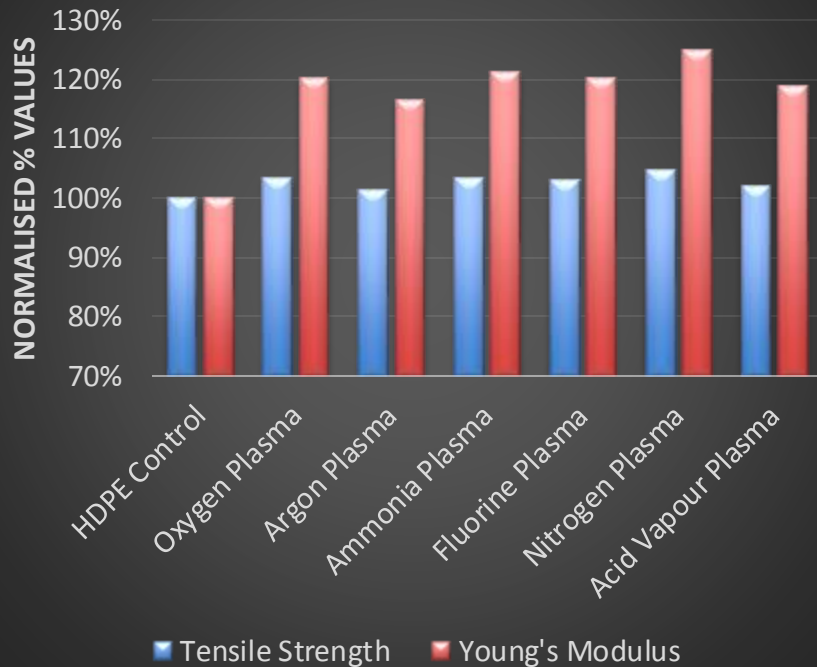
Multitude of applications



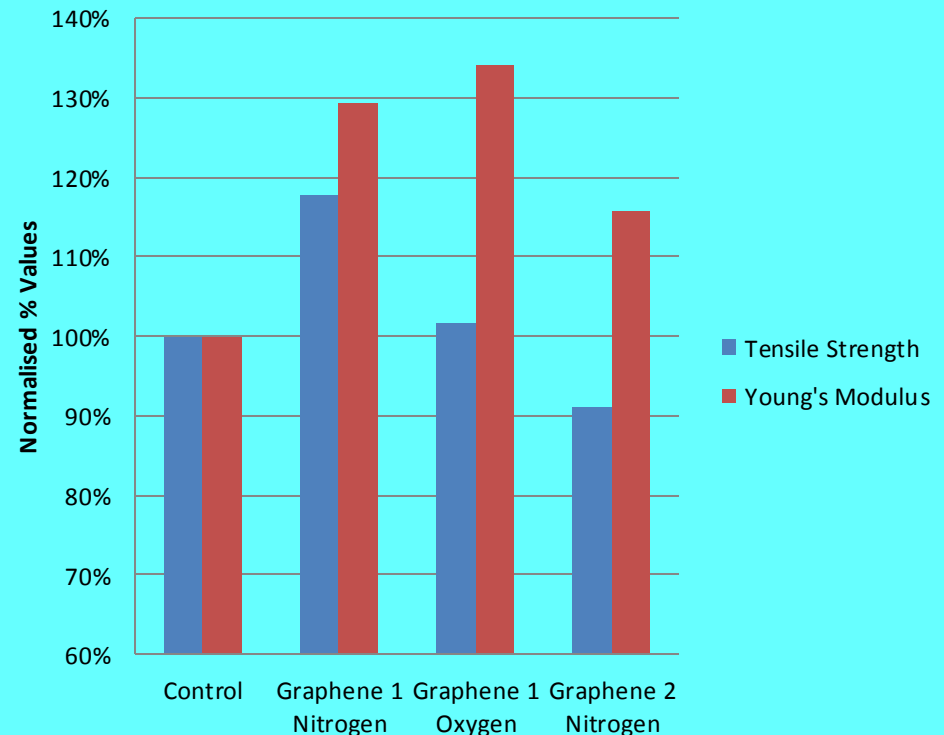
Modified Thermoplastics



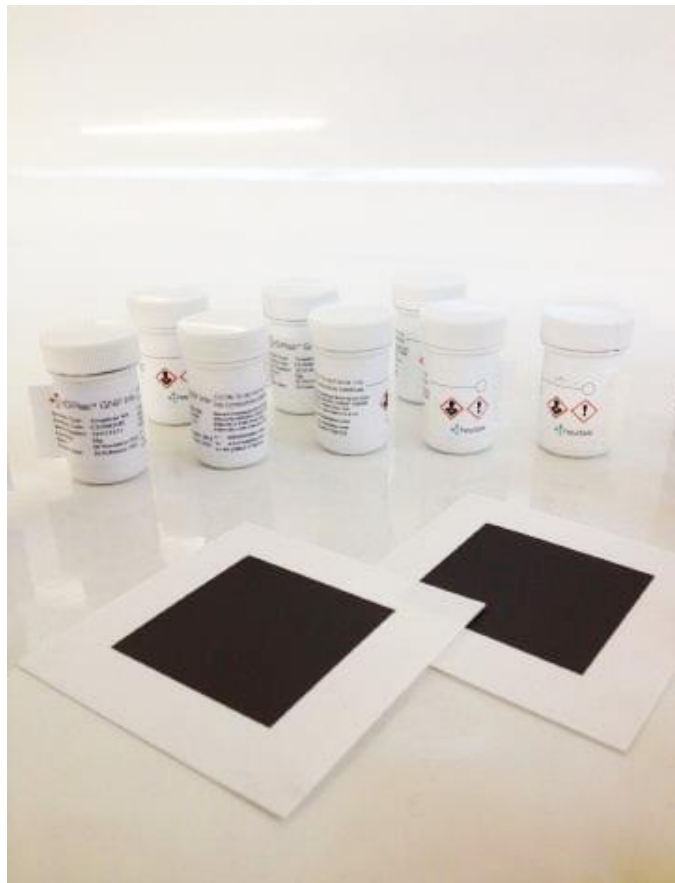
Tensile Performance of GNP Modified HDPE



Tensile Performance of GNP Modified PA66



HDPlas™ Graphene Inks

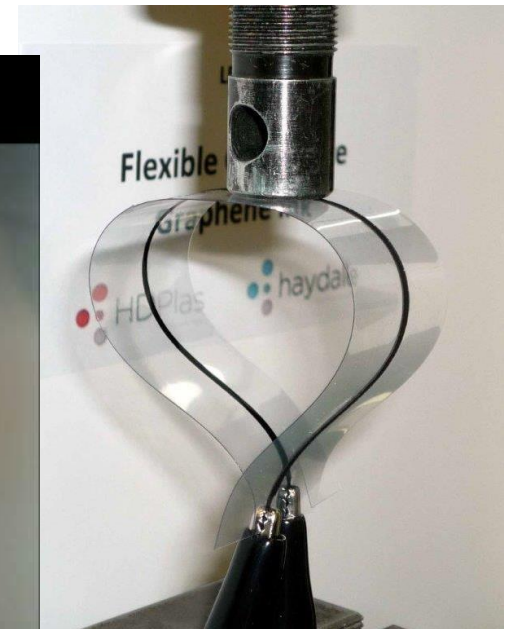
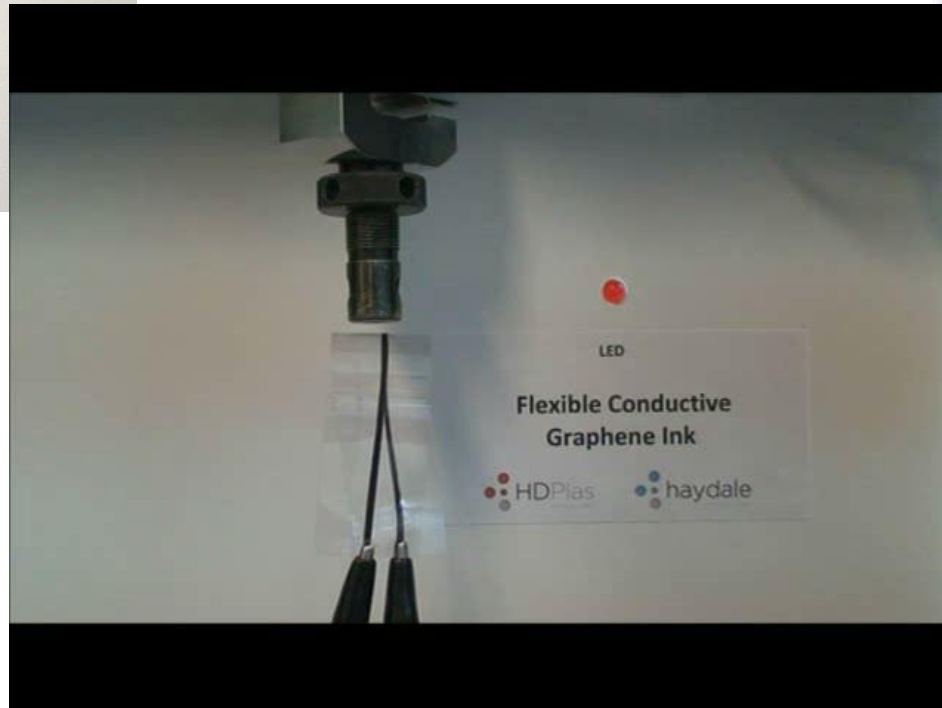


HDPlas™ Graphene Ink IGSC02001 Screen Printable Conductive Graphene Ink

Solids Content	40.0 – 42.0 %
Viscosity	7.0 – 11.0 Pa.s
Coverage	1g of ink will cover approximately 550 sq cm
Sheet Resistance	<20 Ω /sq (230 SS mesh, 13 micron emulsion)
Cured Thickness	Typical 12 microns

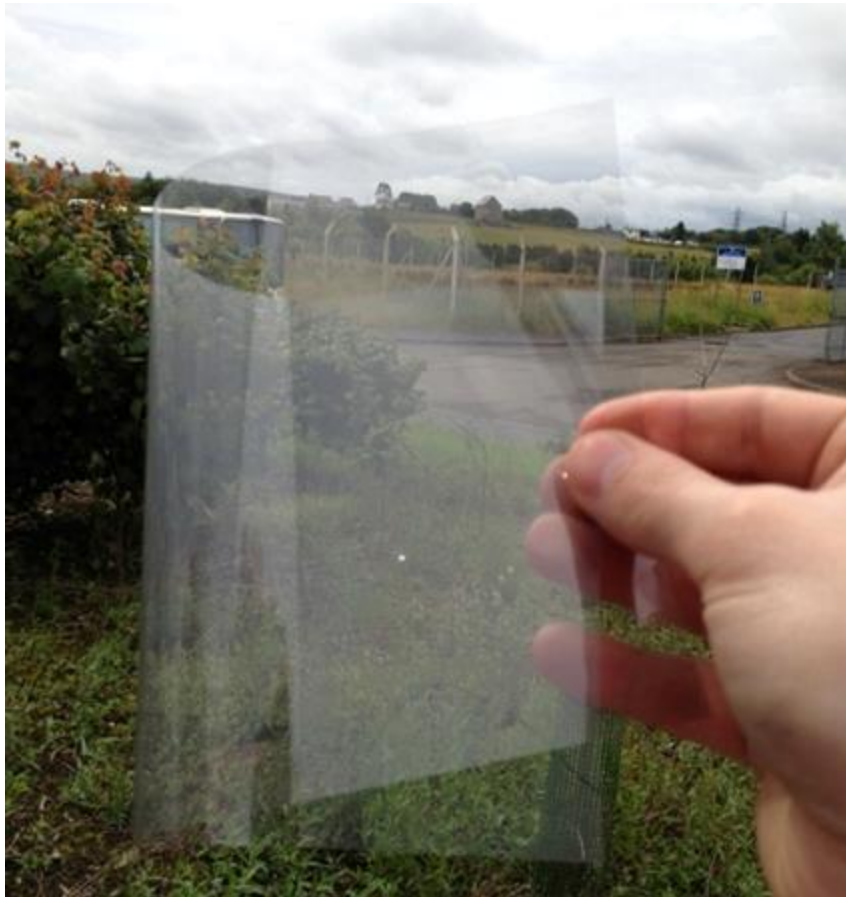
CUSTOMISATION AND FORMULATION SUPPORT AVAILABLE

Flexible Conductive Graphene Ink



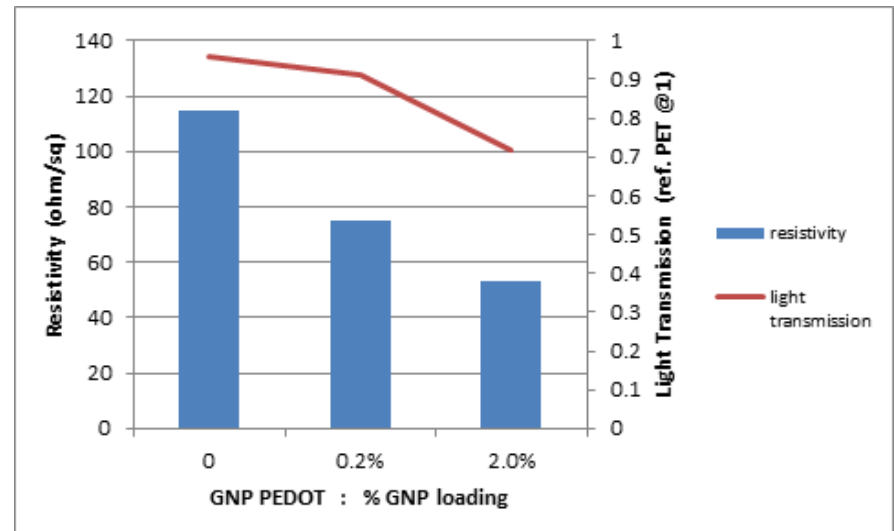
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HDPlas™ Graphene PEDOT



HDPlas™ Graphene PEDOT

PEDOT transparent conductive inks are enhanced with HDPlas™ Graphene. Improved electrical performance with minimal effect on light transmission.



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www.haydale.com

This is Jen.
Graphene is set to change
the way she interacts with
the world around her.

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