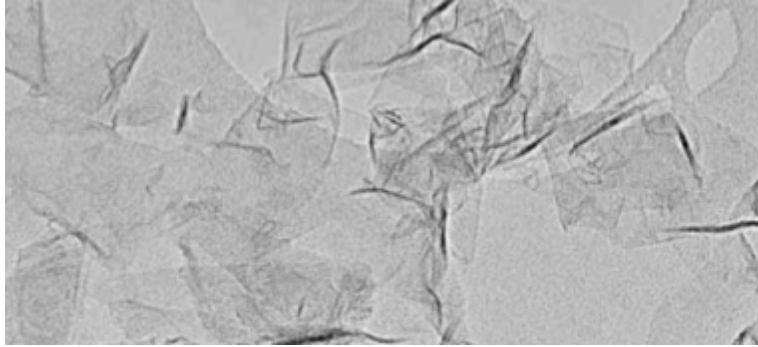


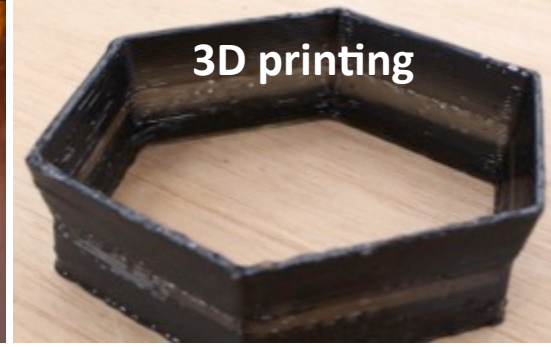
# New Materials & Graphene - The key breakthroughs and applications



Aerospace



Flame resistant



3D printing

15th Anniversary HVM 2017 & 4th Graphene New Materials Conference

2-3 November 2017 Cambridge, UK

[www.cir-strategy.com/events](http://www.cir-strategy.com/events)



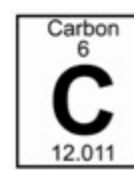
***Professor Krzysztof Koziol***

k.koziol@cranfield.ac.uk

www.cranfield.ac.uk

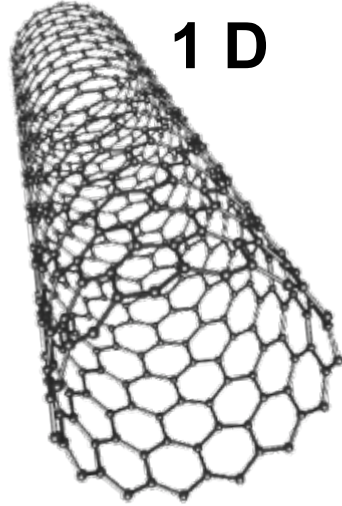


# Nanocarbons

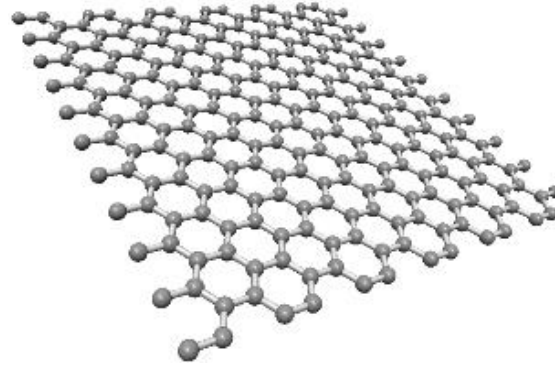


Carbon Nanotube

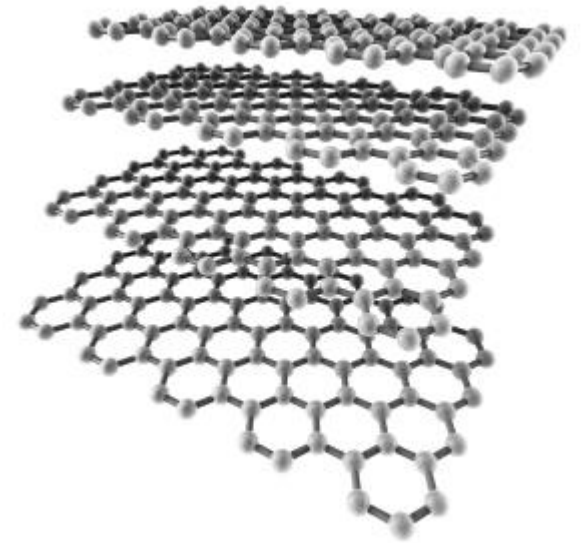
**1 D**



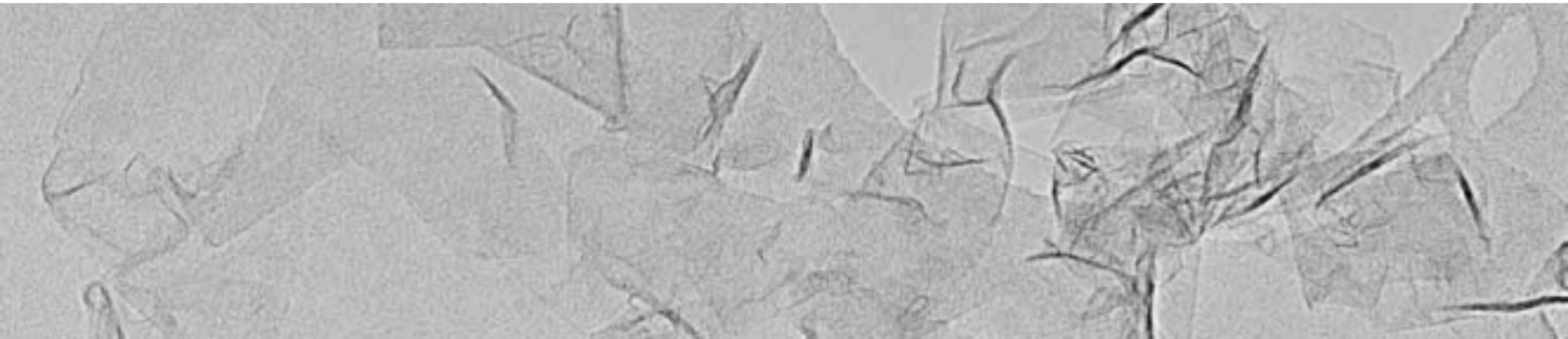
Graphene **2 D**



Graphite **3 D**



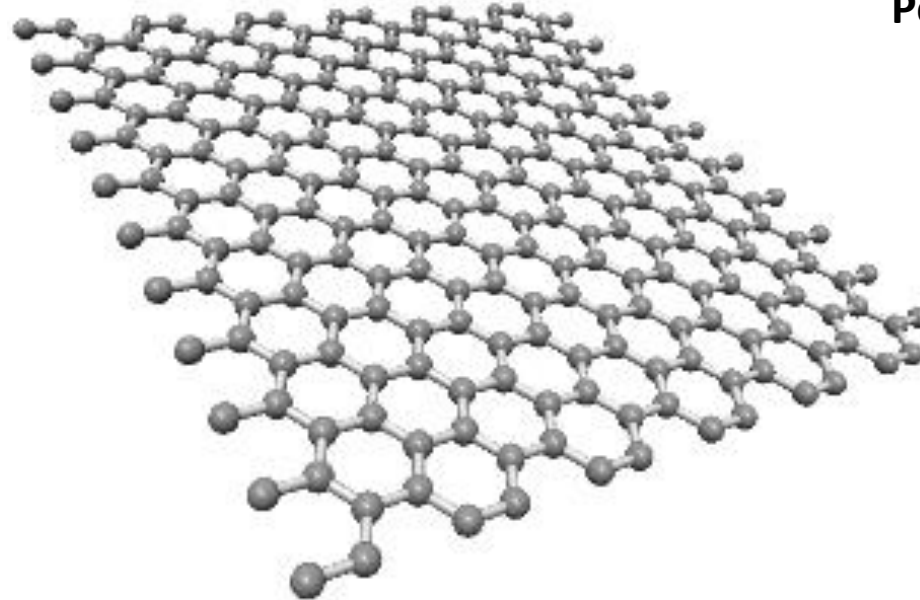
ISO/TS 80004-13:2017(en)





# Graphene

- Very flexible
- Anti flammable
- Ultra light weight
- Corrosion resistant
- High electron mobility (200,000 cm<sup>2</sup>/Vs)
- Absence of skin effect
- Very high surface area (2600 m<sup>2</sup>/g)
- Multifunctional abilities
- Very low electrical resistance
- Extremely high tensile strength
- Very high thermal conductivity (5000 W/mK)
- Shows significant reduction of electromigration
- Resistance has small dependence on temperature
- Can be produced using sustainable methods and raw materials



Power distribution & generation

Telecommunications

Automotive Industry

Microelectronics

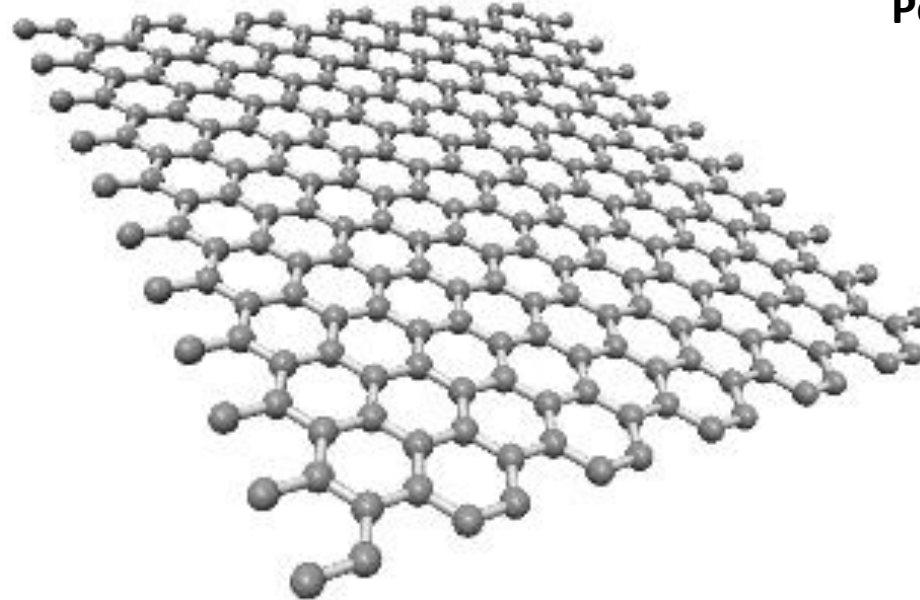
Marine Industry

Aerospace

**Graphene retains the promise of transforming human civilisation more than any other material this century...**

# Graphene

- **Very flexible**
- **Anti flammable**
- **Ultra light weight**
- **Corrosion resistant**
- **High electron mobility**  
(200,000 cm<sup>2</sup>/Vs)
- **Absence of skin effect**
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**Power distribution & generation**

**Telecommunications**

**Automotive Industry**

**Microelectronics**

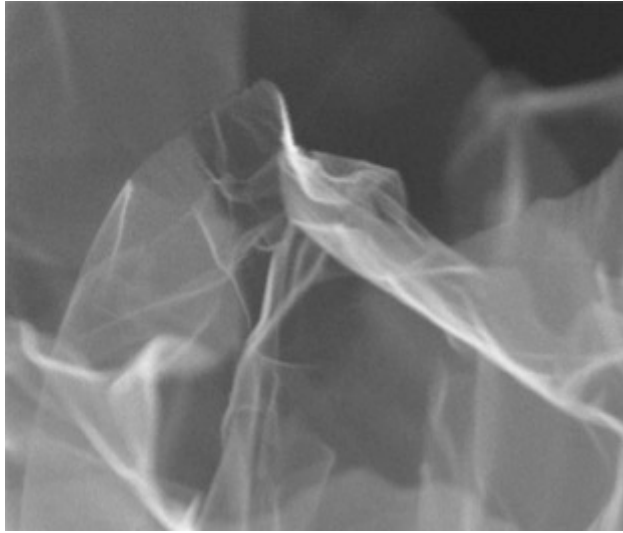
**Marine Industry**

**Aerospace**

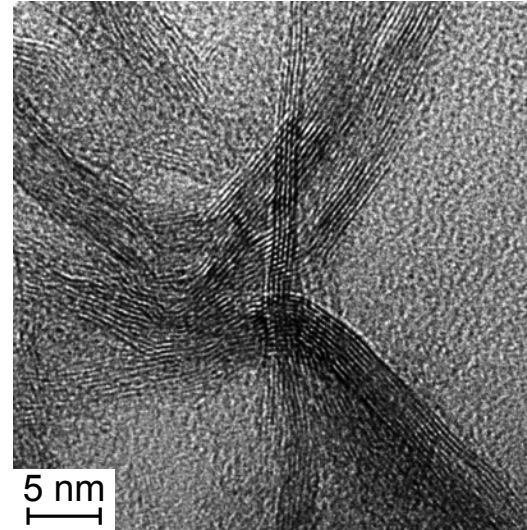
... with enormous capabilities in the continuous fabrication of electrical conductors, electrical networks, electronic circuits and electrical machines.

# Graphene zoo

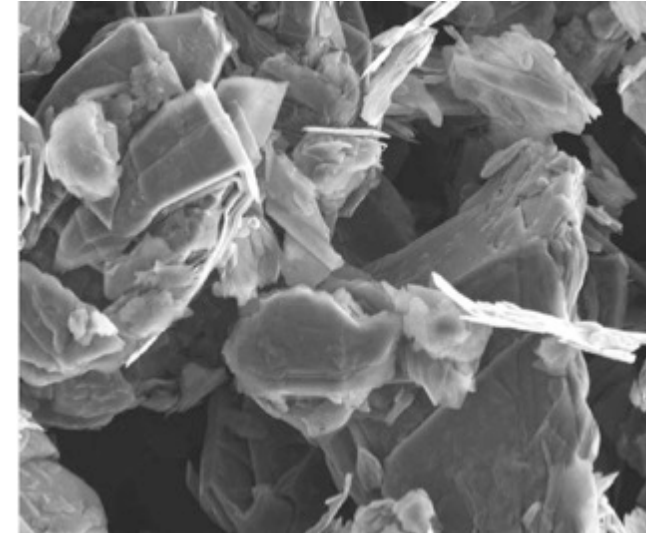
**MONOLAYER  
SINGLE LAYER**



**BILAYER, TRILAYER  
2, 3 LAYERS**

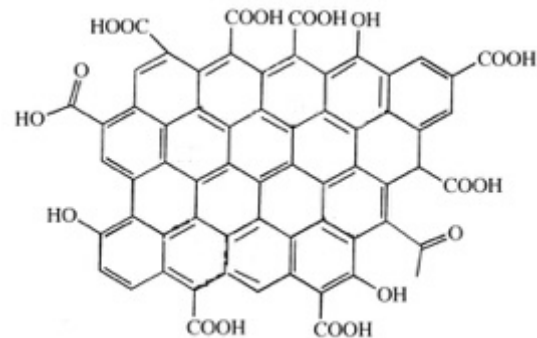


**UPTO 10 LAYERS  
MULTILAYER**

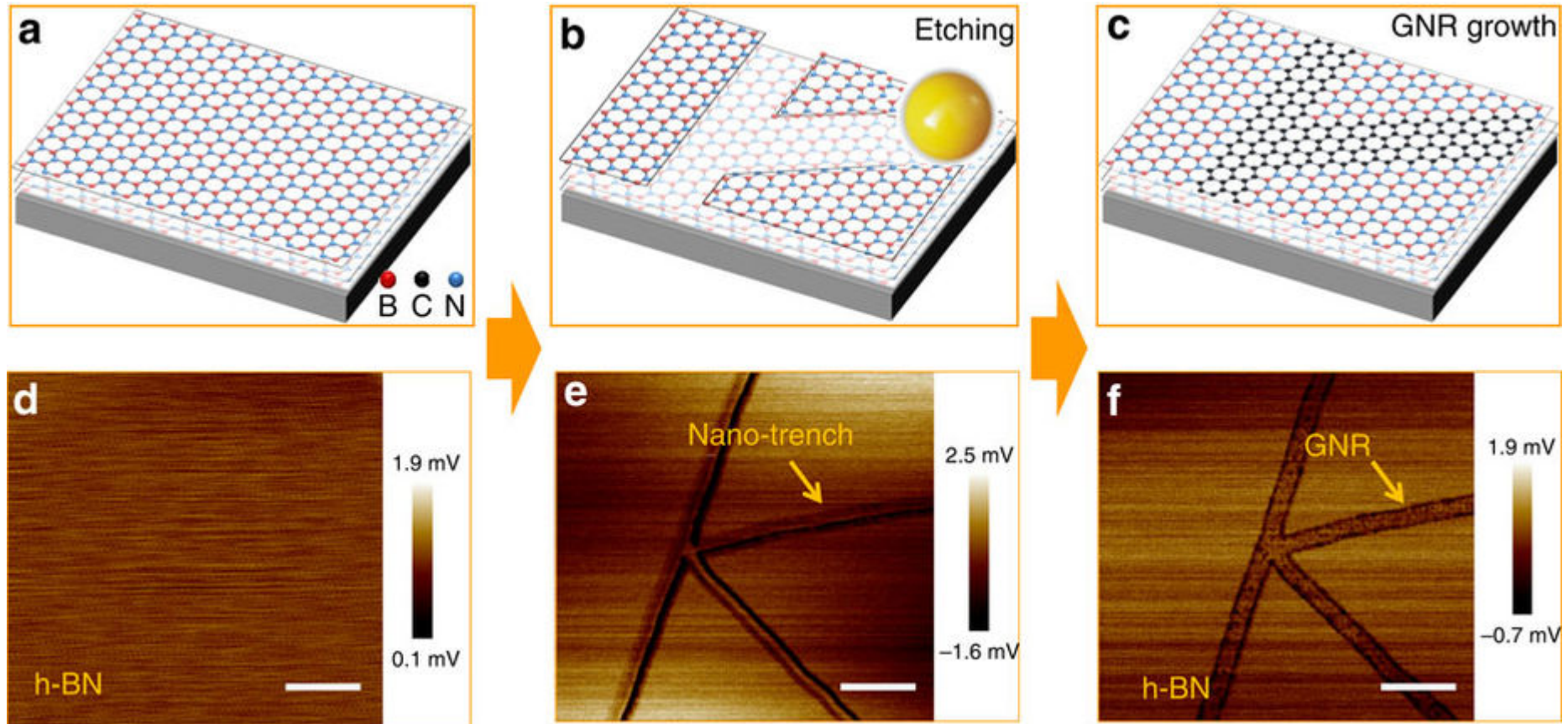


**NANORIBBONS**

**GRAPHENE OXIDE**



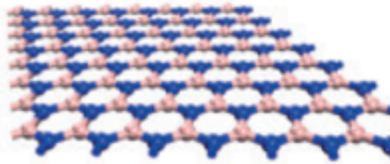
# Graphene Nanoribbons



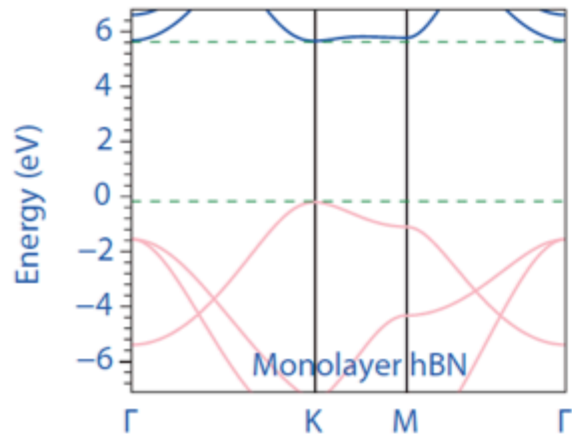
**Oriented graphene nanoribbons embedded in hexagonal boron nitride trenches**  
Lingxiu Chen, Nature Communications, 8, 14703 (2017)

# and other 2D materials

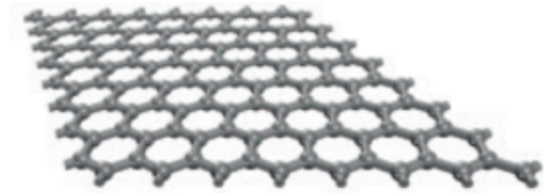
hBN  
(insulator)



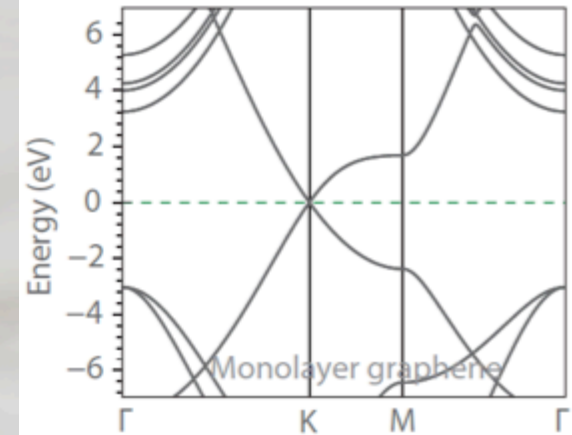
hBN: ~6 eV



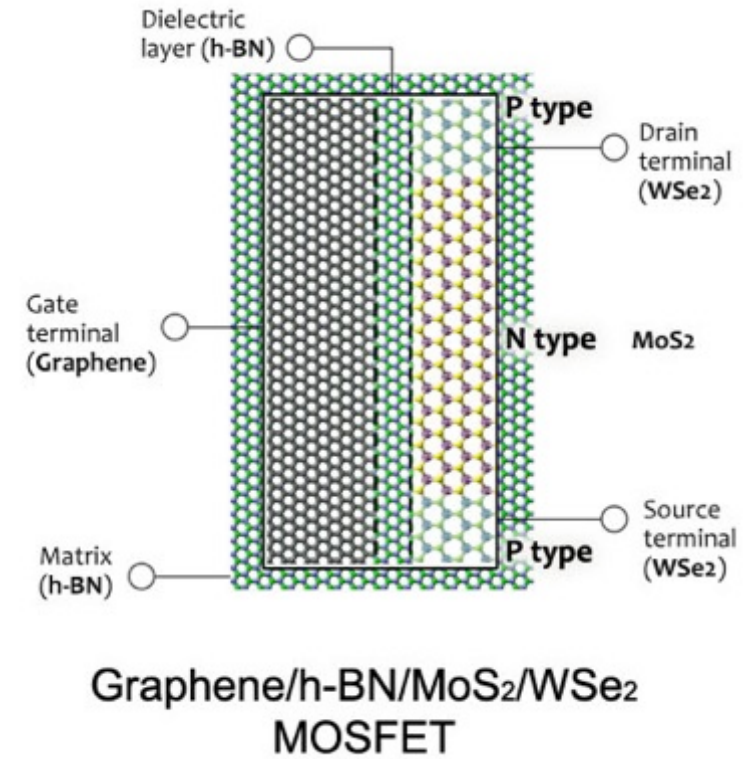
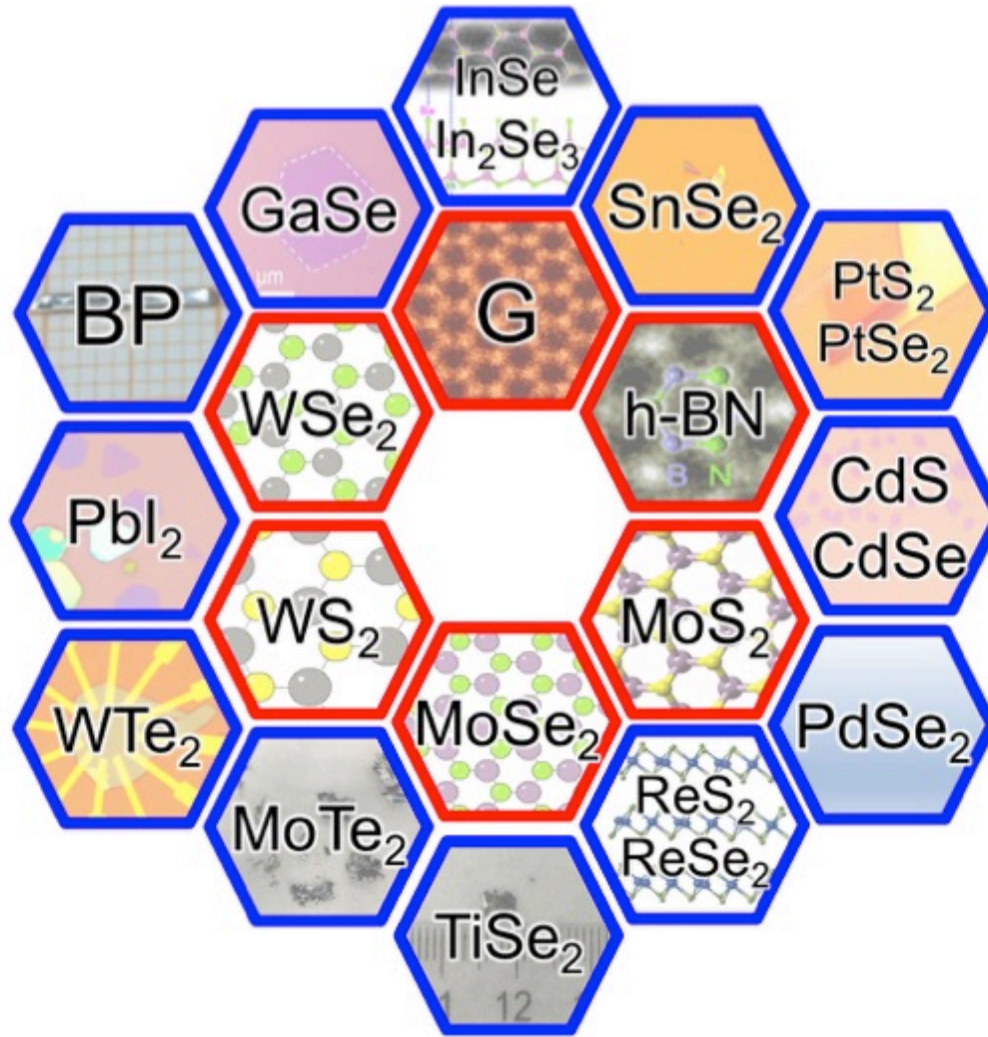
Graphene  
(semimetal)



Graphene: zero-gap



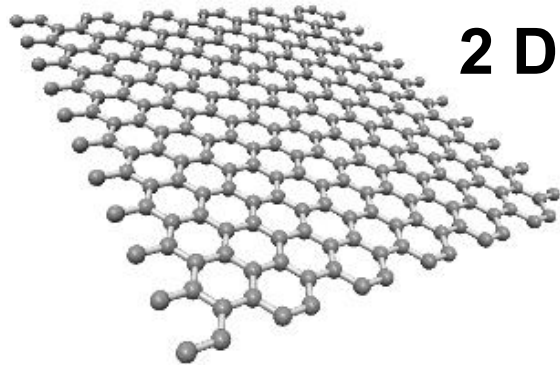
# and other 2D materials







# Graphene development support



Over 10 years (from 2013), the Graphene Flagship programme will receive €1 billion

UK government commitment £120 M

*Graphene, the material with many extraordinary properties, has swallowed around £120m in UK government funds, but development and commercialisation is proving tortuously slow and increasingly dogged with disappointment.*

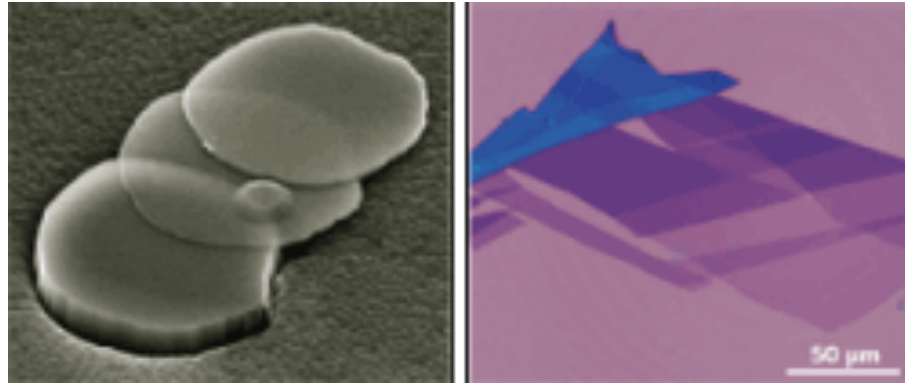
*So concerned are MPs with the lack of progress that late last year they conducted a series of hearings via the House of Commons Science and Technology Committee...*

14 Feb 2017



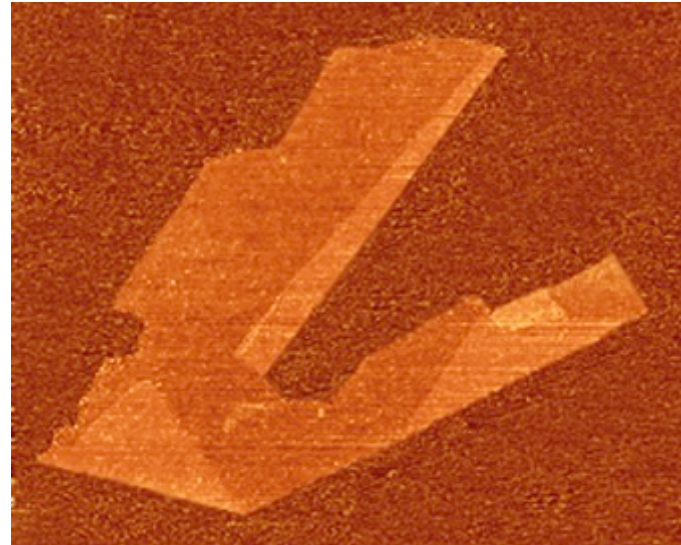
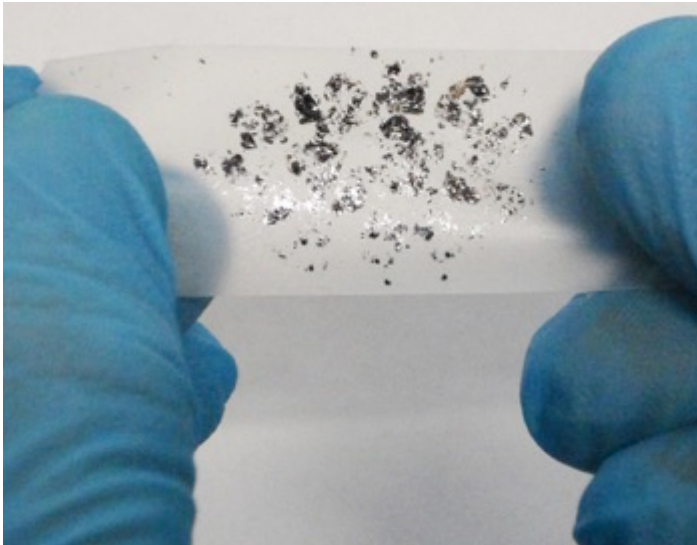
# First graphene made by...

“Scotch tape method”

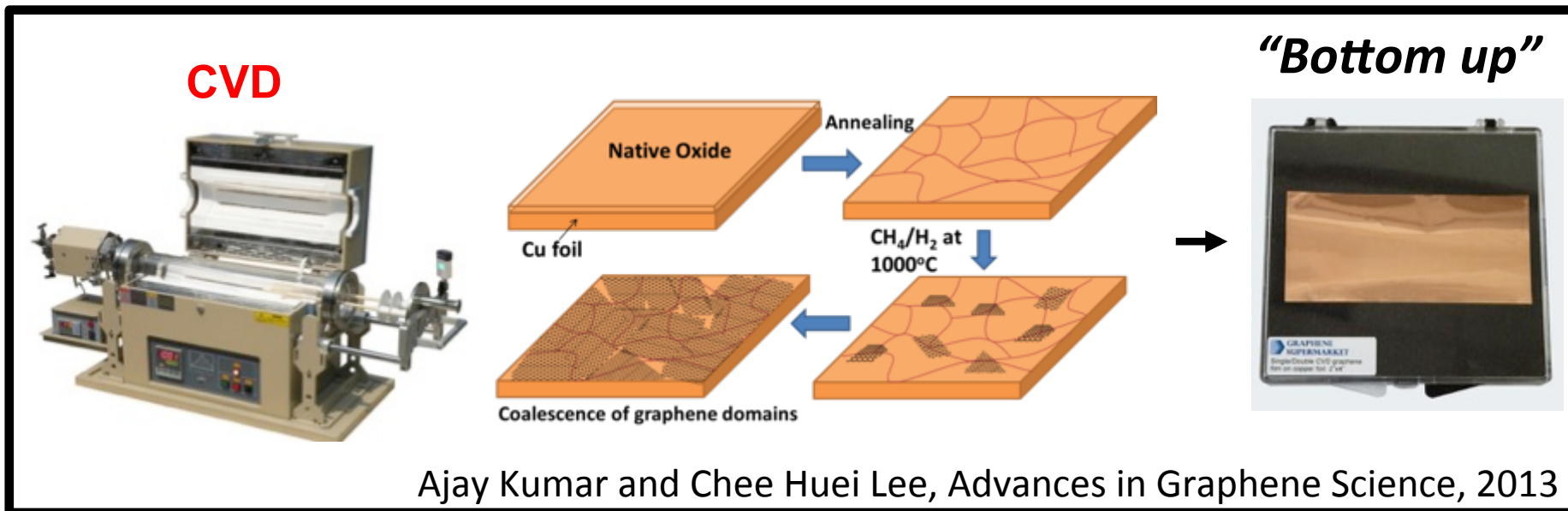
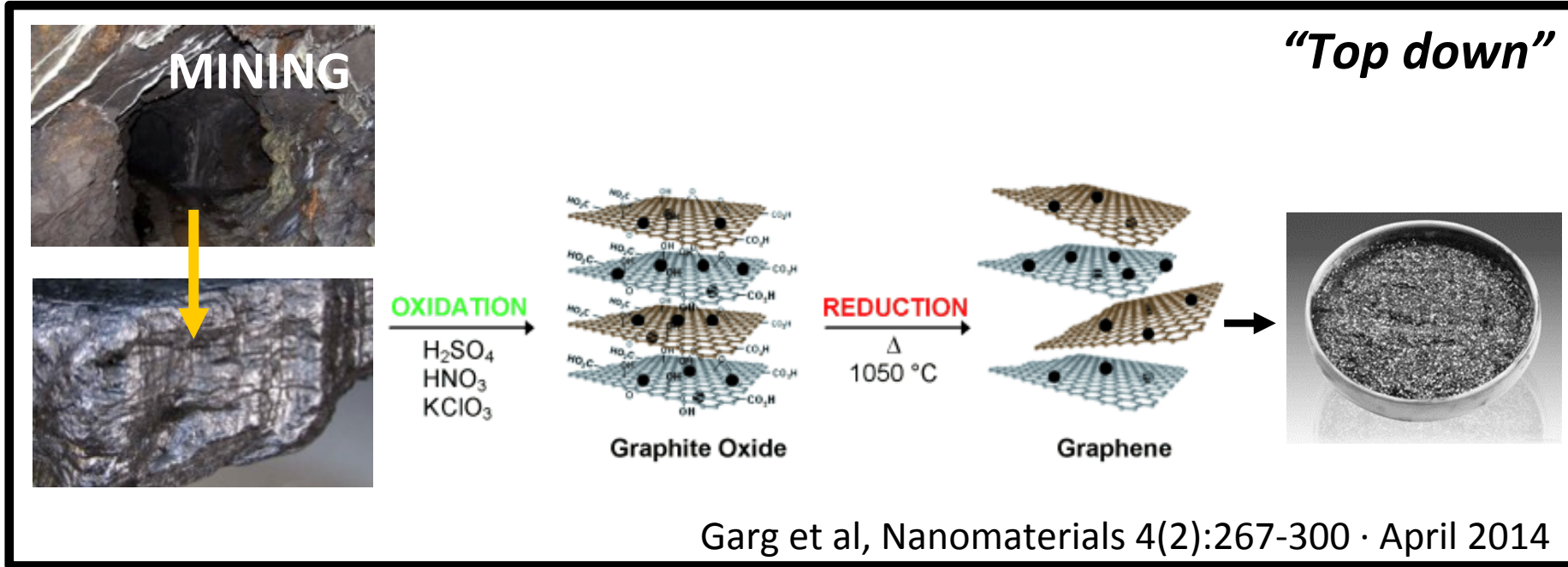


**“Top down”  
mechanical exfoliation**

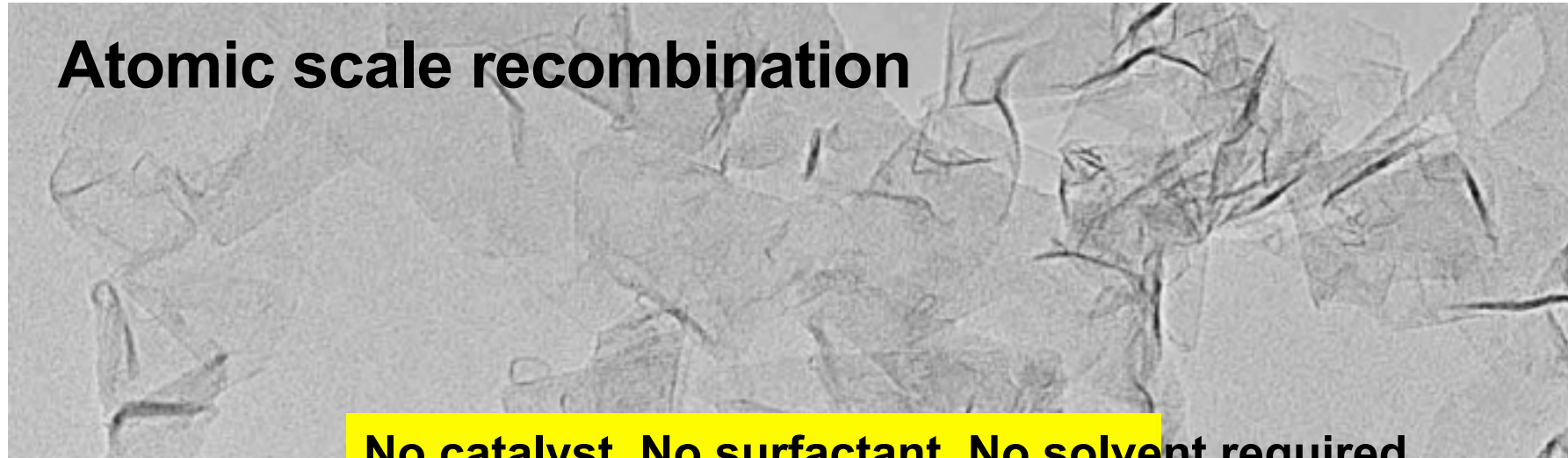
*Prof. Konstantin Novoselov & Prof. Andre Geim*



# Production of Graphene



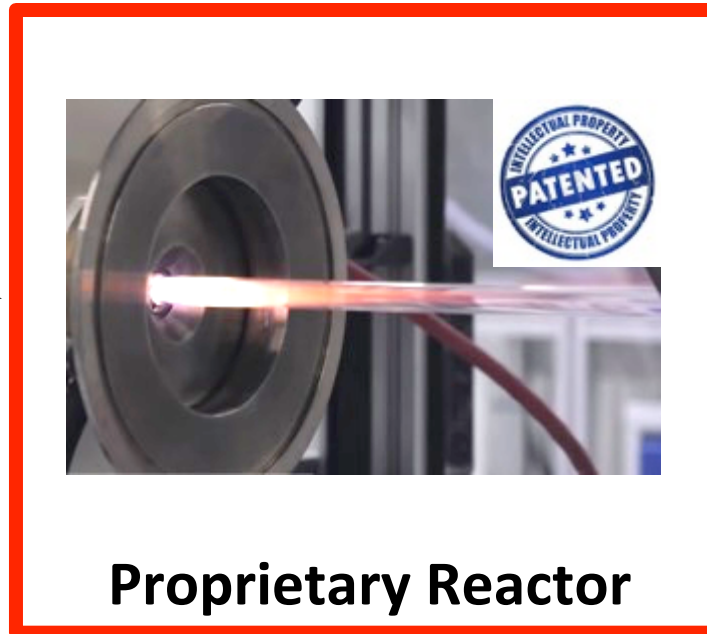
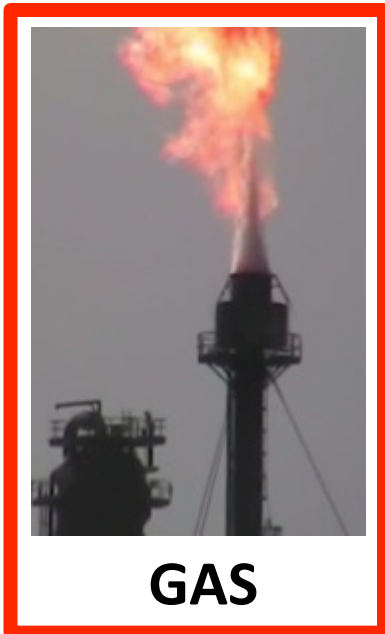
# Production of Graphene



Atomic scale recombination

*“Bottom up”*

No catalyst, No surfactant, No solvent required



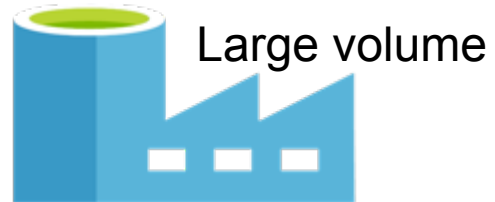


# Graphene Challenges

High Quality



- Contamination
  - Reproducibility
    - Consistency



- Quality Control
  - Traceability





# Supporting Graphene Commercialisation





# Graphene standardisation: developing and testing in-line graphene flake testing instrumentation

Innovate UK



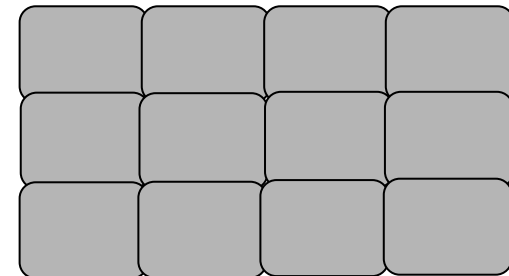
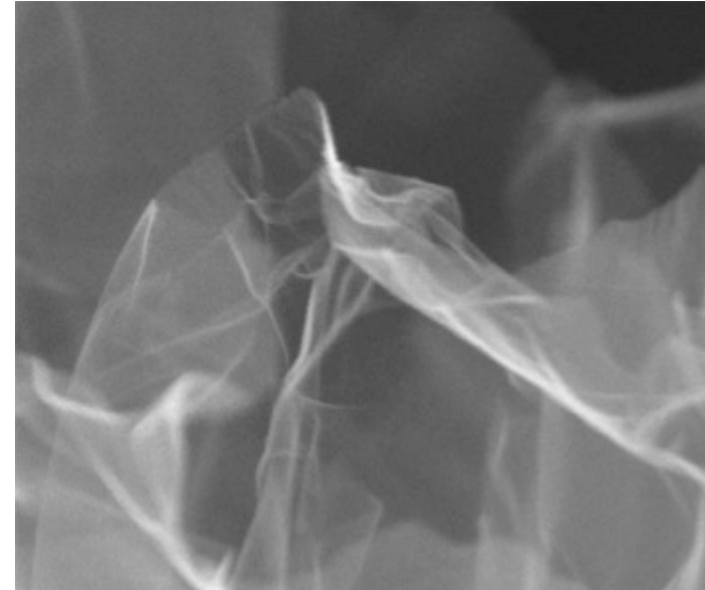
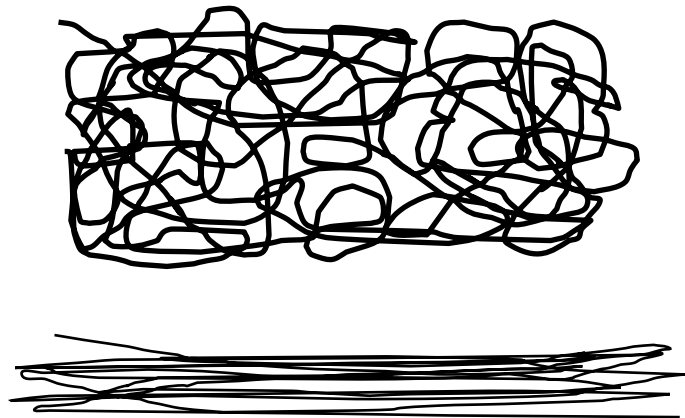
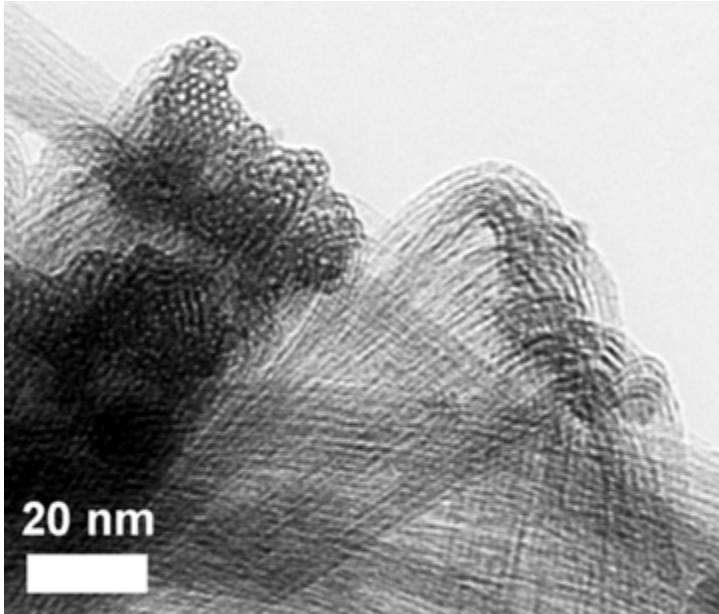


# Limitless Applications...





# Are we choosing the correct material?

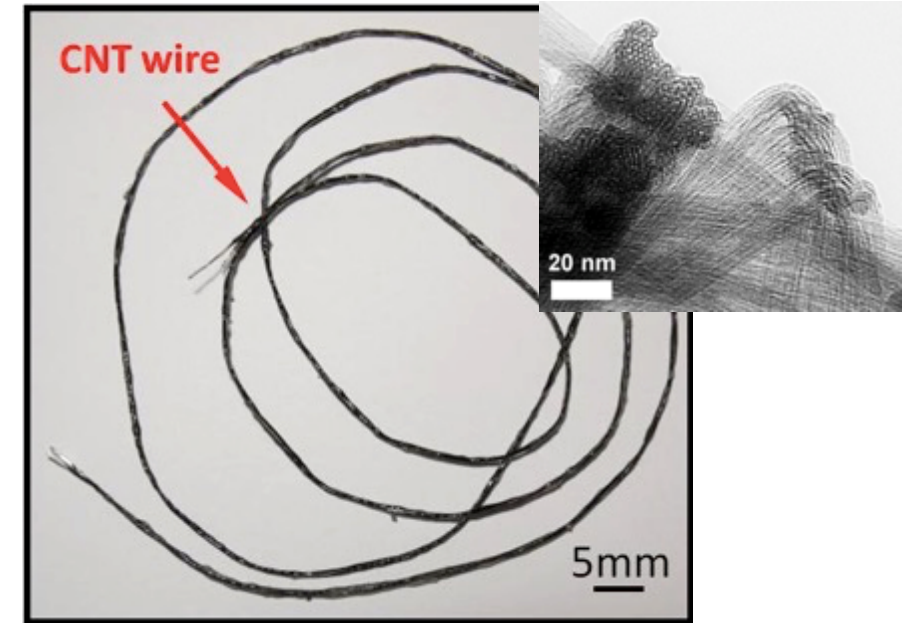


# Power Transmission:

Cu/CNT wires



pure CNT wires

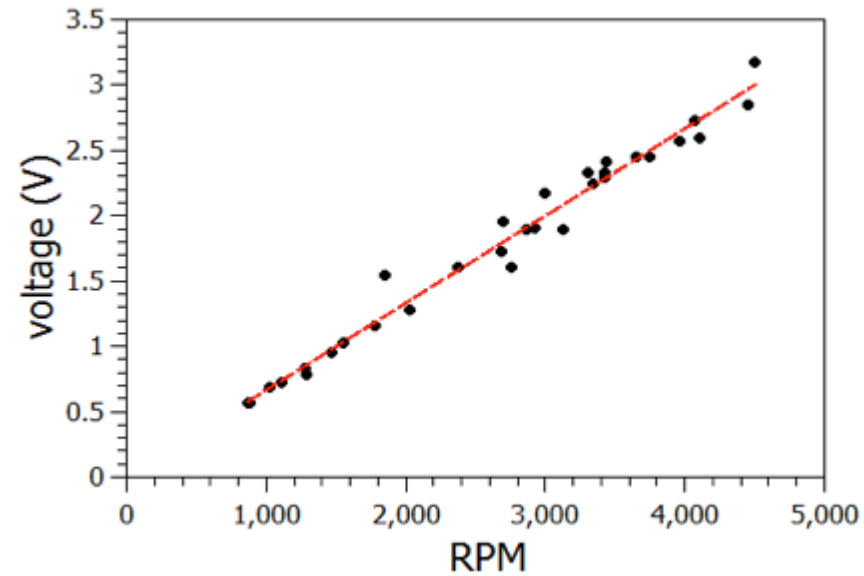


UltraWire



Enhanced Composites and Structures Centre  
Cranfield University

**E-Generator**



**E-Motor**

rpm	$M$	$I$	$P_{CNT}$	$U$
	mN·m	mA	W	V
100	2.502	100	0.9	9.26
150	2.508	130	1.52	12.00
200	2.518	180	2.92	16.49





## PV system/Smart windows

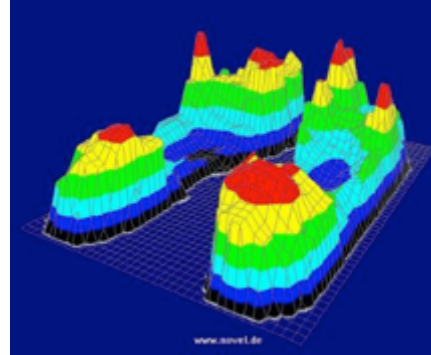


Flexible, transparent solar cell,  
using low-cost organic materials  
and graphene

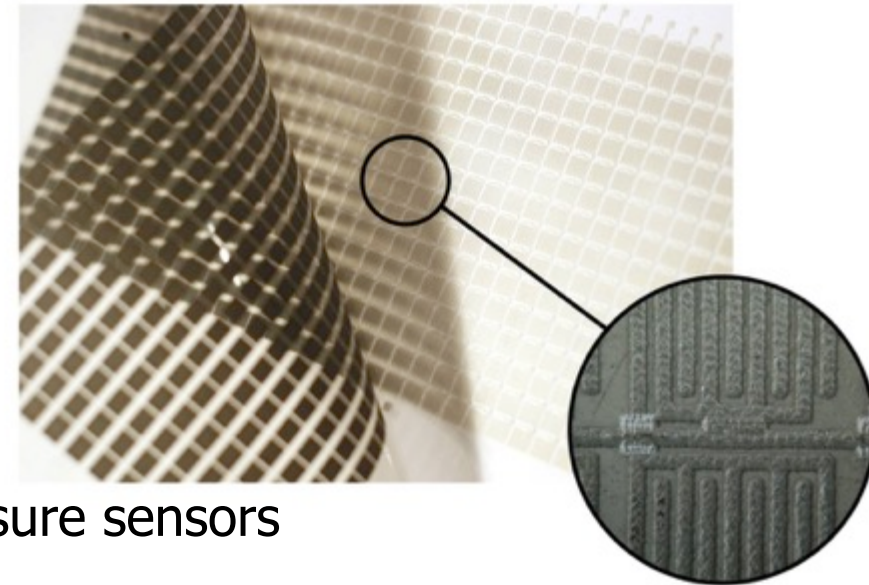
efficiencies of 2.8 to 4.1%



# Pressure sensor and temperature sensor with graphene layer for textronic applications

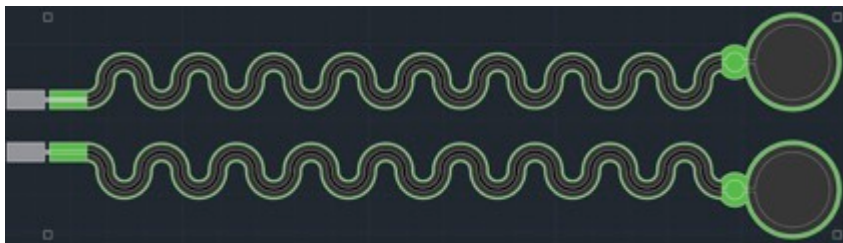
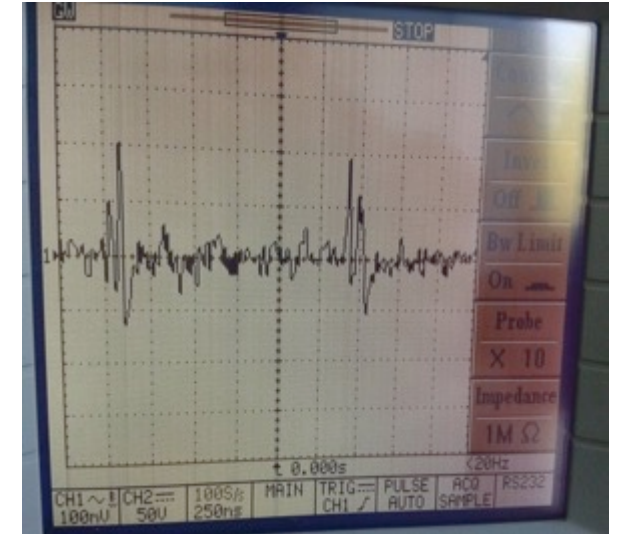
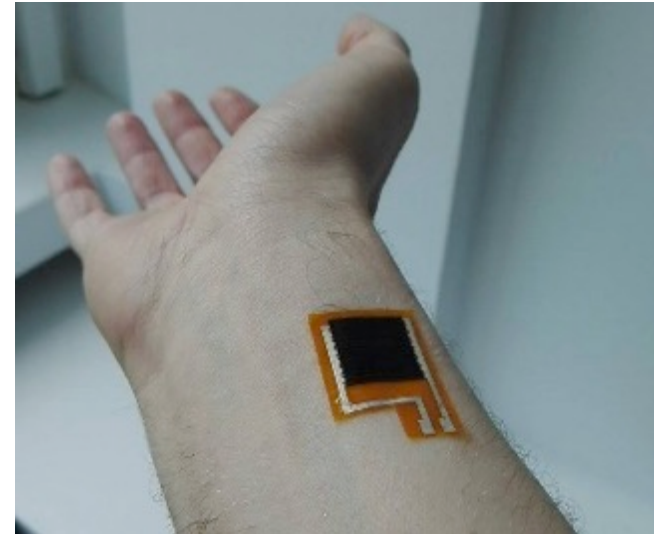
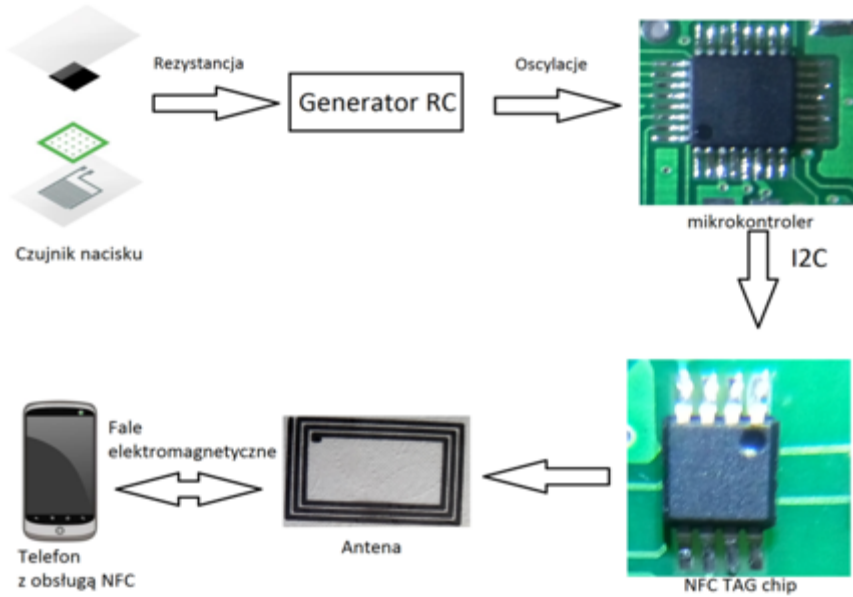


Textronic temperature sensors



Pressure sensors

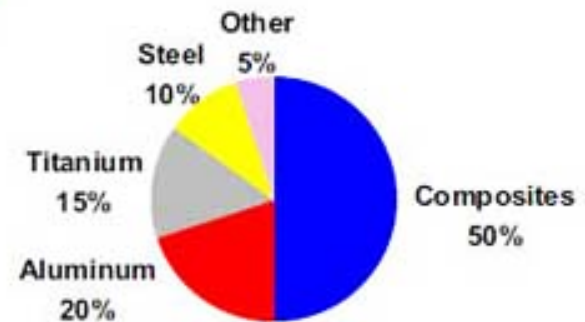
# Pulse and EEG sensor based on graphene



# Graphene based polymer composites



- Carbon laminate
- Carbon sandwich
- Fiberglass
- Aluminum
- Aluminum/steel/titanium pylons





# Graphene reinforced concrete

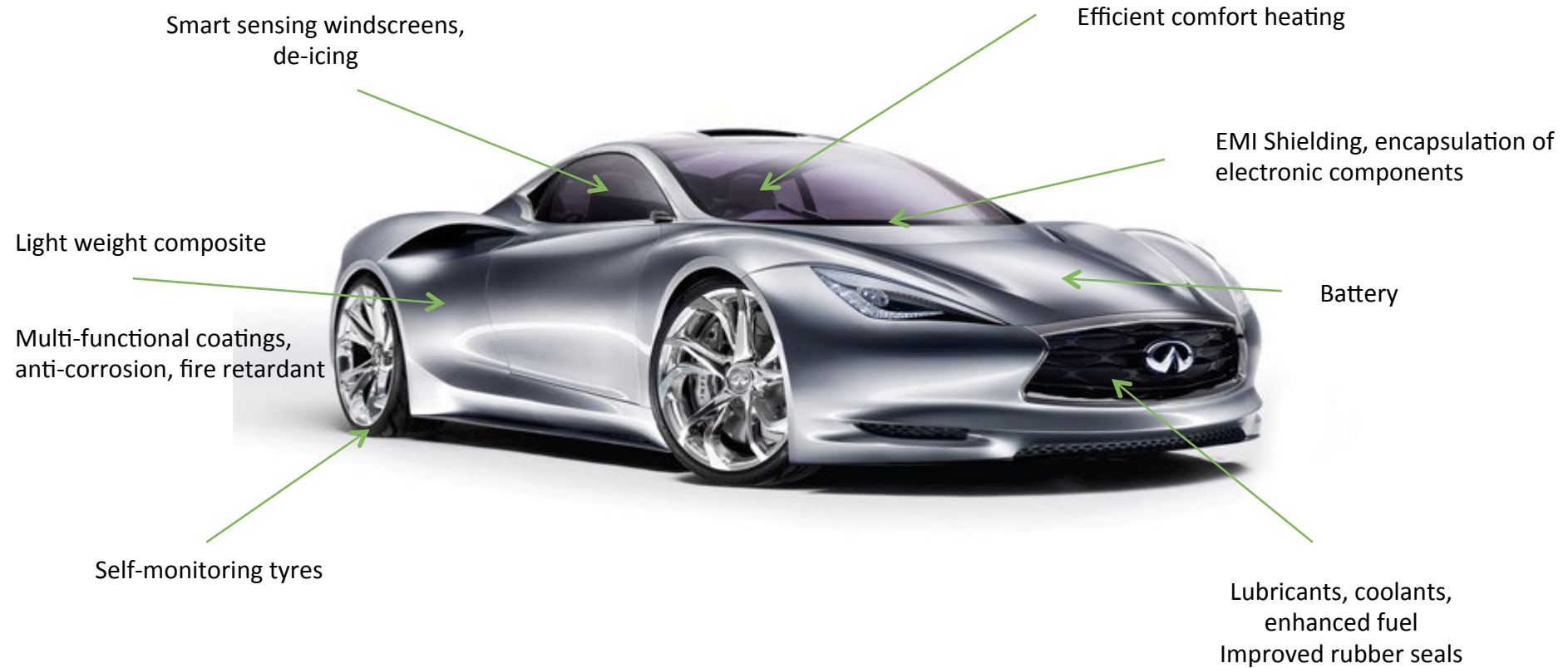


26% in flexural strength and 14% in compressive strength





# Graphene applications in automotive industry





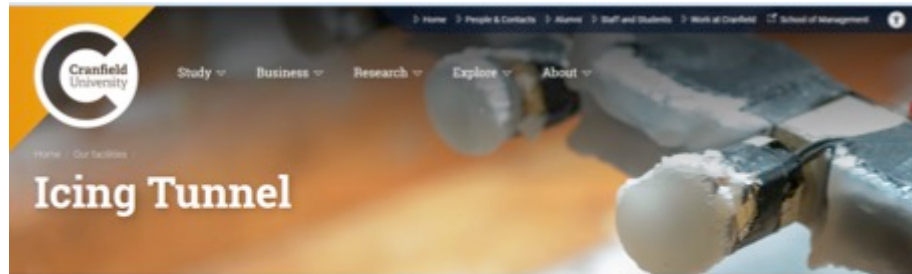
# Graphene heaters: aerospace use



**THAWING** | THE SAFE AND SUSTAINABLE  
FUTURE OF AVIATION  
[www.thawing.eu](http://www.thawing.eu)



# Area Heating: De-icing for wind turbines



Our Icing Tunnel facilities are unique, comprising arguably the largest icing tunnel in the UK and the largest droplet tunnel for icing studies in the world. Opened by HRH Duke of Kent, the facilities have been the focus of a wide range of international research and development work. [Read more](#)

#### Contact the facility





# Area Heating: Freestanding heater

*CamGraph<sup>®</sup> enabled*



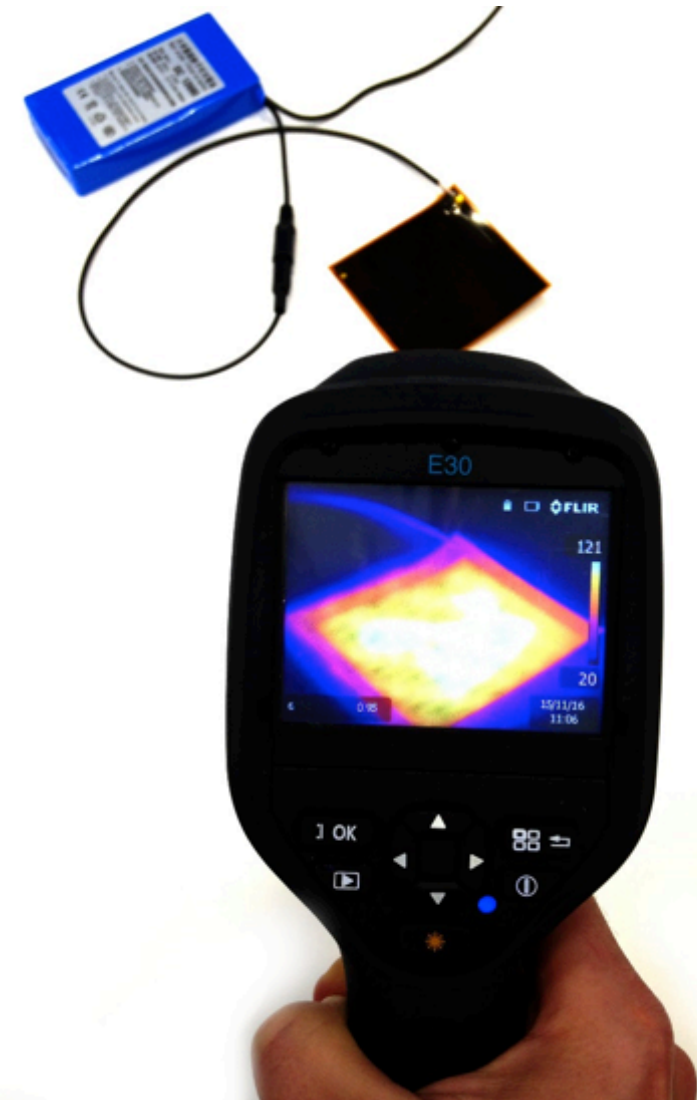
## Advantages over existing heater mats:

- Lightweight
- Thin
- Flexible
- Uniform heating
- Durable

12V graphene heater module example\*

<b>Power density</b>	2.5 kW/m <sup>2</sup>
<b>Voltage</b>	12V
<b>Max temp</b>	250°C

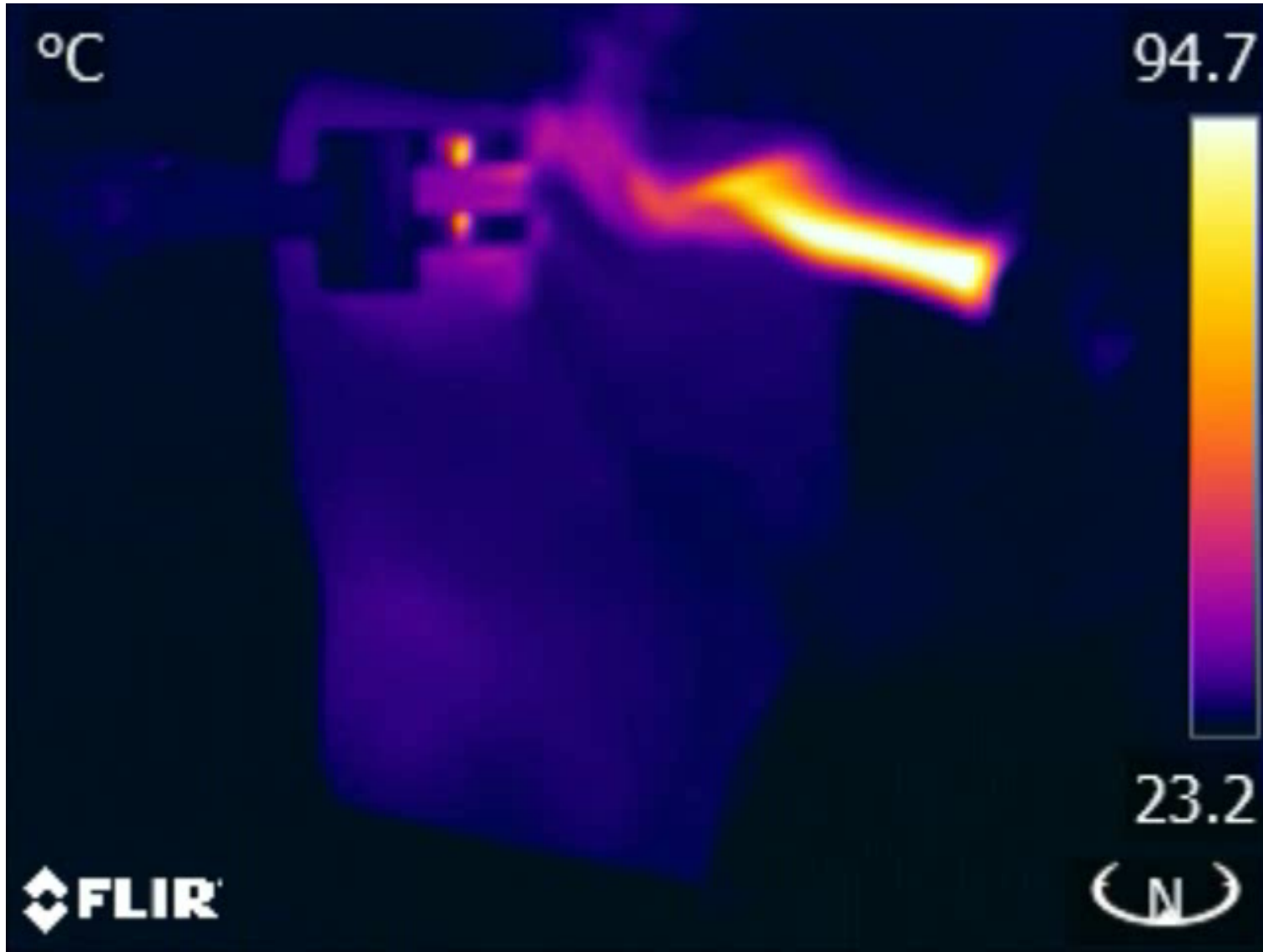
\*12V – 240V modules available





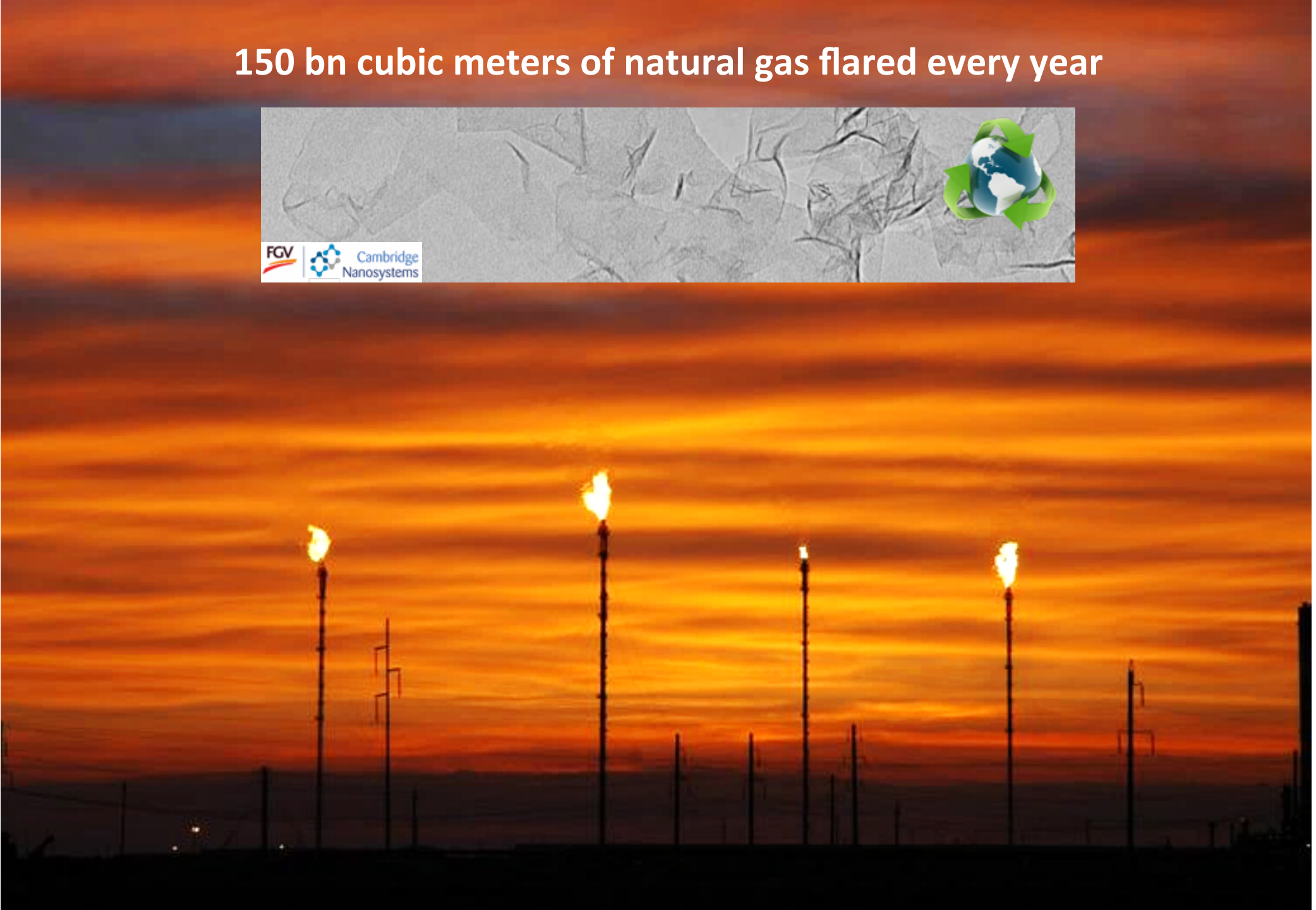
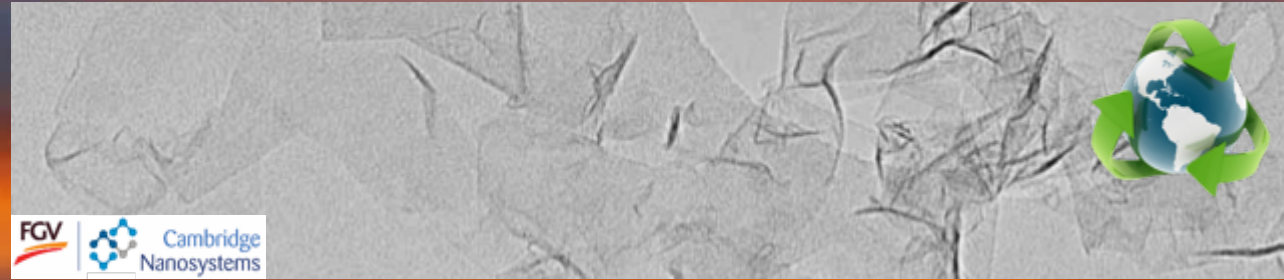


# Fire-retardant graphene coatings





150 bn cubic meters of natural gas flared every year





# THANK YOU

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Cranfield University

School of Aerospace, Transport and Manufacturing  
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