

5th HVM New Materials Conference Summit 2019
Cambridge, UK 6-7 November 2019

www.cir-strategy.com/events



Tomorrow's materials available **TODAY**

GRMs for Industrial Applications

Dr. Stephen A. Hodge

Head of Research (Versarien Plc.)

Versarien[®]
PLC



CAMBRIDGE
GRAPHENE



2-DTECH
Two dimensional materials



aac cyroma

Company overview

- Versarien PLC has built its strength through acquiring and combining expertise from its various subsidiary companies.
- We are now producing a number of proprietary grades of 2D materials on a commercial basis.



2011

Company formed.

2013

Floated on AIM London Stock Exchange.

Objective to exploit IP in material science from leading universities into commercially viable products.

2014

Acquisition of 2-DTech Ltd from University of Manchester with IP for scale up production of high quality 2D materials.

2016

Acquisition of AAC Cyroma Ltd, specialist plastics manufacturer to exploit value chain opportunities with graphene and polymer structures.

2017

Acquisition of Cambridge Graphene Ltd from University of Cambridge with IP for scale up production of graphene inks*

2018

Company signed up global collaborative commercial partners and now supplying industry.

Acquisition of Gnanomat S.L

2019

Start of **Versarien Graphene Inc., USA**
First Nanene™ product launches

R&D

- Three staffed offices at graphene centres of excellence at Universities of Manchester, Cambridge and Belfast, including full access to GEIC and CGC.

 National Graphene Institute
Graphene Engineering
Innovation Centre (GEIC)


The University of Manchester



 UNIVERSITY OF
CAMBRIDGE


Ulster
University

NIBEC
Nanotechnology & Integrated
Bioengineering Centre

 **WMMG**
THE UNIVERSITY OF WARWICK

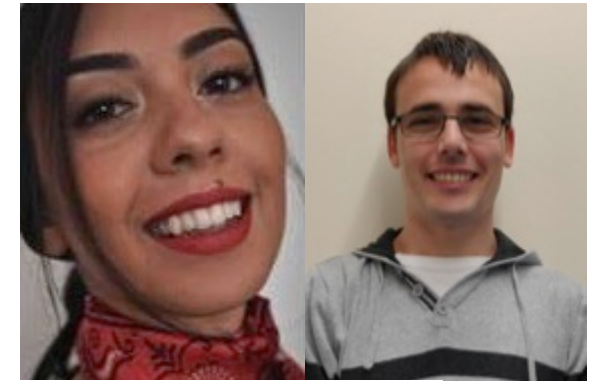
CONFIDENTIAL



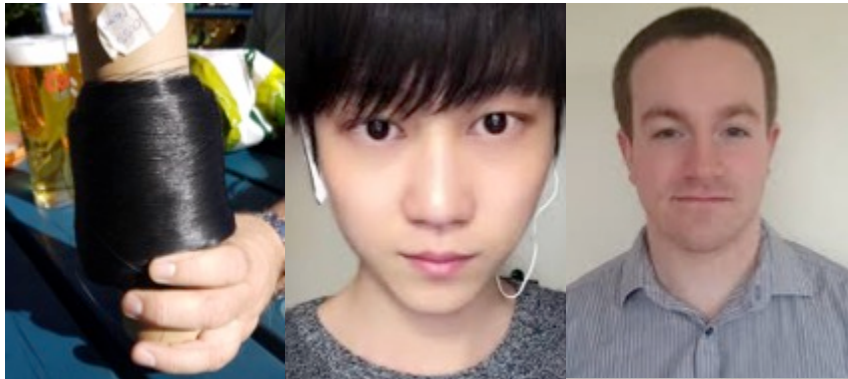
UK R&D Teams



Dr. Stephen Hodge (Head of Research)
Dr. Thanuja Galhena (Project Scientist)
Jeremiah Marcellino (Graphene CDT Student)



Dr. Esra Ozdemir (Research Fellow)
David Reinoso Arenas (PhD Student)



Les Bell (Chief Engineer)
Dr. Suhao Li (Project Scientist)
Dr. John Benson (Process Scientist)
Dr. Subimal Majee (Project Scientist)
Tian Xia (PhD Student)
Dr. Martin Kemp (Nanomaterials Specialist)



UNIVERSITY OF LEEDS

Alexis Charrier (MRes Student)

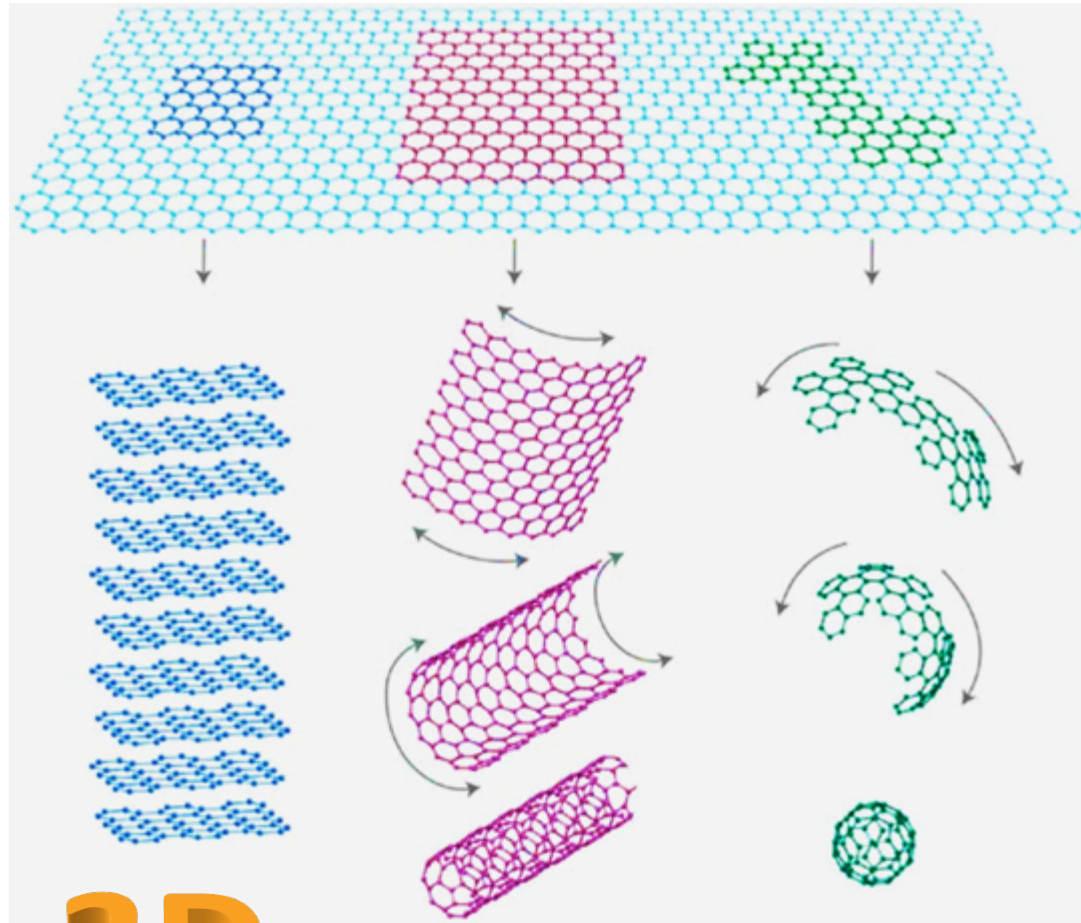


Support

- ◆ Close relationships with Government Departments, including with government support from **Department of International Trade (DIT)** and **Department for Business, Energy & Industrial Strategy (BEIS)** where we are the first UK company to be enrolled in **outwards direct investment (ODI)** strategic policy, with seconded government strategists working for Versarien PLC.



Graphene



3D

GRAPHITE

1D

CARBON NANOTUBES
IJIMA, 1991

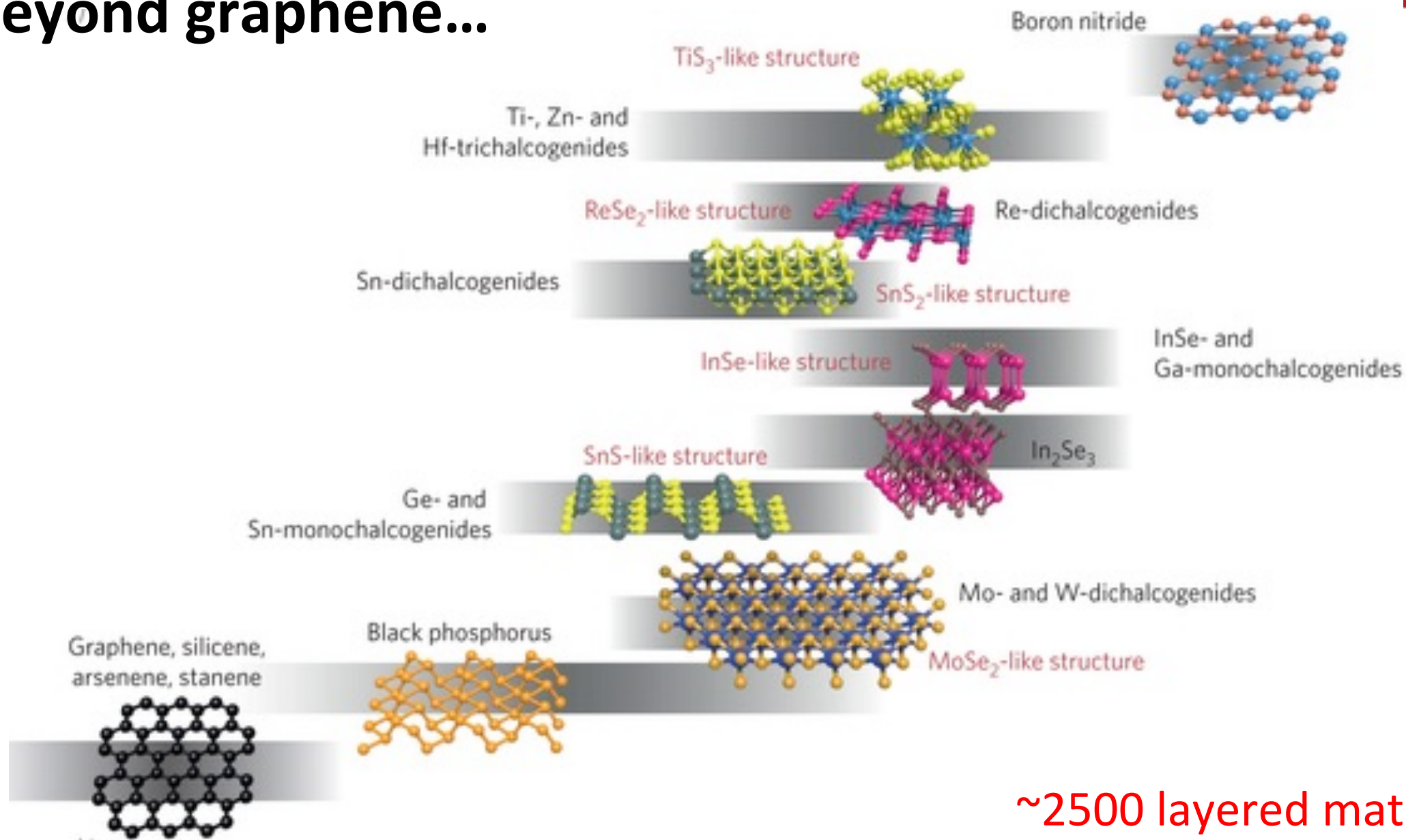
0D

BUCKMINSTERFULLERENE
Nobel prize in Chemistry 1996

2D A.K. Geim, K.S. Novoselov
Nobel prize in Physics 2010

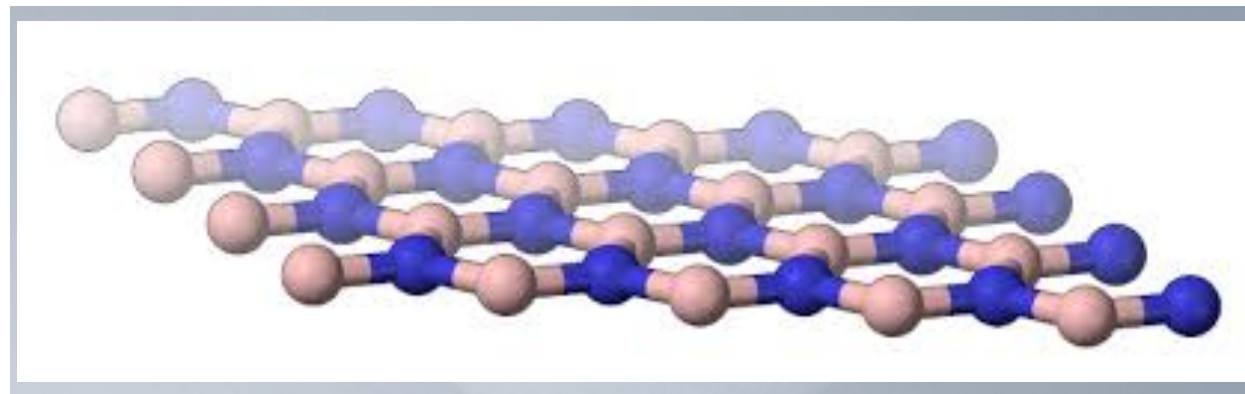
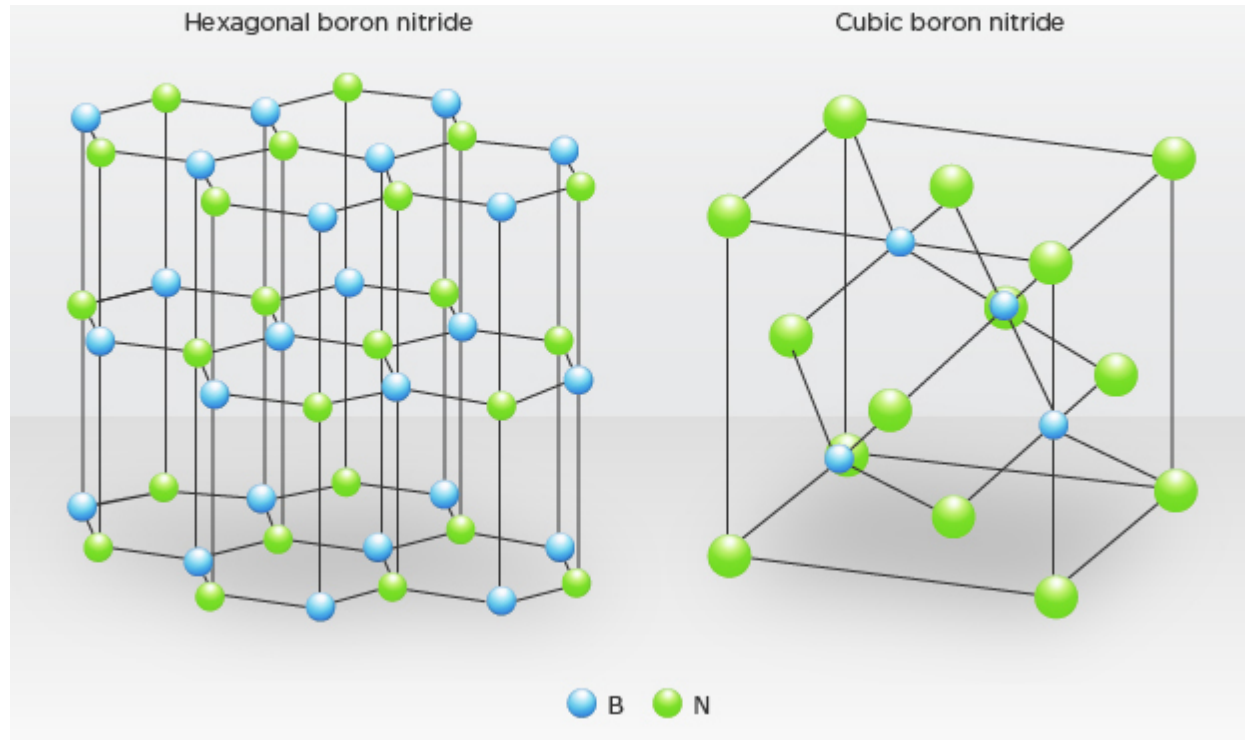
- High electrical conductivity
- Excellent chemical stability
- High mechanical strength
- Excellent thermal stability and thermal conductivity
- Gas impermeability
- Interesting optical properties

Beyond graphene...



~2500 layered materials!

Hexagonal Boron Nitride (hBN)



2D *A.K. Geim, K.S. Novoselov*
Nobel prize in Physics 2010

- Excellent chemical stability
- High mechanical strength
- Excellent thermal stability and thermal conductivity
- Wide band gap material – effective insulator or dielectric material
- UV light absorption



NaneneTM

Versarien



Hexotene

Certifications



**Verified Graphene
Producer 2019-2020**

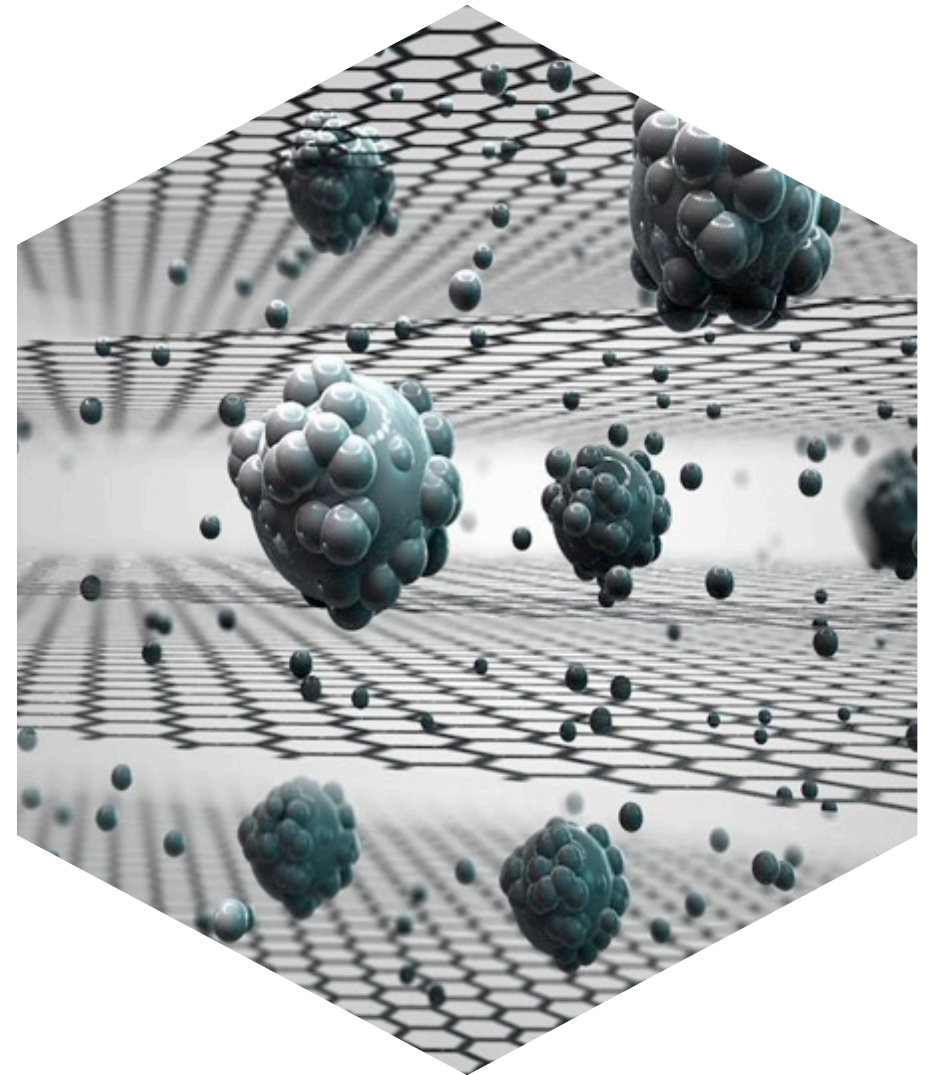


- ◆ Versarien® are the world's only company to pass the Verified Graphene Producer program as administered by The Graphene Council and independent testing at National Physical Laboratory (NPL)
- ◆ Versarien's graphene successfully passed testing at National Graphene Products Quality Supervision & Inspection Center, Wuxi, China
- ◆ Registration, Evaluation, Authorization and Restriction of Chemicals ("the REACH Regulation") of the Substance(s) (graphene/graphene oxide) on its own, in preparations or in articles with registered offices in the Economic Area. Registered for exporting **1-10 tons per annum**
- ◆ Quality Management Systems ISO9001:2015 certified



Applications

- Mechanical enhancement
 - thermosets & thermoplastic composites
- Filtration
 - water purification
- Barrier
 - moisture, gas etc.
- Electrical energy storage
 - batteries, supercapacitors
- Thermal conductivity enhancement
 - heat dissipation
- Electrical conductivity
 - printed electronics



**Graphene
Enhanced Fibre
Reinforced
Polymers (FRP)**

**Aerospace Market ~44,000 tonnes of
CFRP in 2020***

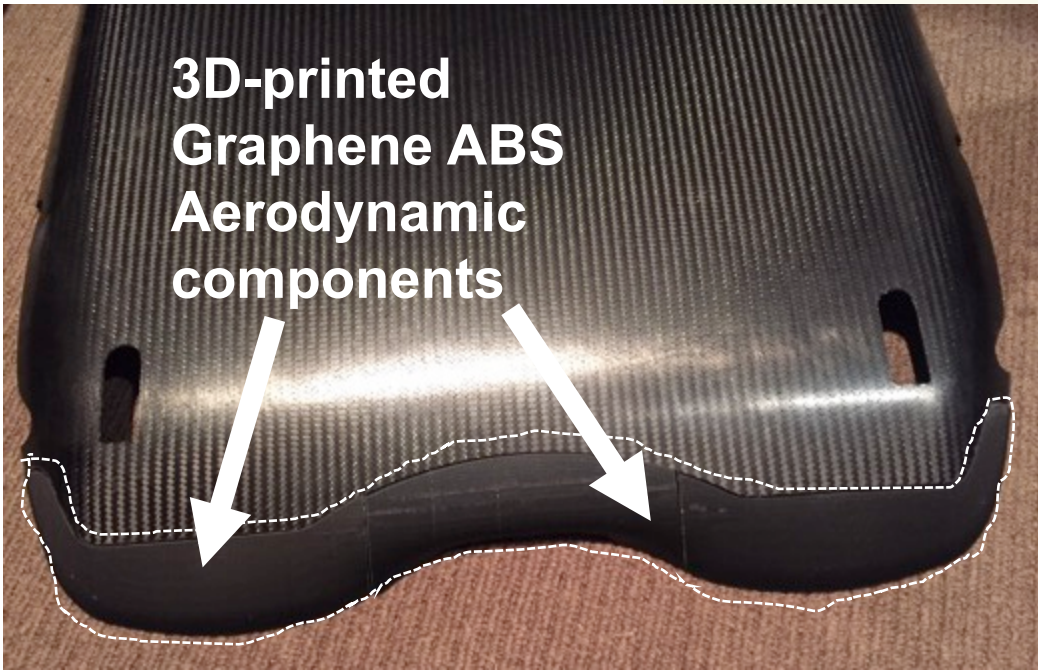
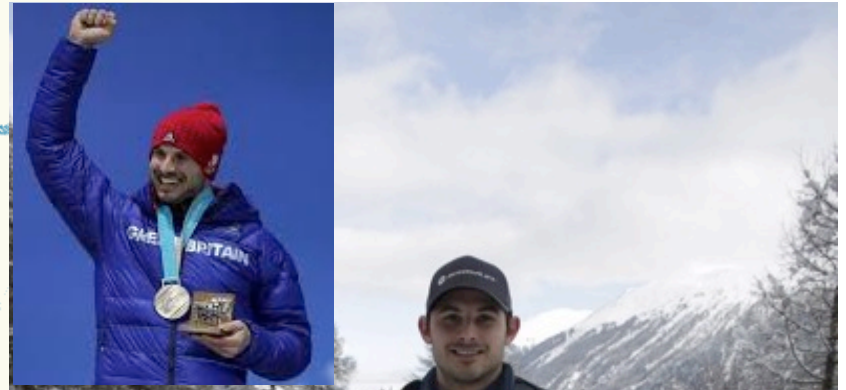
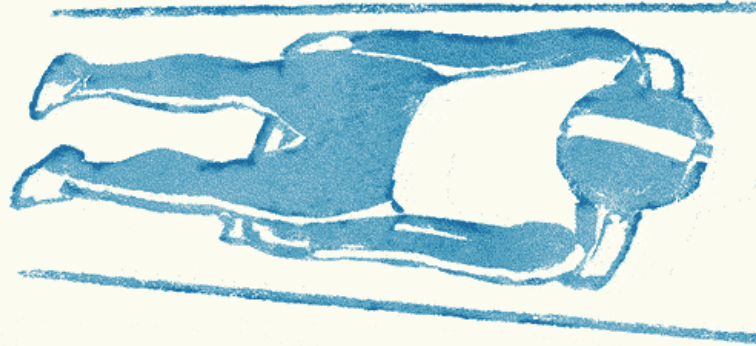
Reduced weight = big fuel savings

 **Nanene**TM
Versarien

**Graphene
Enhanced
Elastomers**

**Graphene
Enhanced
Thermoplastics**

**36M tonnes of thermoplastics will be used in
automobiles every year in 2020**



3D-printed
Graphene ABS
Aerodynamic
components



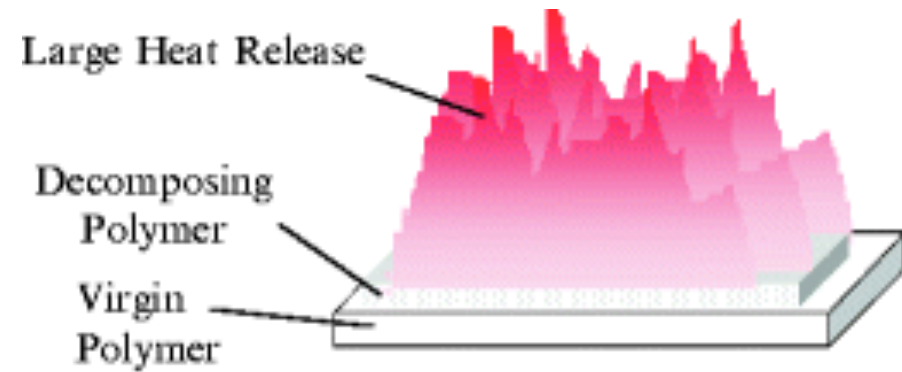
Graphene-
Carbon
Fibre
Reinforce
d Plastic
body

“...the graphene can toughen the material systems up. When you’re at -20C and undergoing g-forces of up to 5G, toughness is a factor.”

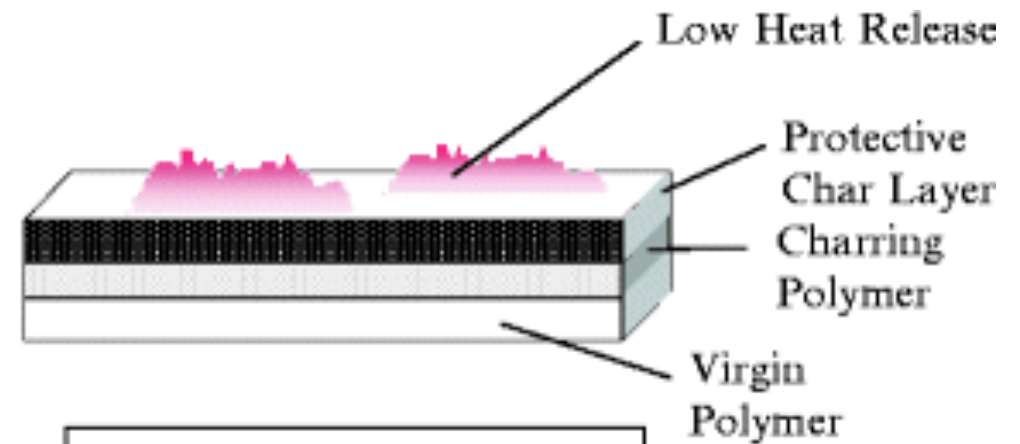
Automotive / Aircraft Interiors



www.aircraftplastics.com



Non-charring Polymer

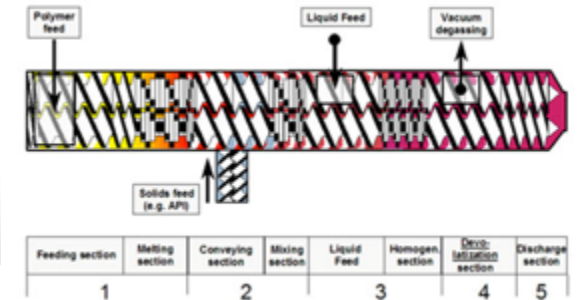


Charring Polymer

Graphene/thermoplastic process flow

Step 1: Twin-screw extrusion compounding of graphene/polymer masterbatch

- WMG for process development
 - 25-50 kg / day
- Industry partners for larger scales
 - >1 ton/day



Filaments

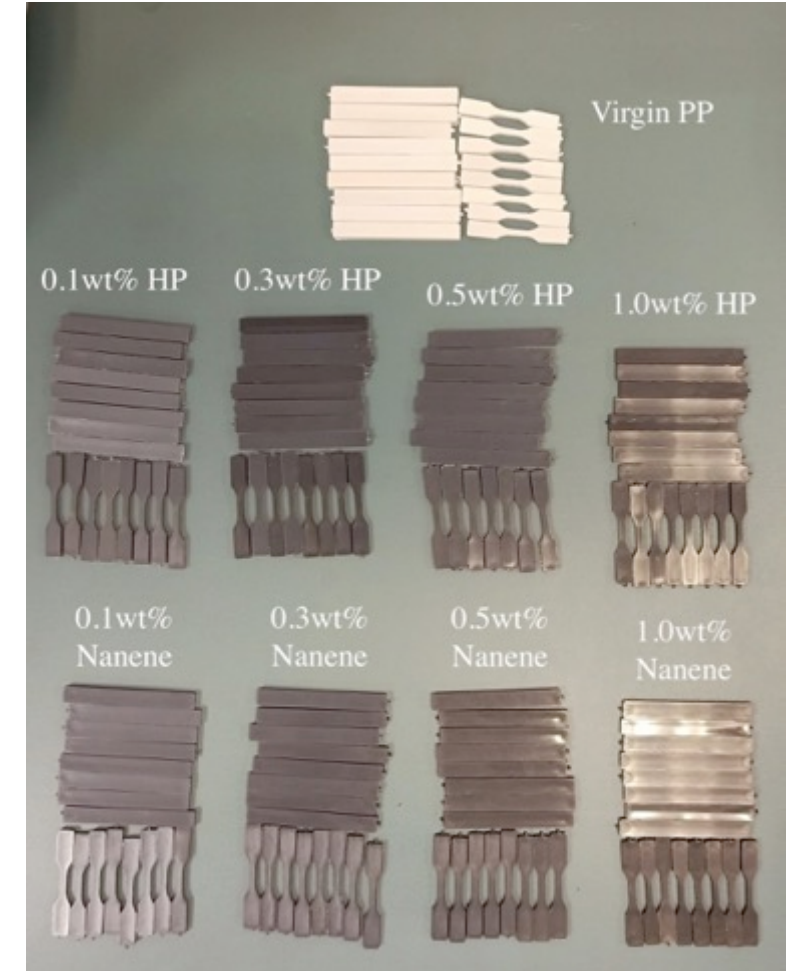


Pellets

Graphene/thermoplastic process flow

Step 2:

- ◆ Injection moulding
- ◆ Vacuum forming
- ◆ 3D printing (FDM, SLS)
- ◆ Film extrusion/blowing

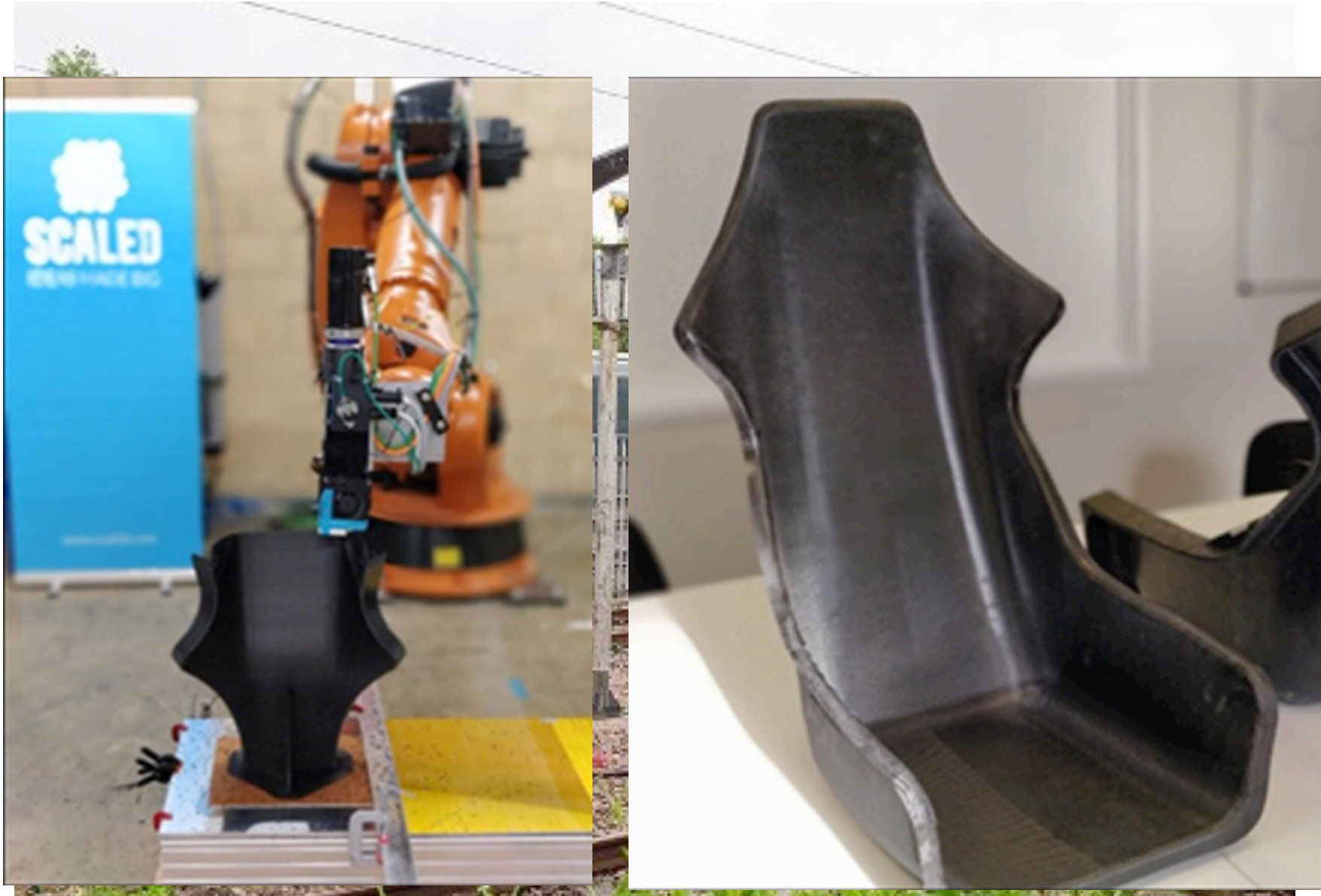


CNCTArch

AECOM

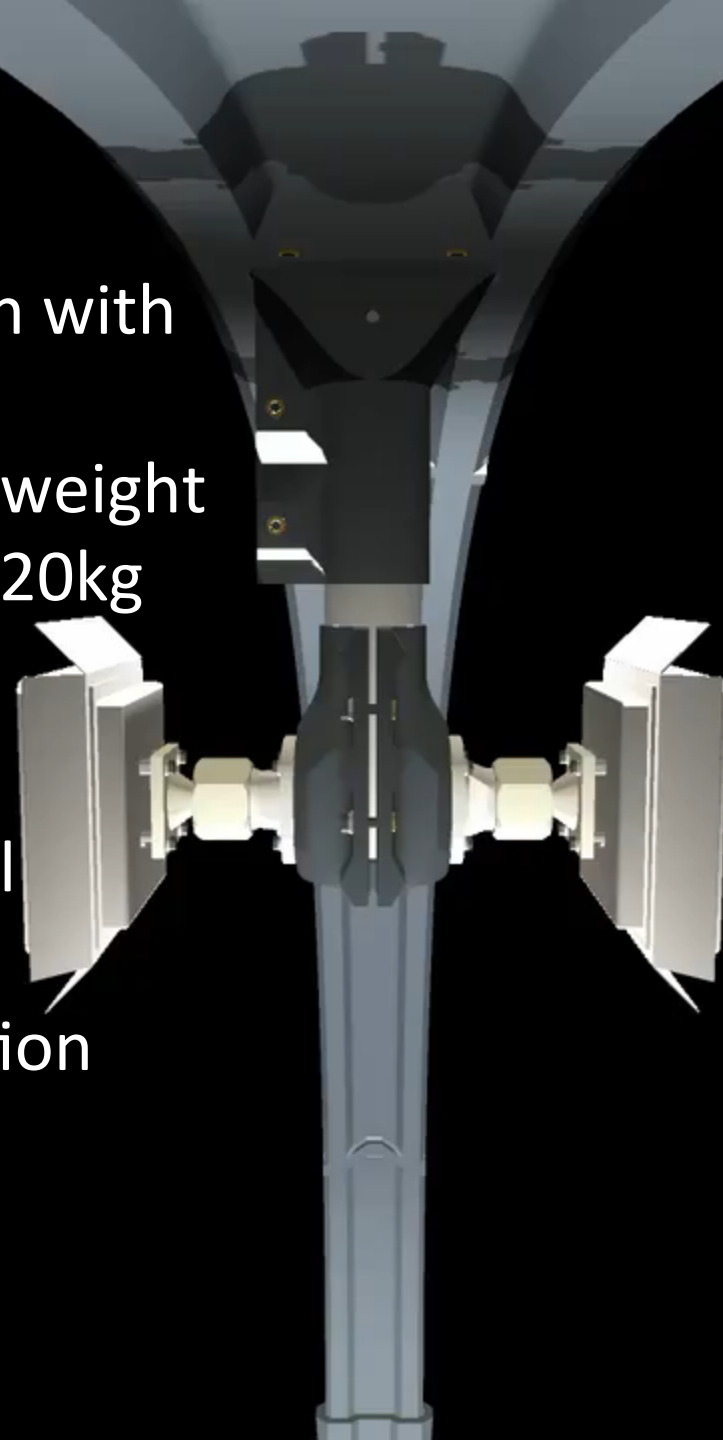
SCALED
IDEAS MADE BIG

**EXPORTING
IS
GREAT**
BRITAIN & NORTHERN IRELAND



Versarien
PLC

- Additive 3d printed arch with Nanene™
 - 4.5 metre high, lightweight
 - Each arch weighs ~120kg
- Reduces the time and cost of installing digital signalling systems and transform the digitisation of transport networks.





GRAPHINKS

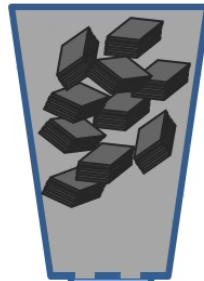
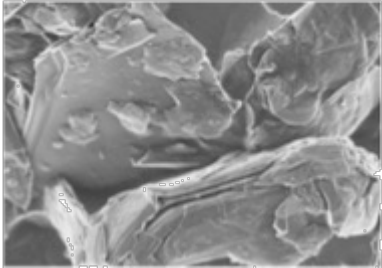
Ink production

ACS Nano, 2017, 11 (3), pp 2742–2755

Inlet reservoir

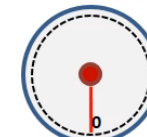
Outlet

Starting particles
27 μ m

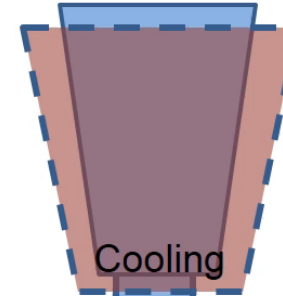


Intensifier Pump

Pressure Gauge



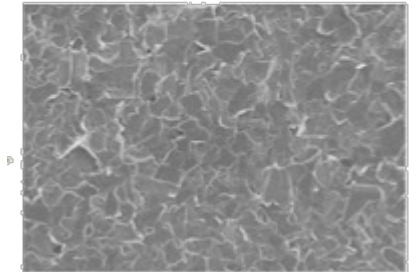
Cooling



Interaction Chamber



Ending particles
<1 μ m



LAB SCALE:
Flow Rate: 100mL/min
Graphene flakes: 6.5 g/h



PRODUCTION SCALE:
Flow rates up to 12 L/min
Graphene Flakes 720 g/h
= 6.5 tonnes/yr or 65k L ink/yr

Graphene Ink – Potential Applications

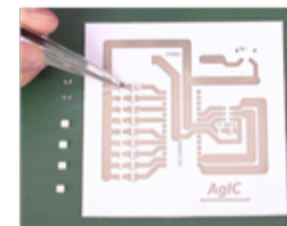
Optoelectronics devices
(Electrodes for
OPVs, OLED, LCD panels,
touchscreens, lighting etc.)



Smart Textiles (Wearable
electronics, conductive tracks on
textiles)

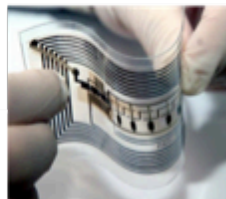


Printed circuit lines
(solar cell grid lines,
interconnections, EMI
shielding, printed
circuit boards)



Large range of
applications

Communication
RF-ID antennas



Energy Storage
(batteries,
supercapacitors)



Sensing (health & food sensors
membrane switches)



Graphene Ink – Potential Applications

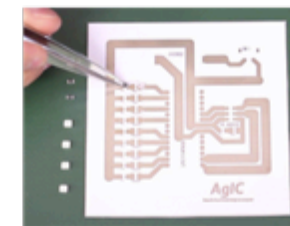
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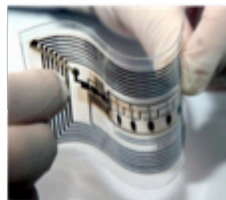


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Large range of
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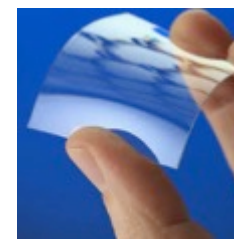
Communication
RF-ID antennas



Energy Storage
(batteries,
supercapacitors)



Coatings
(Anti-corrosion, -bacterial,
-erosion, -static, etc.)



◆ **MediaDevil Artisanphonics CB-01 Earphones**

- ◆ Noise-isolating Premium Wood Earphones with Nanene[®] Graphene-Enhanced Audio
- ◆ Thinner & more flexible earphone diaphragm
 - ◆ Enhances the low-end (bass) of the audio frequency wave (**Independent testing conducted by a leading British premium audio company**)





Grime Violinist at Glastonbury this year



Jari Kinaret Head of the Graphene Flagship on the left and a VIP from the European Commission on the right.

Technical Textiles

- ◆ Printing and dyed fabrics
- ◆ Graphene formulations developed for sportswear:
 - ◆ Independent tests show:

Air permeability improved by 10-25%

Thermal resistance of graphene garment is ~20% lower than the control garment

Material wicking: 50% and 100% increase depending on the direction of capillary action.

Faster drying rate - greater ability for water/sweat to evaporate from the graphene fabric against the control garment.

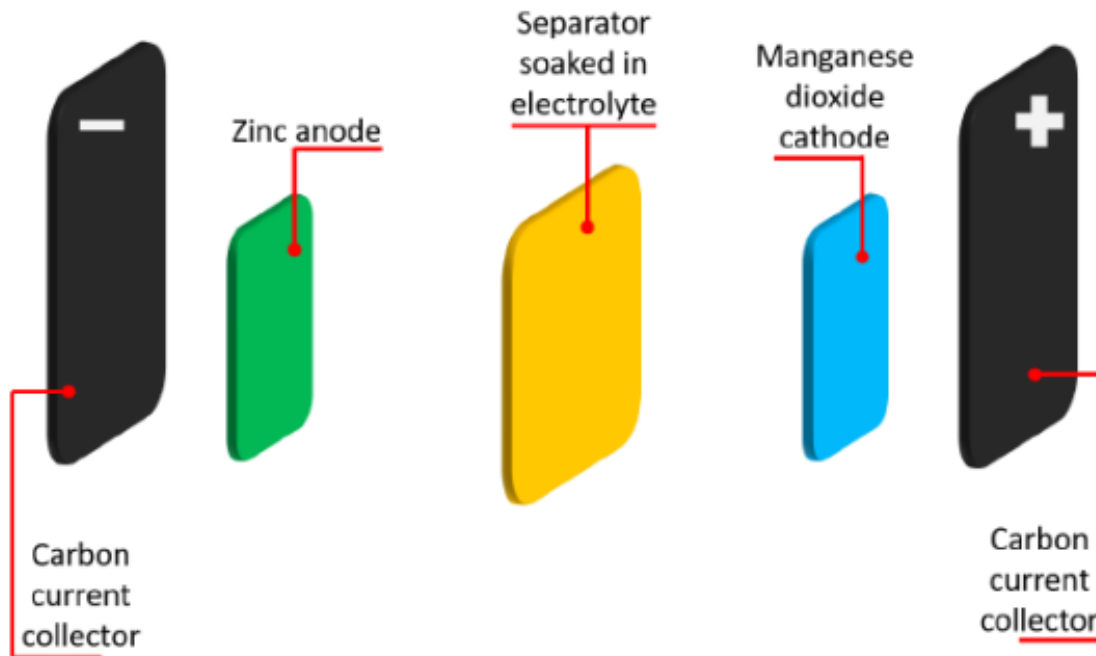




Energy Storage Devices

Flexible Battery

- ◆ Innovate UK project (FLEXIBAT) to reduce the internal resistance by replacing carbon current collector with Aluminium/graphene current collector.



Electrolyte: 1.05M zinc chloride (ZnCl_2) and 7.8M ammonium chloride (NH_4Cl)



Supercapacitors



Electrochemical Double Layer Capacitors

Carbon material (AC, Graphene, CNT, etc)

High accessible surface area ($>1000 \text{ m}^2/\text{g}$)
High electronic conductivity ($0.1-1 \text{ S cm}^{-1}$)
High chemical stability in electrolytes
Low prices
Moderate capacitance 50-200 F/g

**DOUBLE LAYER FORMATION
(electrostatically)**

Pseudocapacitors

Metal oxide (transition metal oxides)

Moderate electronic conductivity
Low specific surface area ($< 100 \text{ m}^2/\text{g}$)
Moderate chemical stability
High specific capacitance (until 750 F/g)

**PSEUDOCAPACITANCE
(electrochemically)**

Conductive polymer (polyaniline, polypyrrole, polythiophene, etc)

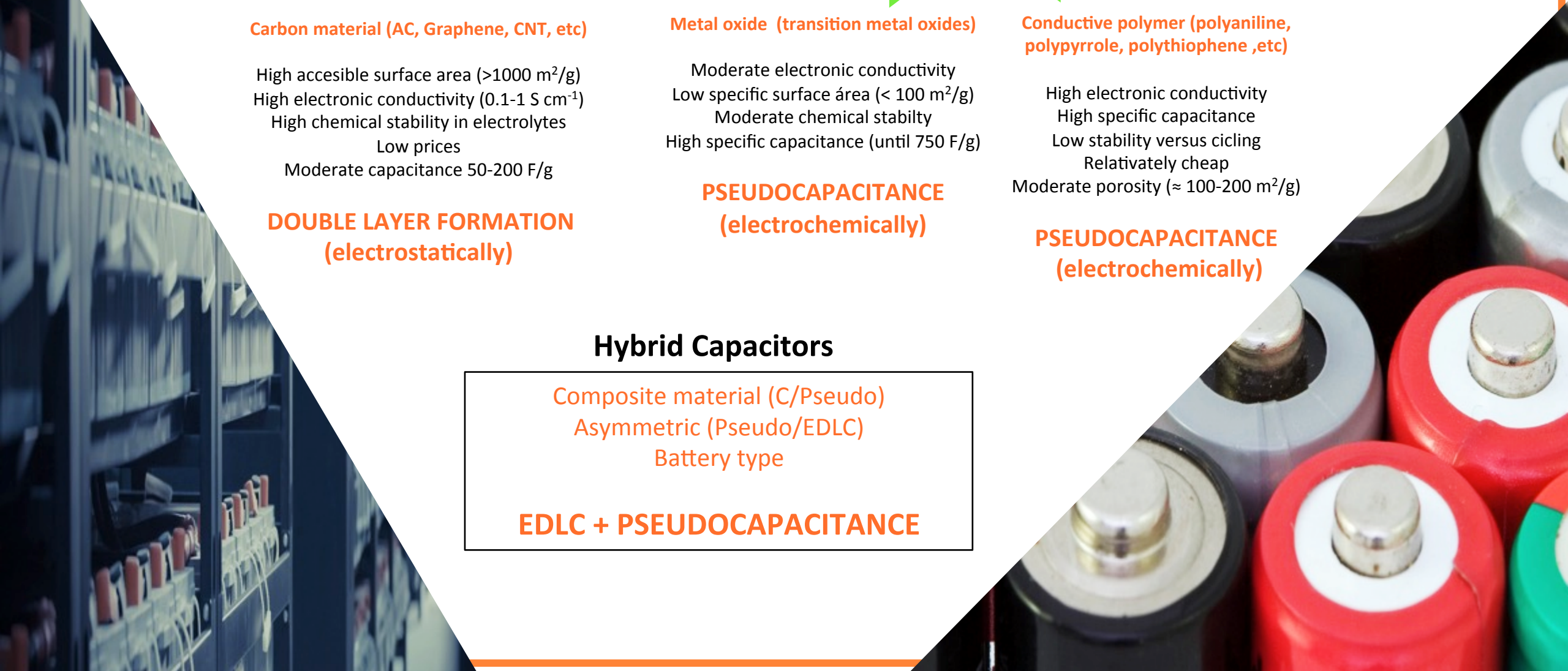
High electronic conductivity
High specific capacitance
Low stability versus cycling
Relatively cheap
Moderate porosity ($\approx 100-200 \text{ m}^2/\text{g}$)

**PSEUDOCAPACITANCE
(electrochemically)**

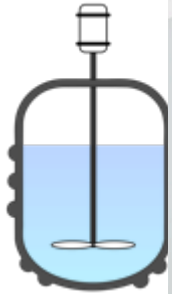
Hybrid Capacitors

Composite material (C/Pseudo)
Asymmetric (Pseudo/EDLC)
Battery type

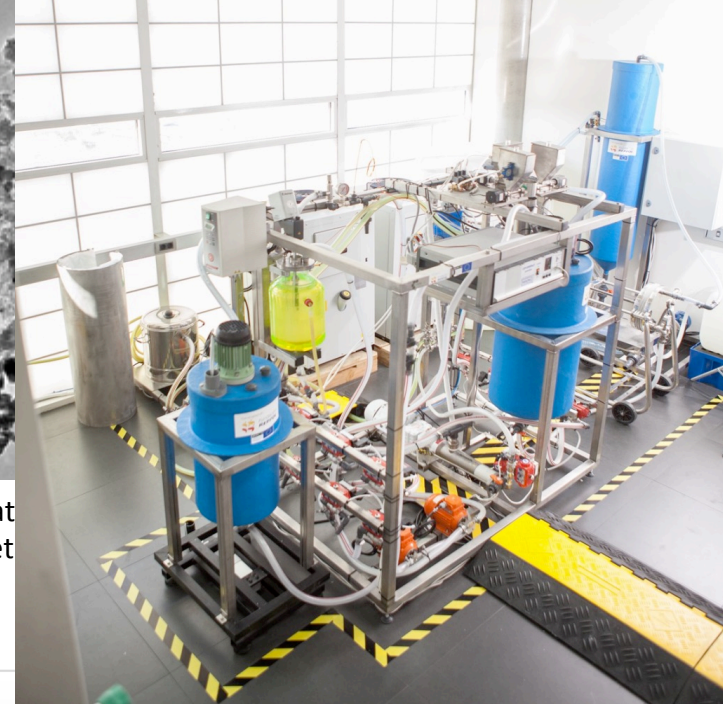
EDLC + PSEUDOCAPACITANCE



Supercapacitors



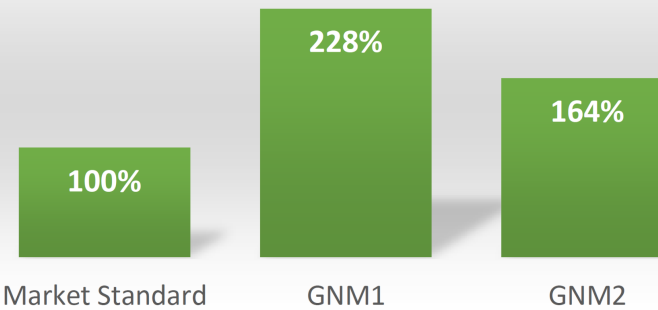
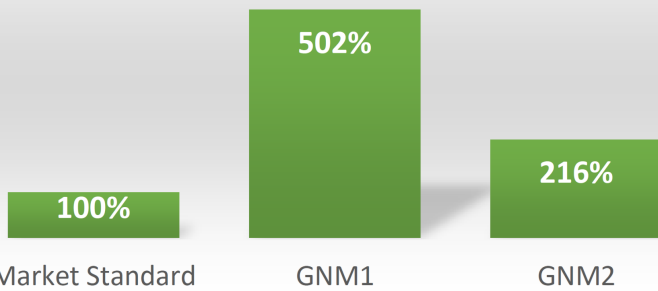
Metal NPs in c



onse:
"pseudocapacitance"

C (F g⁻¹)

Wsp (WhKg⁻¹)



Versarien USPs

- Scaled up manufacturing process to produce 2D materials.
- Modular and automated manufacturing plant to install globally.
- IP processes and trademarks.
- Unique access to global companies via seconded UK Government officials.
- R&D Facilities at Manchester and Cambridge Universities.
- Catapult facilities at leading UK Institutions.
- Financial investment where required.
- World leading research scientists.

Summary

- ◆ Versarien are positioning themselves with a number of leading global companies (Fortune 100 / Fortune 500 companies)
- ◆ The principal objective is to ensure we have true global partners who can work together with Versarien to drive many years of technological innovation with 2D materials.
- ◆ Several years worth of potential development with new un-explored and undiscovered 2D materials

Tomorrow's 2D materials...



The Graphene Council

Verified Graphene
Producer 2019-2020



- Nanene™
- Graphene HP
- Graphene Oxide & Reduced GO (RGO)
- GraphInks™
- h-Boron Nitride (Hexotene™) -
...available today



GRAPHINKS



Hexotene

Versarien
PLC