

Graphene Commercialisation – Summary of Industry Consultation Workshops

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HVM Graphene 2013 Conference, 5 Nov 2013 Cambridge

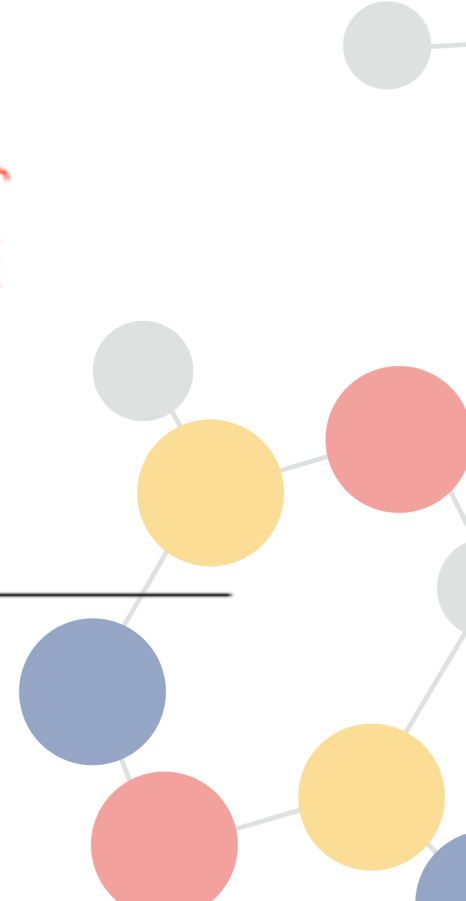
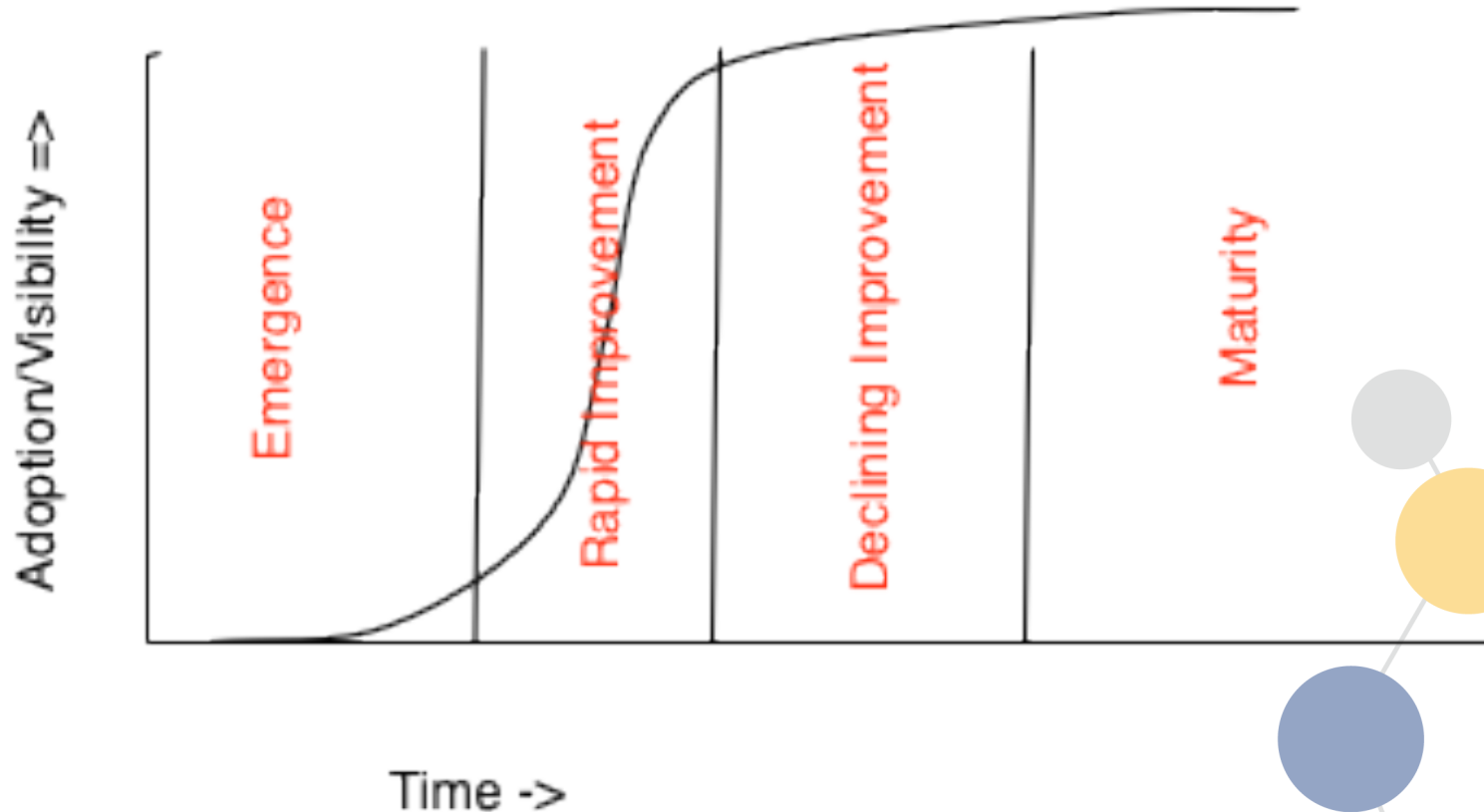
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Technology Strategy Board

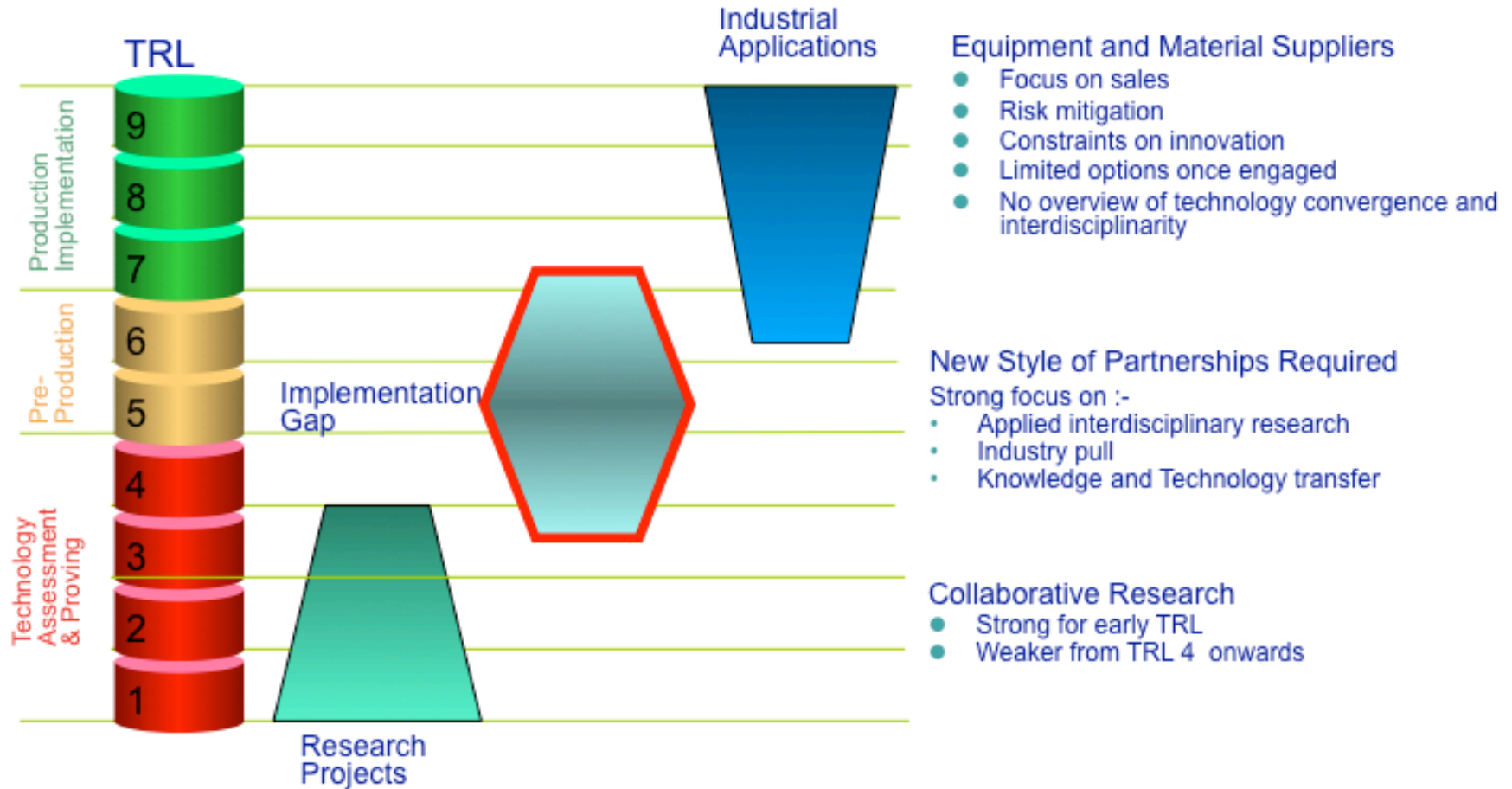
Driving Innovation



Innovation S-Curve

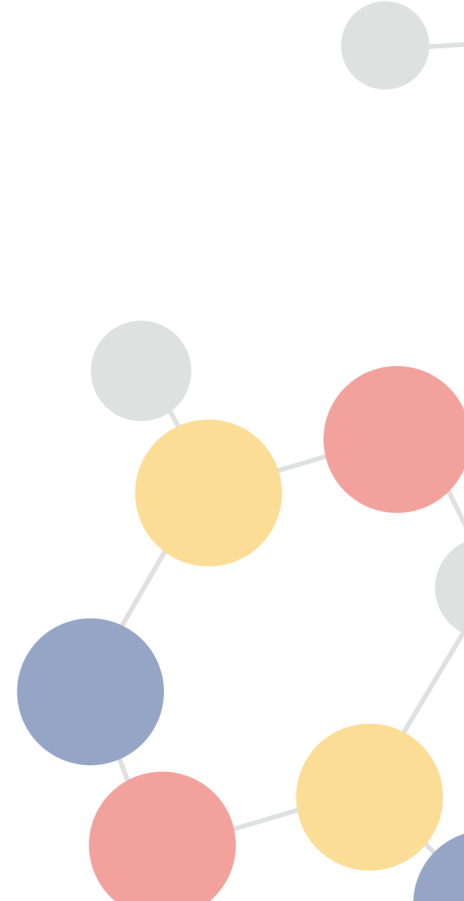


Technology Readiness Levels



Graphene Formats

- ‘Large Area’ epitaxial Graphene:
 - CVD
 - ALD
 - Thermal
- Flake or ‘Bulk’ Graphene
 - Liquid phase exfoliation of graphite
 - Graphene oxide route
 - CVD ‘graphene reactor’
 - Vapour phase deposition



Consultation Format

- Two industry consultation events held in March 2013:

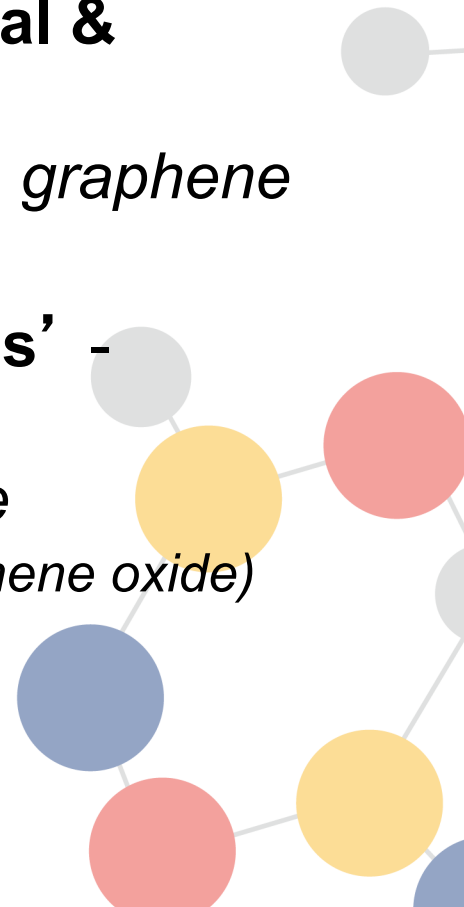
‘Commercialisation of Graphene for Electrical & Electronic Applications’ - London

Primarily considered ‘large area’ or ‘epitaxial’ graphene

‘Graphene for Bulk & Structural Applications’ - Manchester

Primarily considered ‘Flake / ‘Bulk’ Graphene

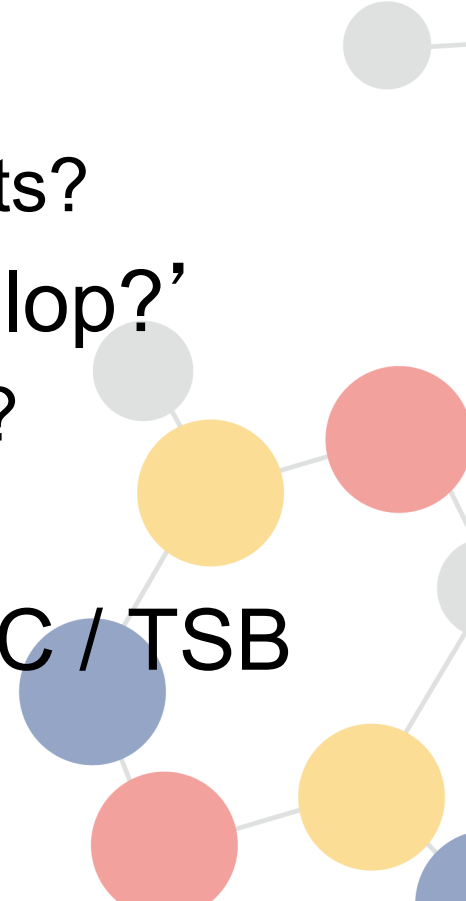
– (Included mono/ few / many layer forms and graphene oxide)



Consultation Events - Questions Considered

1. ‘How big are the potential markets for graphene?’
 - what are the potential markets?
 - the potential value of these markets?
2. ‘How long will they take to develop?’
 - what are the timescales to realise?
 - the barriers & accelerators?

Outputs: Produce reports for EPSRC / TSB



'Commercialisation of Graphene for Electrical & Electronic Applications'

– London March 2013

End Users – Large Companies

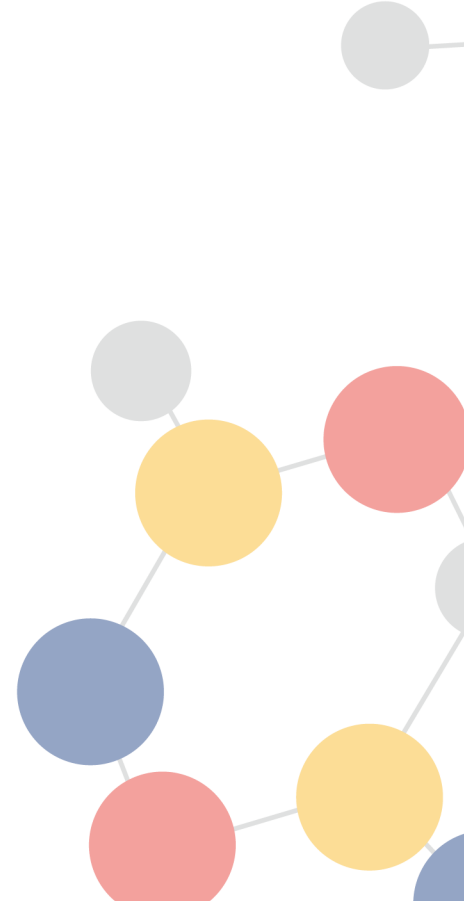
- **Philips Research** - Ruud Balkenende
- **Johnson Matthey** – Dr Rob Potter
- **Intel** – Bernie Capraro
- **BAE Systems** – Dr Russ Morgan

End Users - Specialist SME Companies

- **Plastic Logic** – Dr Mike Banach
- **Novalia** – Chris Jones

Supply Chain

- **Oxford Instruments** – Frazer Anderson
- **JEMI** – Ian Burnett
- **Printed Electronics** – Steve Jones



'Graphene for Bulk & Structural Applications'

- Manchester March 2013

Graphene - the Patent Landscape

- Rich Corken, Head of Informatics, Intellectual Property Office

Graphene Commercialisation – Challenges & Opportunities

- Dr Andy Goodwin, Commercial Director – Thomas Swan & Co Ltd

Industrial Challenges for Graphene in Coatings & Chemicals

- Dr Simon Gibbon, AkzoNobel

Graphene Synthesis: A Perspective on Scale-Up Issues

- Prof Karl Coleman, CTO, Durham Graphene Science

Progress in Graphene Standards and Measurement

- Dr Andrew Pollard, NPL

Facilitated Break-out Sessions



Large Area Graphene - applications 1

Application	Market Sector	Global Product Market Size £
Compound Semiconductor wafers	Electronics	£200m+
OLED	Lighting	£10bn
Sensors, optics and electronics	Electronics	£100m
Sensors, optics and electronics	R&D	£100m
Chemical detection	Defence	£100m
Flexible screens + flexible electronics and Sensors + Detectors	Process Equipment Supply	£?
Touch Screens	Consumer electronics	£?
Transparent electrodes, optoelectronics	Flexible Electronics and Advanced optoelectronics	<£4m £5bn (2025)

Large Area Graphene - applications 2

Application	Market Sector	Global Product Market Size £
Flexible displays, lighting, photo-voltaics / transparent electrode (ITO replacement)	Flexible electronics	£50bn (2020)
Plastic electronics – transistors and other electronic components for ultra-high speed electronics	Wearable electronics, consumer electronics, smart packaging, healthcare, automotive, aerospace	£25bn (2020)
Imaging	Aerospace	£100m
SSL	Electronics	£?
RF and Microwave devices	Defence	£100m
Electronic components	Test & Measurement	£30m

Large Area Graphene - applications 3

Application	Market Sector	Global Product Market Size £
Flexible OLED	Displays etc	£3-5bn (2020)
High frequency flexible electronics	Electronics	£?
Printed electronics in toys	Consumer Electronics / Toys	£2bn (2018)
Electronic toys	Toys	>£10bn
Invivo & Invitro sensors	Healthcare	£?
Conducting cables / Composite conductors	Electrical/Electronics	£?
Conductive inks	Flexible electronics	£?
Interactive posters/Point Of Sale/ Promotional/Marketing/ Packaging	Consumer Electronics	£2bn

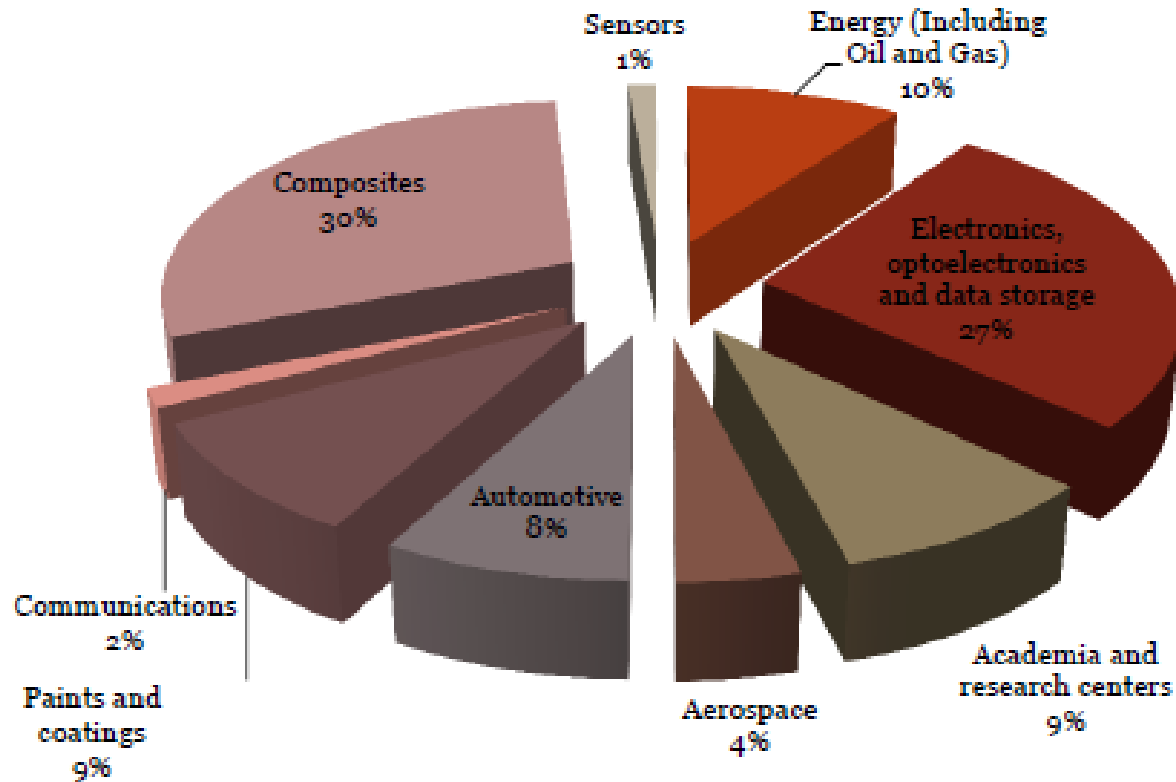
Bulk Graphene – Engineering & Energy Applications 1

Application	Market Sector	Global Product Market Size £
Catalysts, fuel cells, batteries, solar cells	Energy	>£10bn
Structural materials, supercapacitors, packaging	Composites, Energy, Barriers	<£3.3m (2013) £100m (2023)
Imaging	Aerospace	£100m
Thermally & electrically conducting composites	Composites	£?
Fillers for Resins & Composites, Lightweighting	Aircraft structures, UAVs, Space satellite structures	£?

Bulk Graphene – Engineering & Energy Applications 2

Application	Market Sector	Global Product Market Size £
Anodes for Lithium-ion batteries. Supercapacitors	Energy storage	£1bn (2023)
High gas barrier packaging film	Packaging	£?
Cases for mobile phones, domestic products	Consumer Products	£?
Membranes- Gas & water separation, CO2 capture, water purification	Aircraft fuel tanks, Environment	£?
Solar panels	Energy	£?
Antimicrobial coatings	Healthcare	£?

Demand for Graphene by Market, tons, percentage 2017



REF: Future markets Inc 2012

Bulk Graphene Recommendations 1

1/ Networking and Coordination of UK Based Graphene Activities

2/ Support for the Scale-up of Graphene Production

- Quantity - to manufacture 1kg quantities of graphene with a range of characteristics
- To make this material available to UK companies for application development
- To fund research into conversion of graphene into an intermediary product (e.g functionalisation, formulation, dispersion etc).
- Support for the Development of Applications of Graphene
- A fundamental requirement is lack of application specific data.... to demonstrate feasibility and benefits of using graphene in specific applications..

Bulk Graphene

Recommendations 2

3/ Community Engagement

- ...The purpose would be to allow information sharing such as test data and standards, open cross-market opportunities and provide access to support mechanisms, as well as assist supply chain development.

4/ Measurement and Standards

- An important aspect of commercialisation is health, safety and standardisation, with REACH legislation an important factor for the UK to address pre-emptively. ...Is it recommended that the work of NPL and the CIA should be expanded to include graphene.

5/ Support for Market Development

- ...the international dimension is therefore seen as crucial to future commercialisation, particularly noting that many of the OEMs interested in graphene are multinationals. ...(e.g. via Science Innovation Network) and trade missions (e.g. via UKTI). Involvement of UK organisations in the Graphene Flagship should be actively encouraged, noting the potential to join the consortium through the open call in November 2013

Bulk Graphene Timescales to Significant Market Volumes

1-3 years

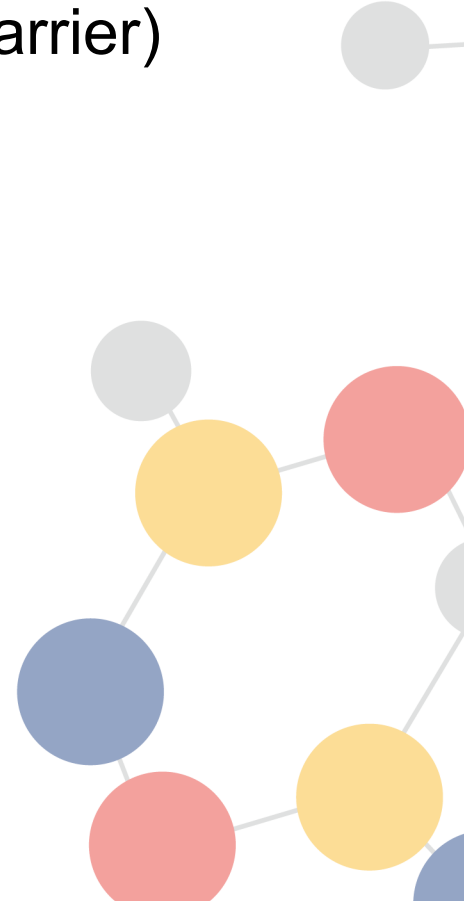
- Energy storage devices
- Barrier materials (e.g. high end packaging /barrier)
- Paints, coatings, inks

3-5 years

- Composites (e.g polymer)
- Membranes
- Barrier materials (e.g. consumer packaging)

5-10 years

- Healthcare



Key Issues & Recommendations for Electrical and Electronic Applications

Supply Chain

- The development, equipment manufacturing and supply chain in the UK for graphene enabled applications is starting to thrive, especially the process/deposition equipment manufacturers.

Materials Supply

- There is a current urgent need for good quality material to be produced of a consistent and repeatable quality which can be up-scaled in terms of volume while maintaining reproducibly low electrical resistance (Ohms per square). This will then enable a range of new products to be commercialised. Also, two specific additional related issues need to be addressed immediately:
 - a) How can we make good (Ohmic) electrical contacts to this material so that we can incorporate (its potential excellent) electrical properties into an electrical circuit, for improved system performance? Ideally the developed process-step should be in the form of a ‘drop-in’ into an existing production process flow, most probably replacing an existing process-step.
 - b) How can we make a device from this material at a reasonable cost, employing cost competitive deposition and measurement techniques?

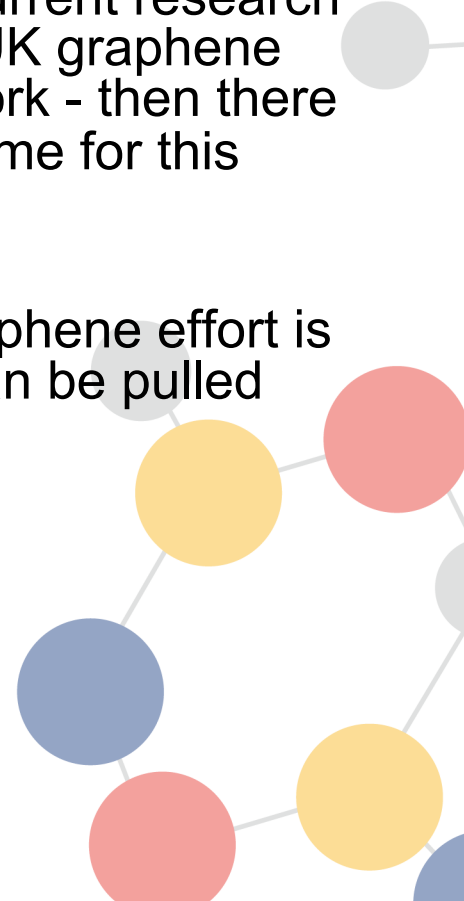
Key Issues & Recommendations for Electrical and Electronic Applications

Funding

- EPSRC Investment in the academic infrastructure must be built on in the next few years by industry to safeguard our national economic interest. The studies undertaken in the current research funding should also be targeted at developing the UK graphene **supply chain**, in addition to applications-related work - then there will be a worthwhile and significant economic outcome for this country.

Coordination

- A top down approach to coordinating all the UK graphene effort is strongly suggested as the community is small so can be pulled together by government organisations.



Key Issues & Recommendations for Electrical and Electronic Applications

Time scales for commercialisation

- The UK needs to target applications that can be ready taken up by UK industry & UK-based companies, for economic return-on-investment to the country (within the next five years or so).
- For exploitation in the first 5 year time-frame, **Sensor and super-capacitor applications** should be targeted (which can be directly implemented by our existing companies in these two sectors). Here relatively low-volumes of material are required, the production of which can be achieved with a modest capital equipment spend. Also, there should be a concomitant development of the **supply-chain** for these two application areas.
- In the longer term, in the 8 to 10 year time-frame, applications in the electronic display arena will also occur, although it is envisage that this development will be **primarily** driven by the large multi-nationals in Korea & Japan. For Nanoelectronics applications (chips), more than 10 years will be required for commercialisation.

Barriers to commercialisation

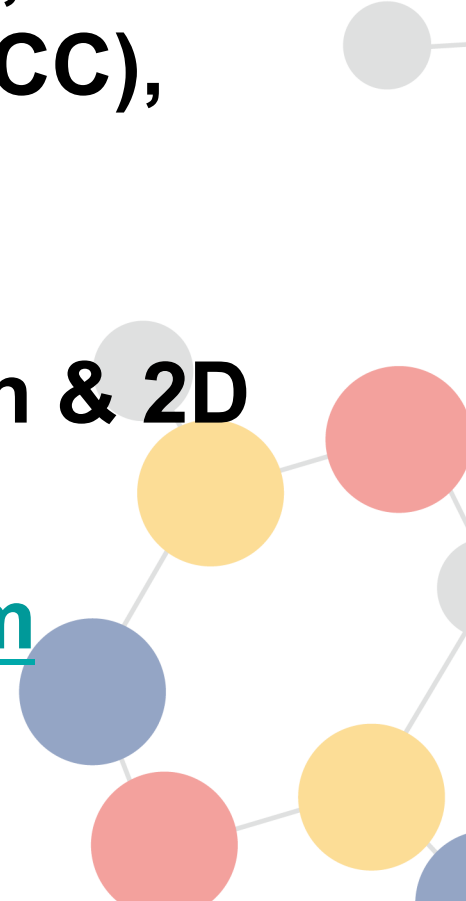
- On the manufacturing side, the main barriers are:
- production volumes being too small
- the quality/ constituency not being reproducible/ repeatable.

This leads to difficulties in producing prototypes and supplying larger feasibility studies.

Graphene Events

- **Graphene & Nanofillers for Composites Workshop, 5th December 2013, National Composites Centre (NCC), Bristol**
- **Industrial Measurement & Characterisation of Nanocarbon & 2D Materials, 10th Dec, Newcastle**

For details see www.nanoktn.com



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