www.manchester.ac.uk/business

MANCHESTER 1824
The University of Manchester

National Graphene Institute

GRAPHENE - Beyond the sticky tape

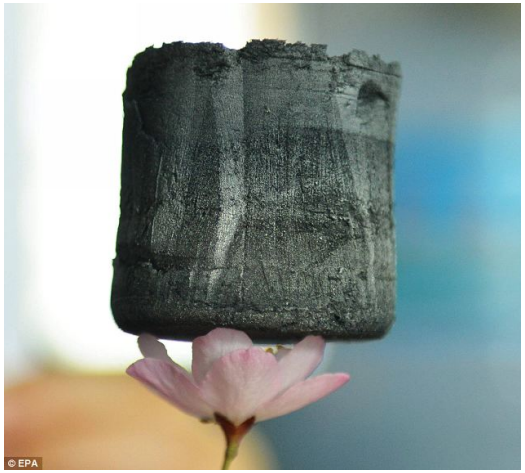
Paving the way towards the commercialisation…

Ania Servant, PhD, MSc

MANCHESTER 1824
The University of Manchester

Graphene superlatives

- 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 T (million times of those in copper)
- highest intrinsic mobility (100 times more than in Si)
- conducts electricity in the limit of no electrons
- lightest charge carriers (zero rest mass)
- longest mean free path at room T (micron range)
- most impermeable (even He atoms cannot squeeze through)
- ……?



MANCHESTER 1824
The University of Manchester

Graphene properties

- **Morphological**

Surface area – 1gr = 2630 m^2
Aspect ratio varies – typically 2 for solvent exfoliation

- **Optical**

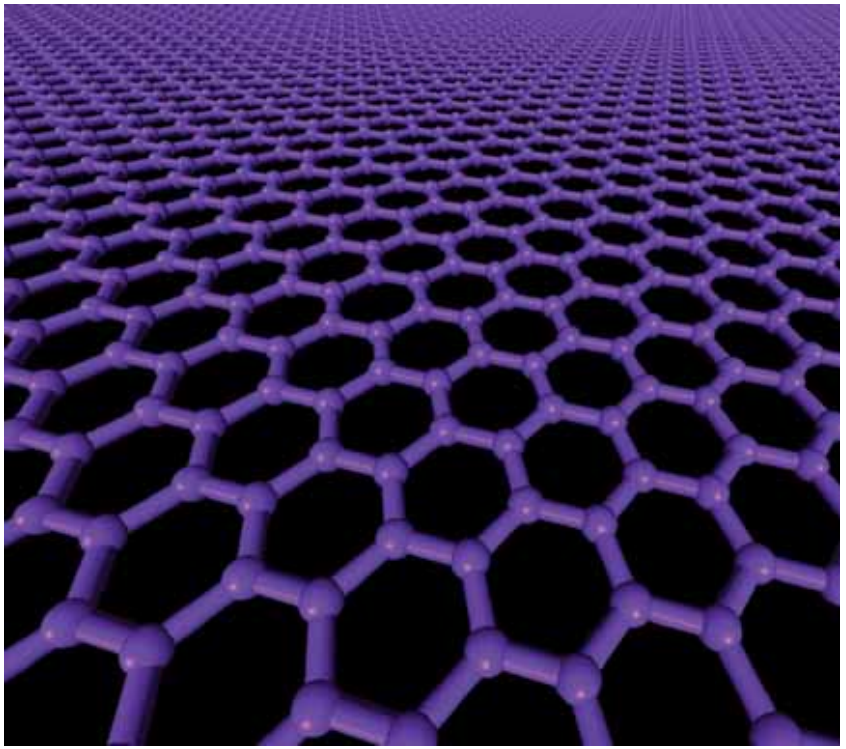
Transparent to light (97.7 %) and electrons

- **Mechanical**

Stiffness = 1 Tpa
Strength = 130 GPa

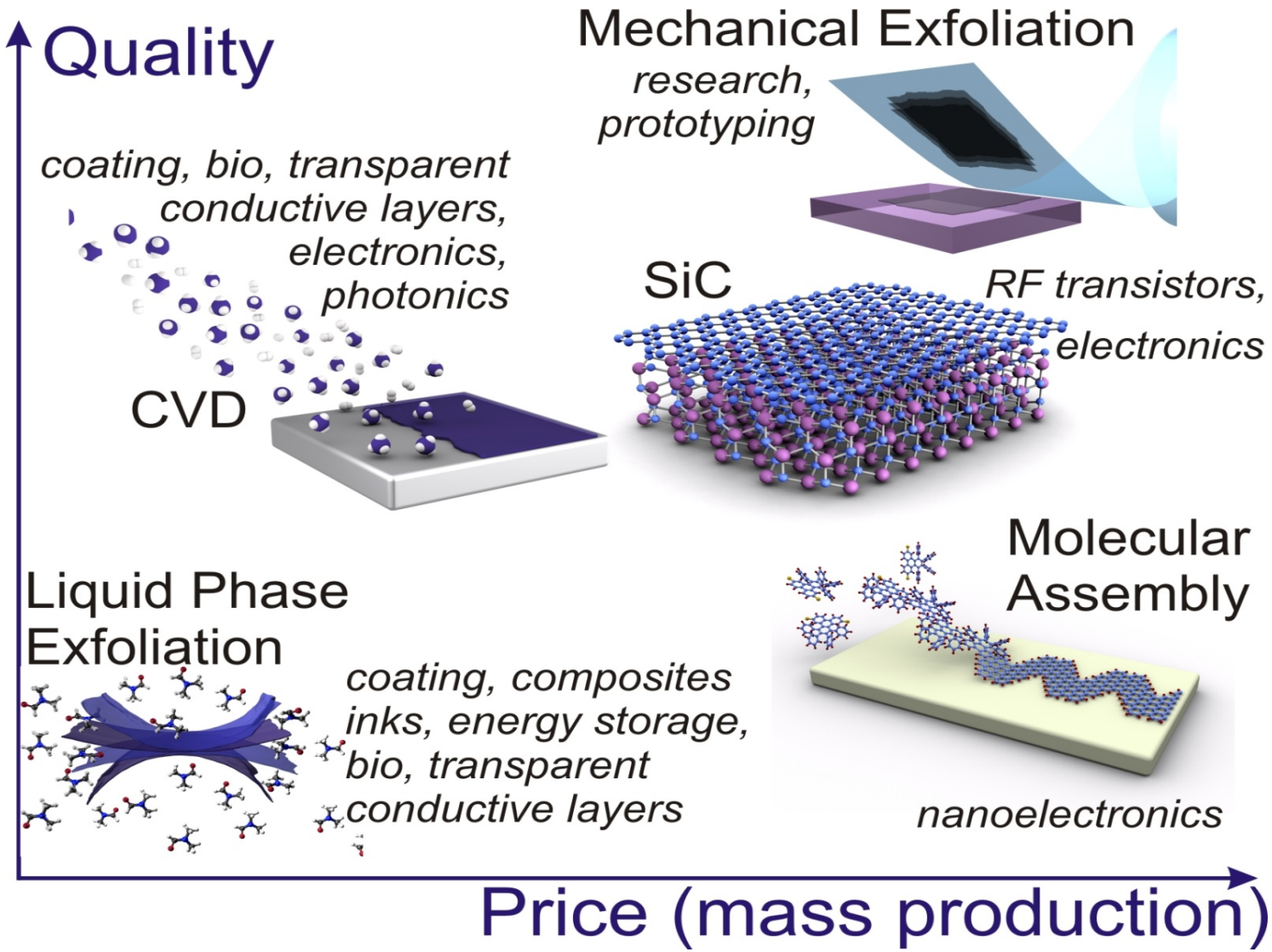
- **Chemical**

Easily functionalised
Processable

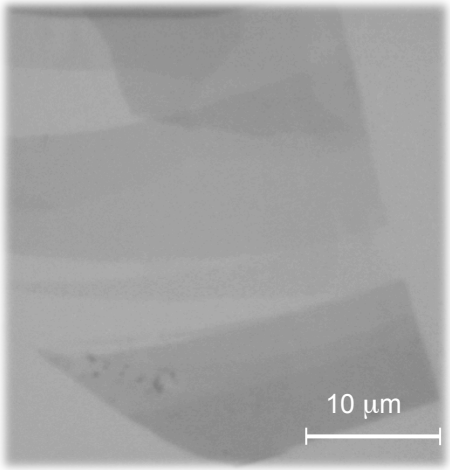


MANCHESTER 1824
The University of Manchester

Producing graphene

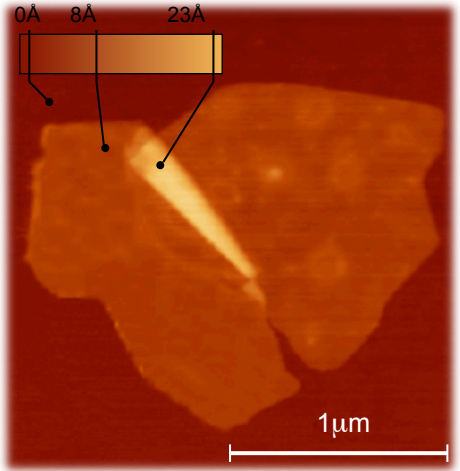


Beyond graphene: other 2D materials



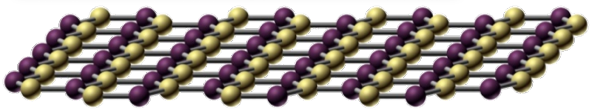
2D boron nitride

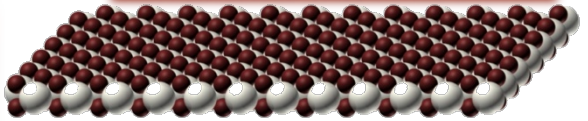
2D $NbSe_2$



From 3D systems

Beyond Graphene

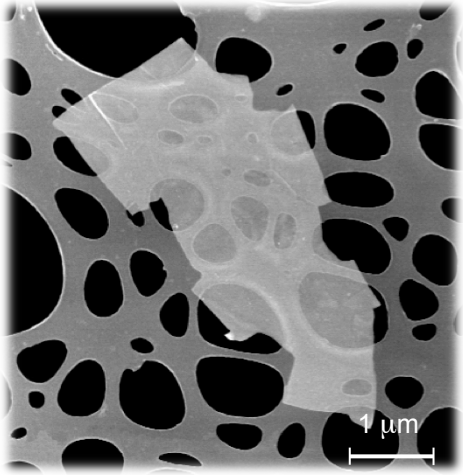




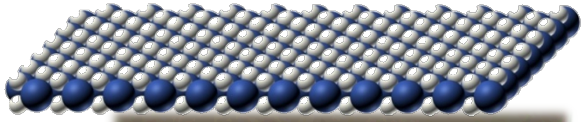
Novoselov et al., PNAS (2005)

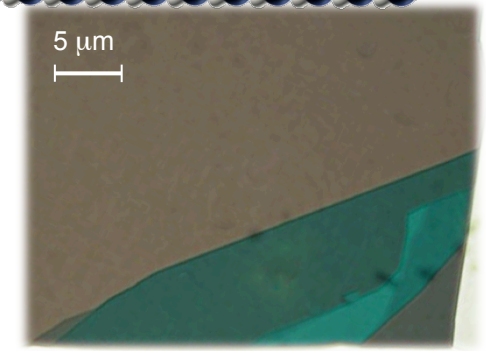
High Quality

Different From 3D Precursor



2D $Bi_2Sr_2CaCu_2O_x$

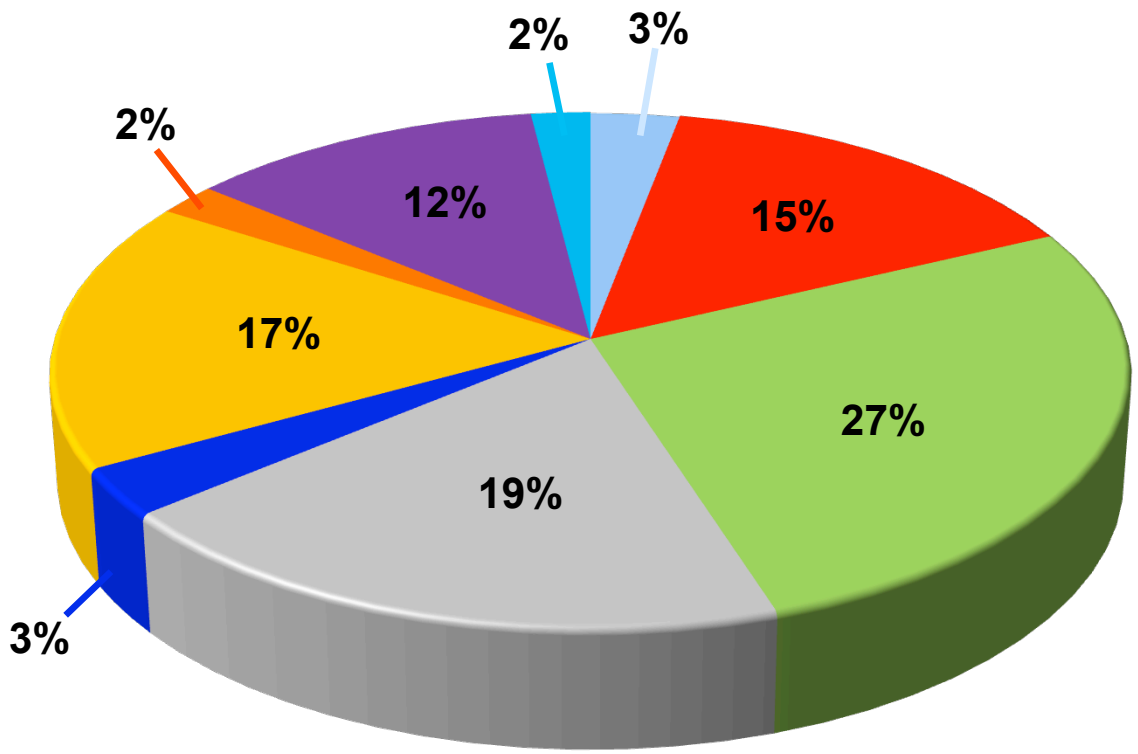




2D MoS_2

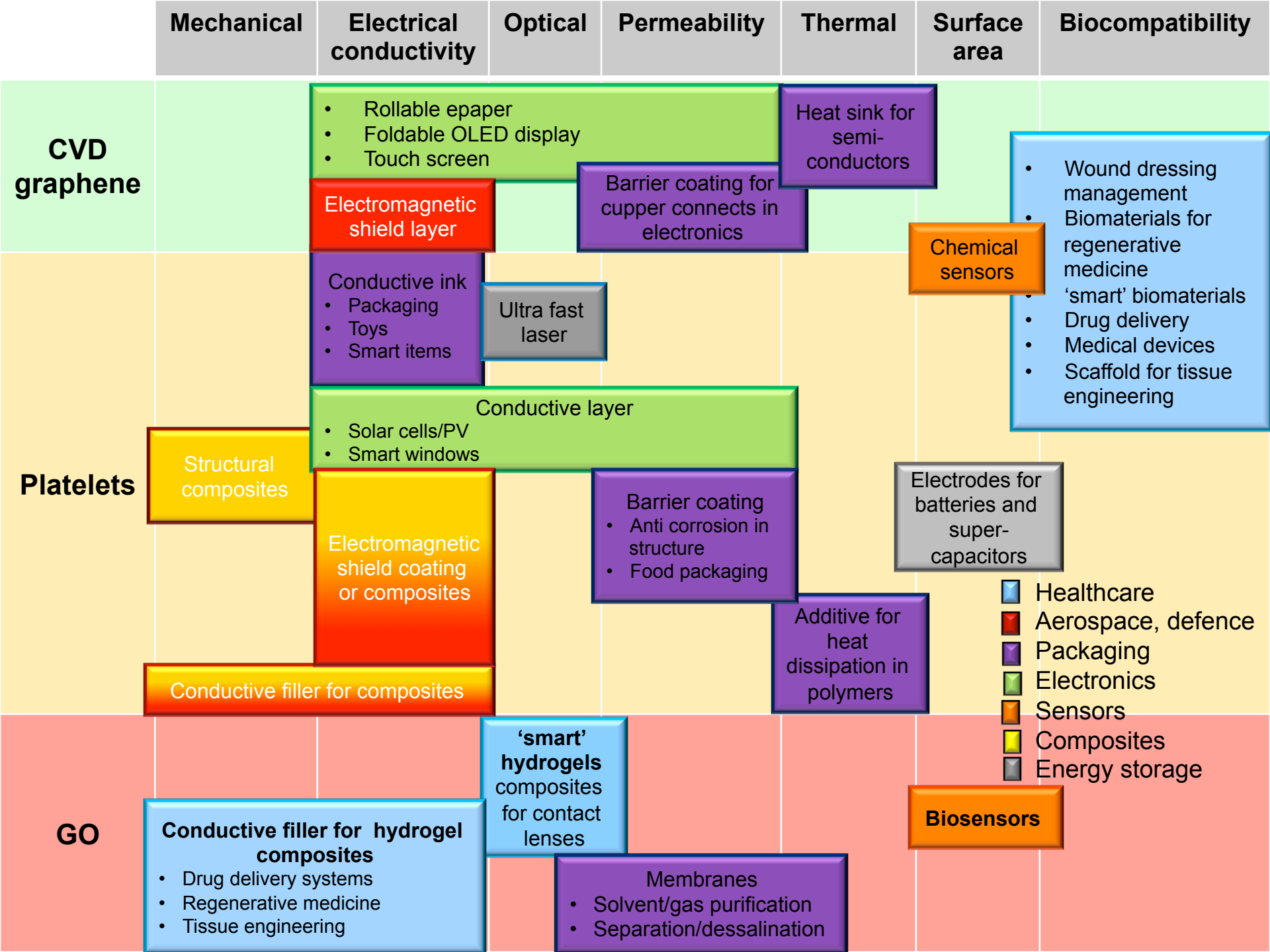
MANCHESTER 1824
The University of Manchester

Application sectors



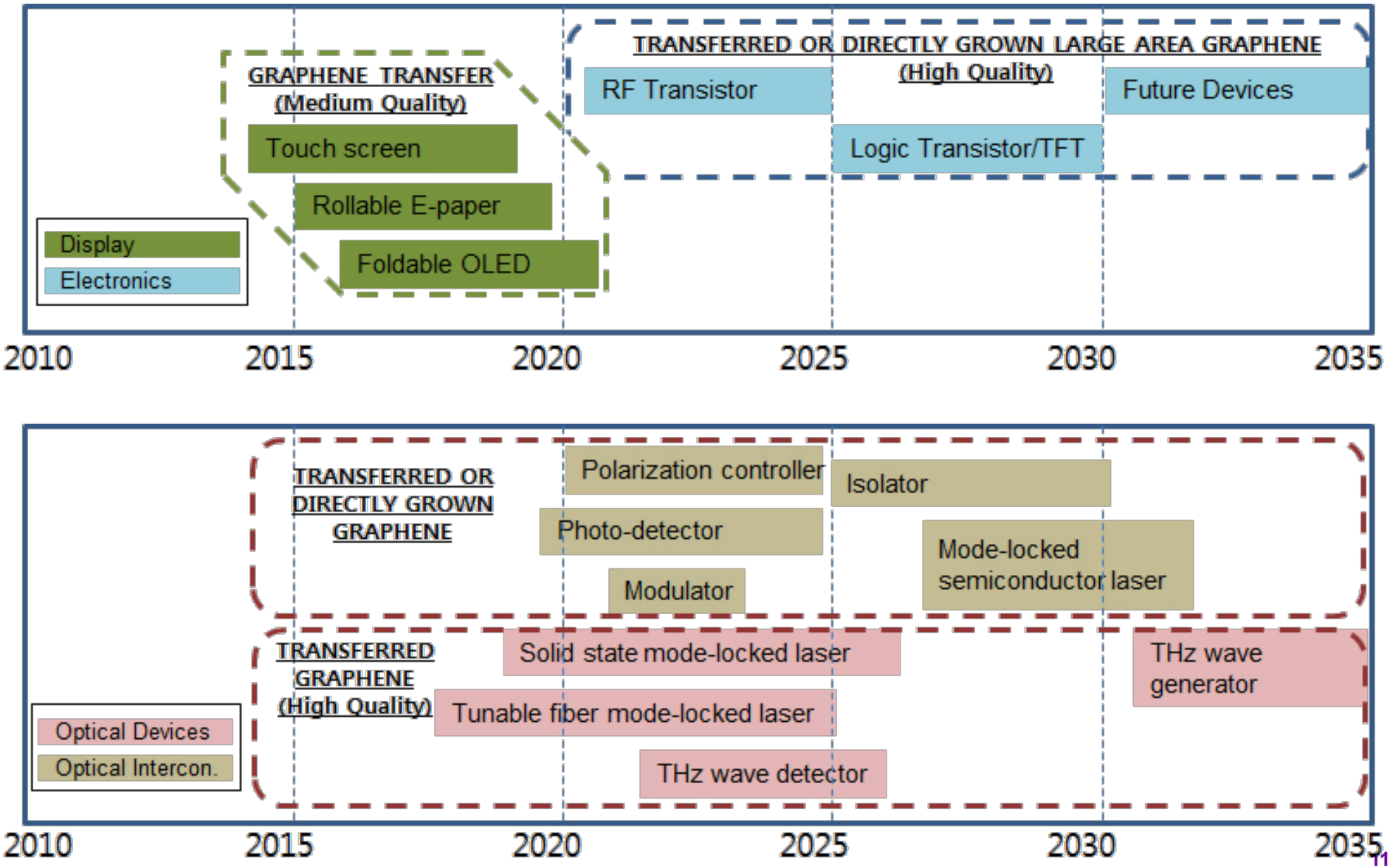
- Healthcare
- Aerospace & defence
- Electronics, optoelectronics and semi-conductors
- Energy Storage
- Automotive
- Plastics, composites
- sensors
- coating, packaging and paints
- telecommunications

Source: Future Markets


Mechanical
Electrical conductivity
Optical
Permeability
Thermal
Surface area
Biocompatibility
CVD graphene
Platelets
GO
Rollable epaper
Foldable OLED display
Touch screen
Heat sink for semi-conductors
Electromagnetic shield layer
Barrier coating for cupper connects in electronics
Chemical sensors
Wound dressing management
Biomaterials for regenerative medicine
'smart' biomaterials
Drug delivery
Medical devices
Scaffold for tissue engineering
Conductive ink
Packaging
Toys
Smart items
Ultra fast laser
Conductive layer
Solar cells/PV
Smart windows
Structural composites
Electromagnetic shield coating or composites
Barrier coating
Anti corrosion in structure
Food packaging
Electrodes for batteries and super-capacitors
Additive for heat dissipation in polymers
Conductive filler for composites
Healthcare
Aerospace, defence
Packaging
Electronics
Sensors
Composites
Energy storage
'smart' hydrogels composites for contact lenses
Biosensors
Conductive filler for hydrogel composites
Drug delivery systems
Regenerative medicine
Tissue engineering
Membranes
Solvent/gas purification
Separation/dessalination

MANCHESTER 1824
The University of Manchester

Graphene road map



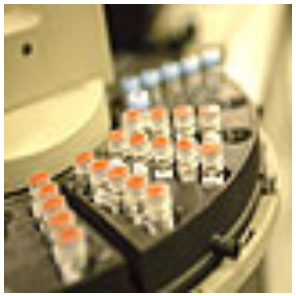
MANCHESTER 1824
The University of Manchester

The National Graphene Institute (NGI)

http://www.graphene.manchester.ac.uk/

MANCHESTER 1824
The University of Manchester

The National Graphene Institute (NGI)



Physics
Fundamental properties
Novel 2D materials and hetero-structures

Spinouts
Graphene research
2-Dtech
Graphene Industries

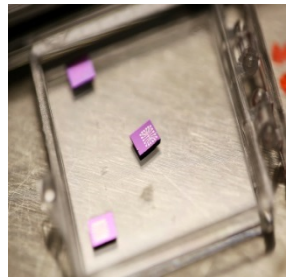
Materials
Process routes
Characterisation
Standards

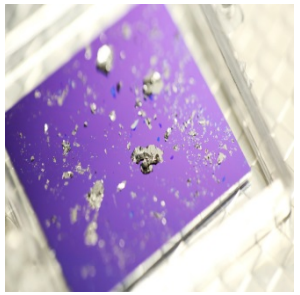
NGI Capabilities

Life Sciences
Sensors, drug delivery
Tissue engineering
Nanotoxicology

Electronics
Sensors
Semiconductor devices

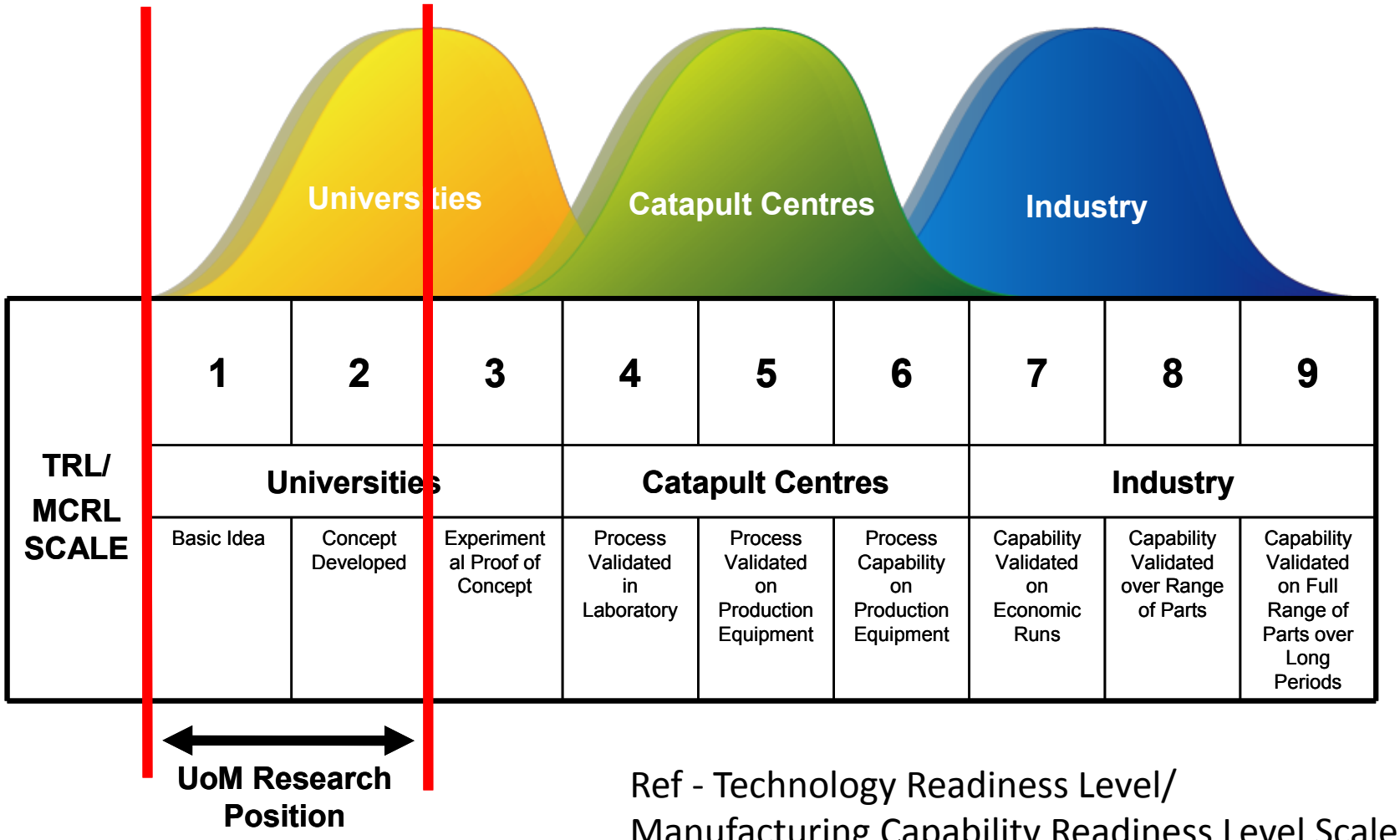
Chemistry
Composites
Membranes, barriers and coatings





MANCHESTER 1824
The University of Manchester

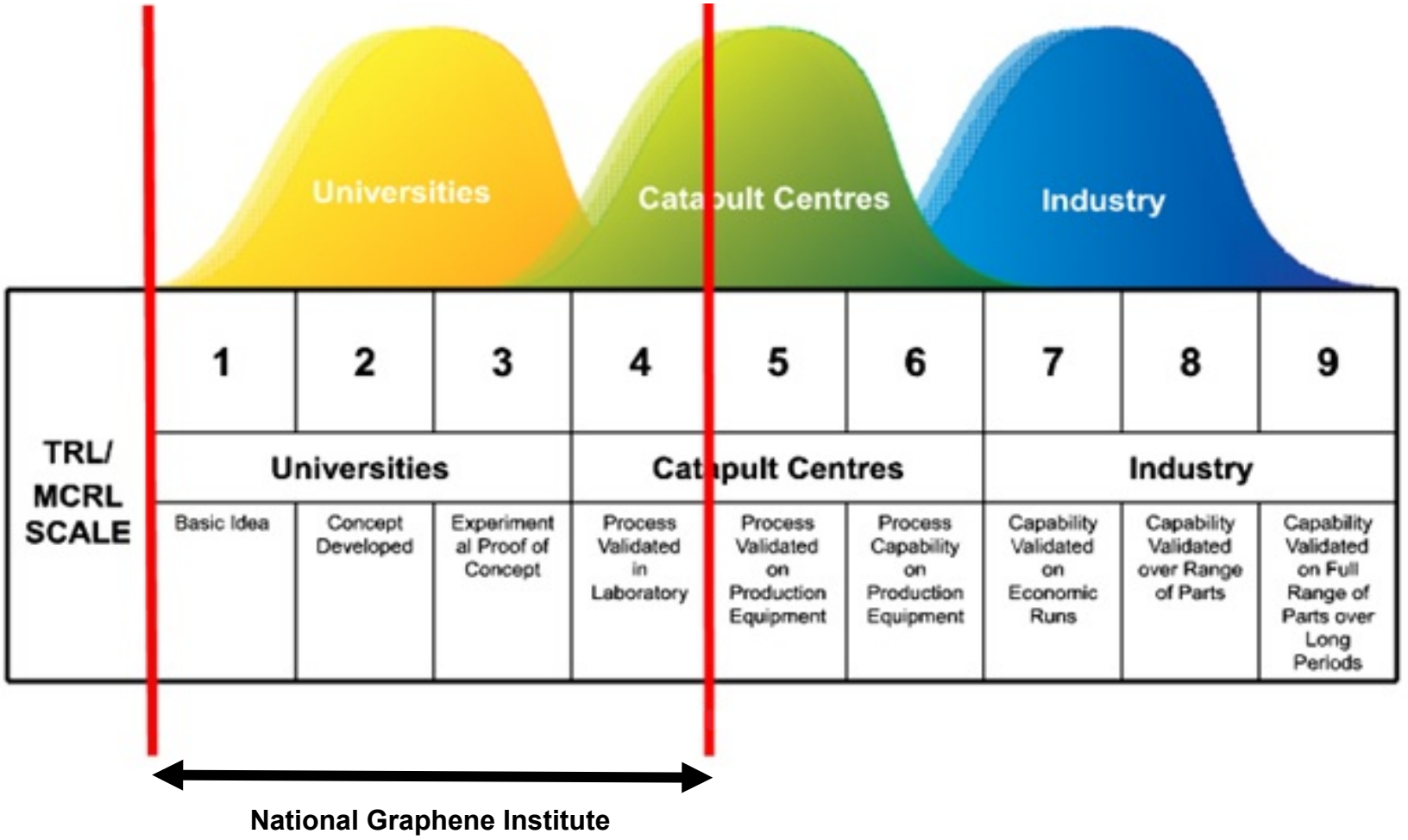
Graphene research



Ref - Technology Readiness Level/ Manufacturing Capability Readiness Level Scale (Source – NASA)

MANCHESTER 1824
The University of Manchester

The National Graphene Institute (NGI)



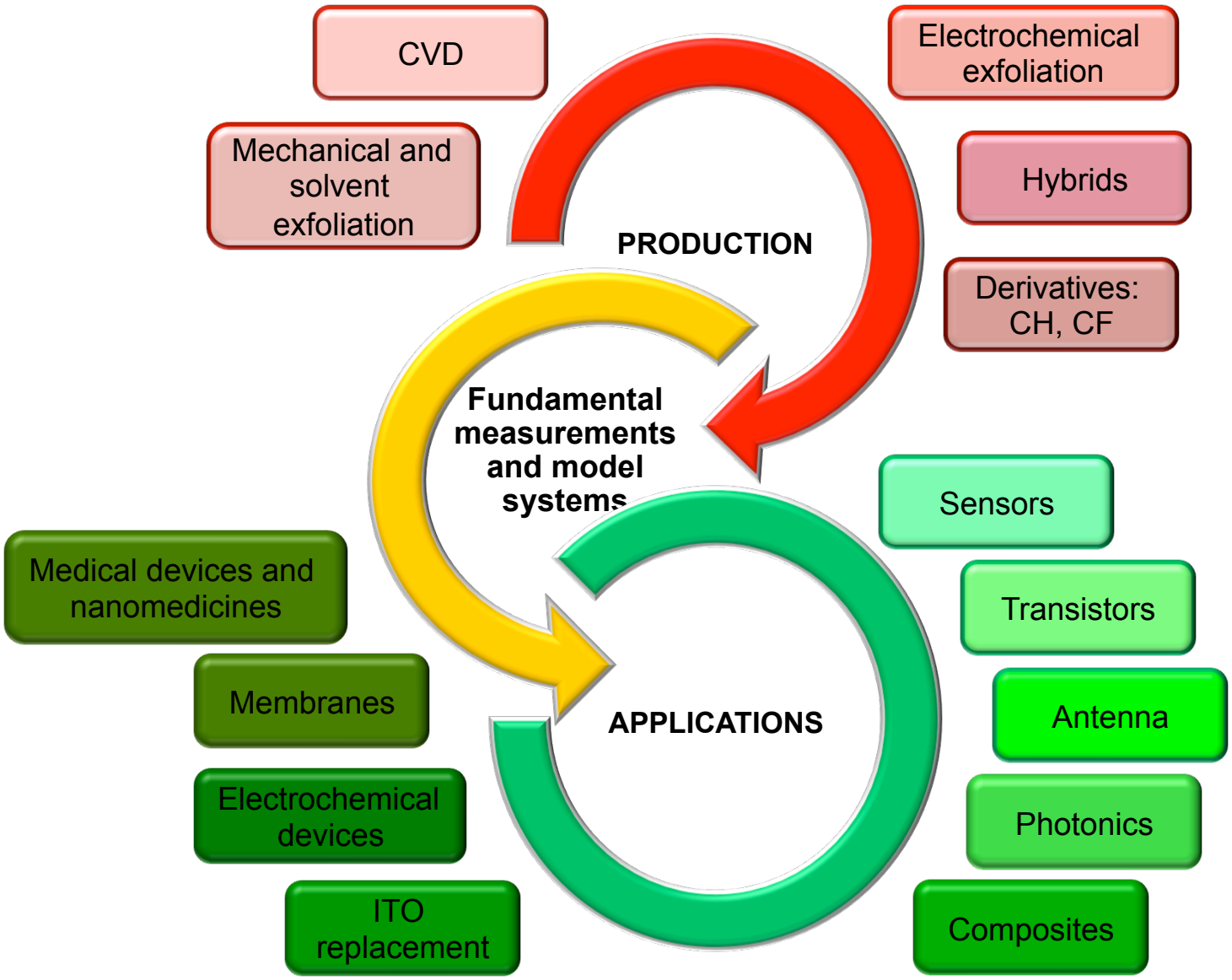
MANCHESTER 1824
The University of Manchester

Knowledge Exchange @ the NGI

To carry out short-term feasibility style, knowledge exchange application projects in the areas of advanced composites, barriers/membranes, surface modification/coatings, energy-storage materials, biomaterials and medical devices

MANCHESTER 1824
The University of Manchester

Graphene capabilities @ the NGI



MANCHESTER 1824
The University of Manchester

NGI Partnership models

Strategic Partnerships

- Mutual partnerships with strategic (≥5 year) goals
- Support for underpinning infrastructure and company /sector specific research
- Both parties bring IP and resources
- Expected ≥£10m programmes
- Partners influence research direction
- Partners gain ins
  research di

Project Partnerships

- Helping companies to put graphene on their roadmaps
- Individual projects, typically 1-3 year duration and topic specific
- Includes Collaborative R&D, Feasibility Studies/ Consultancy, Studentships, KTP, CASE, IAA..

Graphene Industry Group

- The UK National Grouping for graphene materials, characterisation, standards and applications
- Regular industry briefings
- Focus Groups to build Project and Strategic Partnerships

MANCHESTER 1824
The University of Manchester

NGI Industry partners

Strategic Partner

Project Partners: Graphene-based membranes

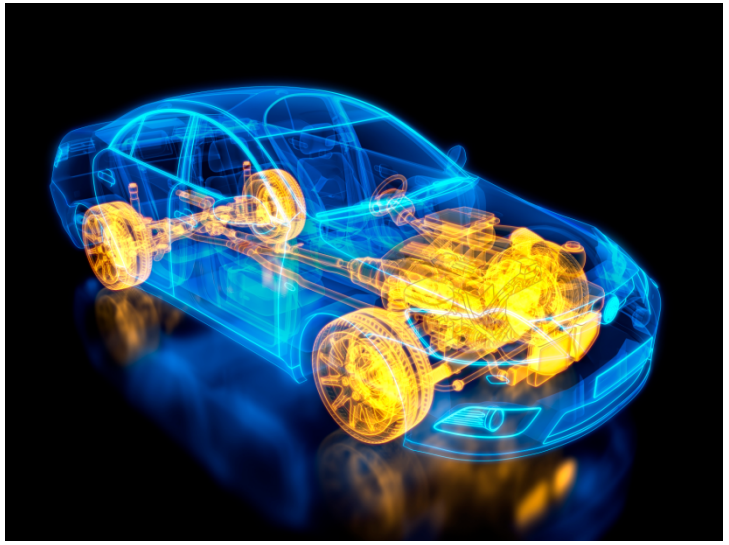
Project Partners: Electrochemical Energy Storage

Project Partners: Other

MANCHESTER 1824
The University of Manchester

Graphene-based composites

- Electrical Functionality
  - Better lightning strike resistance
  - Good anti-static behaviour
  - Improved high-voltage insulation
- Barrier Functionality
  - Improved environmental protection
  - Leak-proof composite gas tank cylinders
- Damage Tolerance
  - Better impact performance
  - Improved fatigue resistance
  - Better wear resistance
  - Strain sensing
- High Temperature Tolerance
  - Improved heat distortion temperature
  - Better fire retardancy



MANCHESTER 1824
The University of Manchester

Graphene-based membranes

- Molecular Separations
- Ionic Conductors
- Sensors
- Barriers

CROWN
Brand-Building Packaging™

➢ Crown is working with the NGI to improve its food packaging products and customer experience through the use of graphene-based membranes as barrier materials

Batteries and capacitors

- Supercapacitors: energy bottle-neck (3-5 W h kg^{-1})
- Batteries: power bottle-neck (10^3 W kg^{-1})

- SHARP is working with the National Graphene Institute to explore the benefits of graphene in electrochemical storage devices.
- SHARP is excited to be part of a project that is looking to produce graphene on a cost competitive scale.

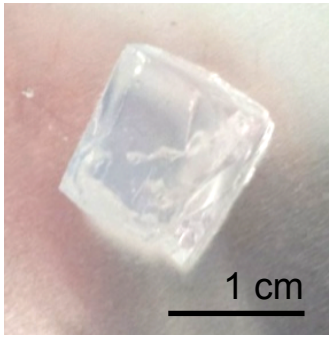
SHARP

0.2 Ah

20Ah

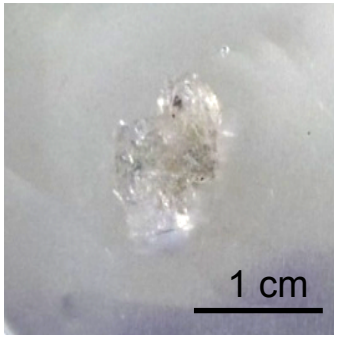
MANCHESTER 1824
The University of Manchester

Biomaterials and Medical devices

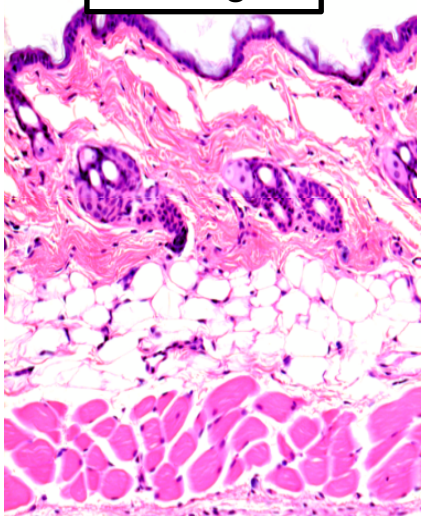


10 V

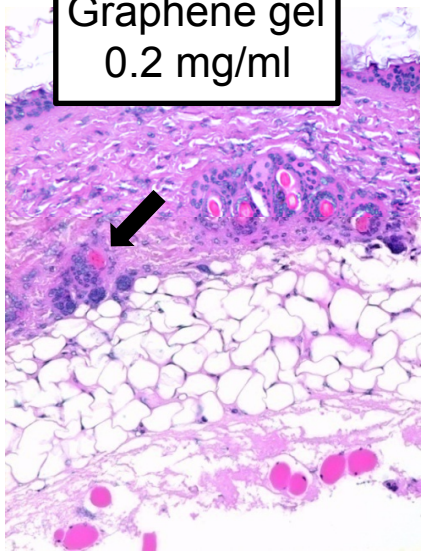
10 min



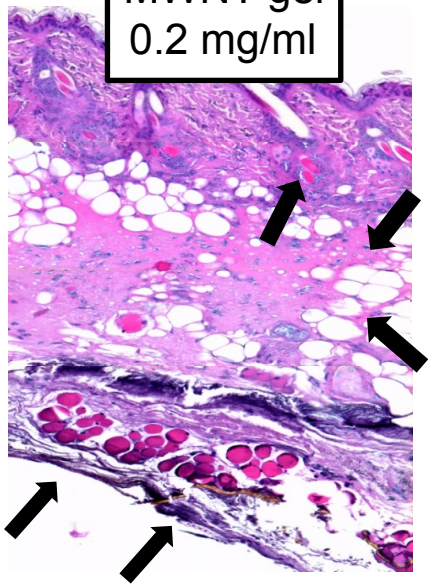
Blank gel

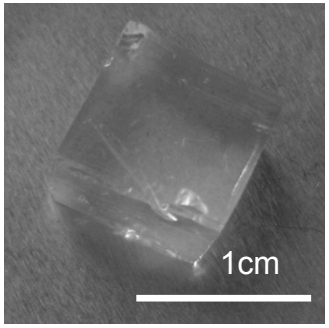


Graphene gel
0.2 mg/ml



MWNT gel
0.2 mg/ml





Servant *et al., Adv. Health. Mater.*, **2014**, *in press*
Servant *et al., BMCL Digest*, **2014**, *24*, 1638-1649