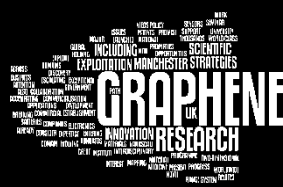

Innovation and business growth in a strategic emerging technology:

New methods for real-time intelligence on graphene enterprise development and commercialization

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Global Text Mining Conference, Atlanta, GA
September 16, 2015

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3. Manchester | Atlanta | Beijing | **Innovation Co-Lab**

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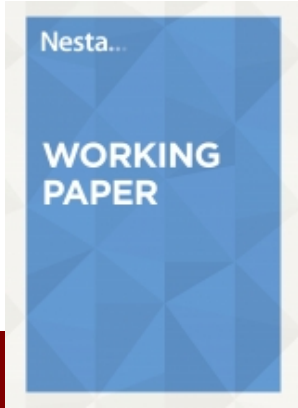
Overview

1. About graphene
2. Spread of graphene activity
   - Publications and patents
   - Policy interventions
   - Emerging applications
3. Business strategies and commercialization
   - New method for real-time intelligence: web mining
4. Case study application
   - What are Graphene SMEs doing?
5. Insights and implications

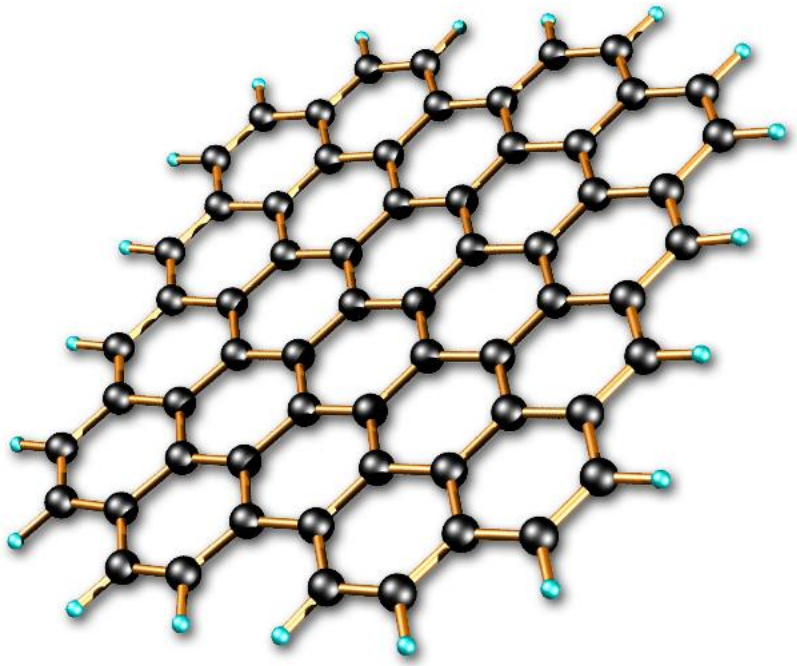


This research was supported by Nesta | Download paper at: http://tiny.cc/grre

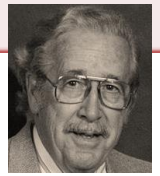
Graphene is a *novel* nanotechnology material

- **Technical characteristics**:
  - Single layer of carbon atoms
  - Incredibly strong
  - High thermal and electrical conductivity
- **Formats**
  - Graphene nanoplatelets (GNPs)
    - Discs of graphene: high strength, conductivity
  - Graphene films
    - Monolayer film: conducting, semiconducting, transparent
- **Diverse set of *incremental* and *transformative* applications**:
  - Batteries
  - Displays
  - Hydrogen storage
  - Transistors and electronics
- **EHS claims**
  - If nanoscale only in one dimension, possibly less risky than CNT

Acknowledgements: Shapira, Youtie, Arora, 2011

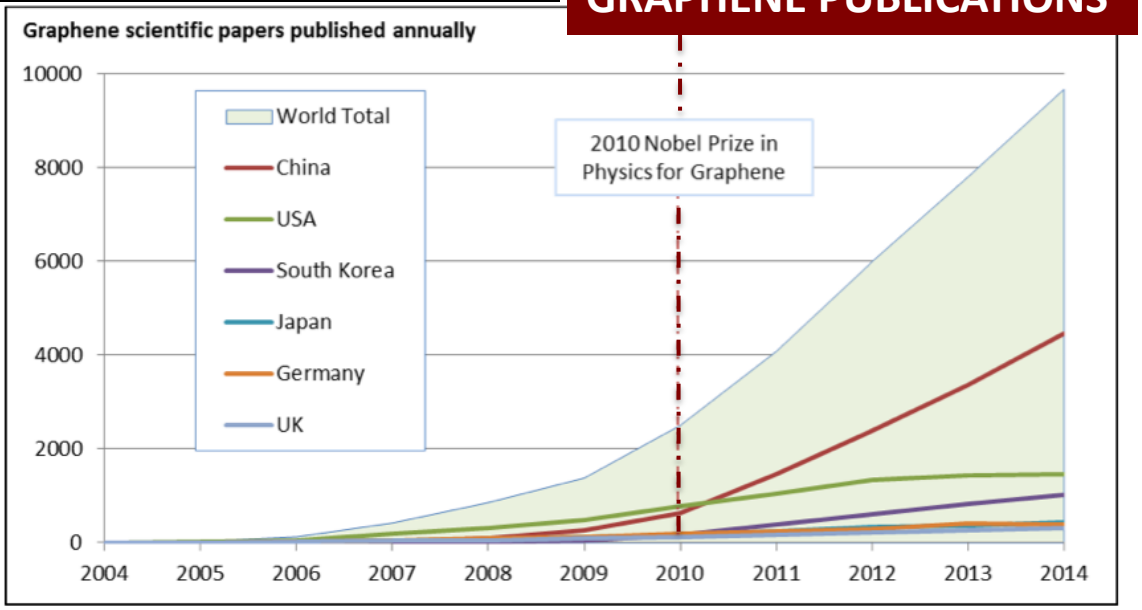


1947	2004	2010	2014
Wallace – Theory of Graphene	Graphene isolated - Geim & Novoselov *Science*	Nobel prize in Physics	33+K papers 12+K patents

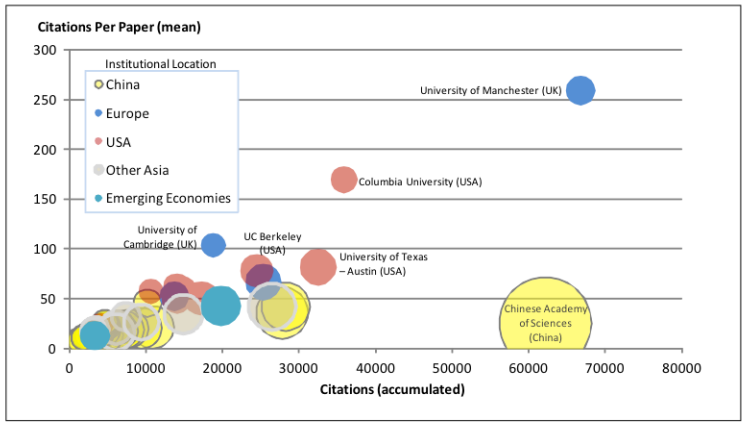


2.1 Spread of graphene

GRAPHENE PUBLICATIONS

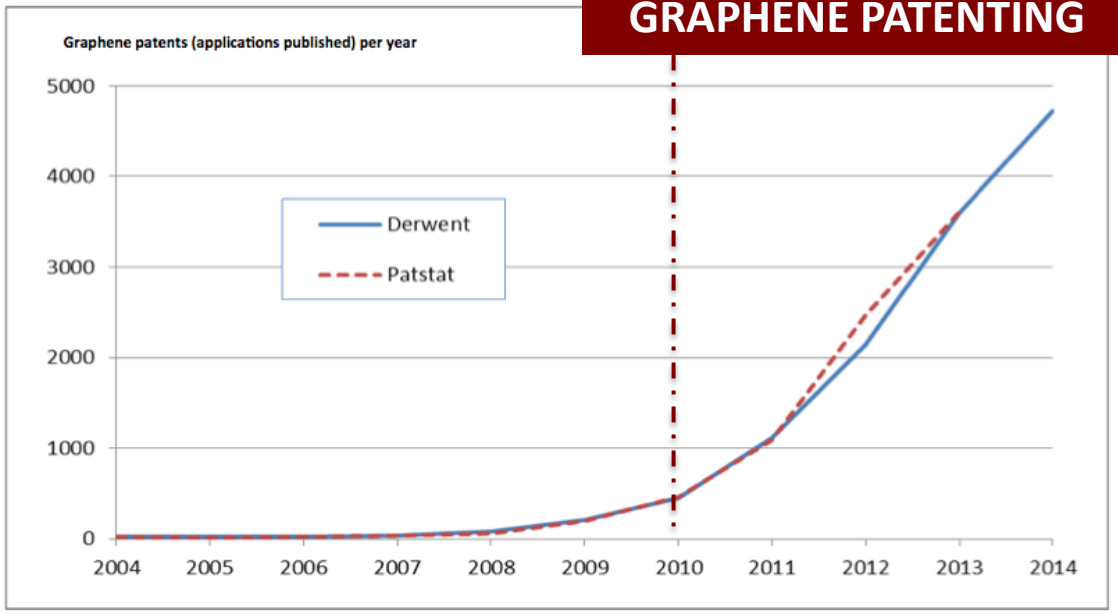


Analysis of Web of Science publication records, 2001–2014 (SCI articles and reviews with term "graphene" in title, N = 32,994; country assignments based on all reported author institutional addresses). For further discussion of this search term approach, see Shapira et al. (2012).



Source: Analysis of Web of Science publication records for period January 2004 through 31 March 2015 (see Figure 1). Size of bubble is proportional to number of papers authored. Top five institutions with highest mean citations per paper labeled plus (as a reference point) the Chinese Academy of Sciences

GRAPHENE PATENTING



Source: Analysis of published patent applications in two different sources: (1) Derwent Innovations, Thomson Reuters (N=12,439, 2004-2014); and (2) PATSTAT (N=7,982, 2004-2013). Relevant patent applications identified by graphene in title or topic fields.

- ❑ Many of the top companies patenting graphene are multi-nationals

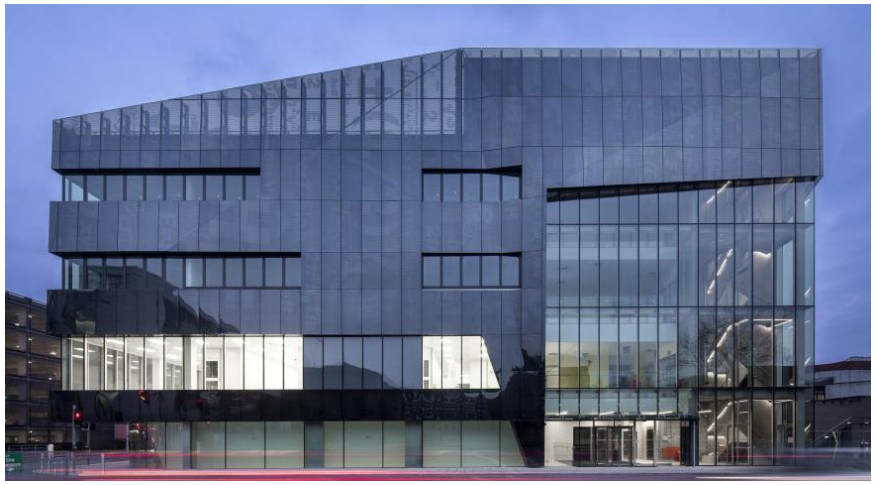
Leading global assignees	Patents to 2013
Samsung	150
IBM	44
Oceans King LST	32
Baker Hughes	29
Sekisui Chemicals	25
BASF	23
Fujitsu	23

European Companies with interests in graphene (examples)
BAE Systems
Nokia
Philips
BASF
Thales Group
Plastic Logic
Dyson
(48 companies in EU Graphene Flagship)

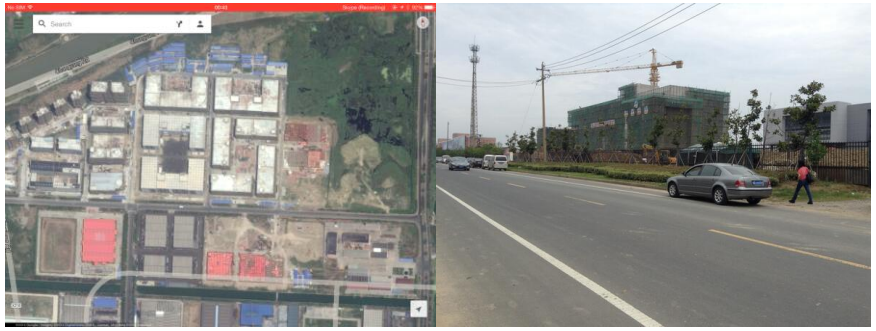
Sources: Patent Insight Pro 2013, Graphene Technology Insight and web searches

Policy interventions

- **Governments have intensified their investments in graphene research and innovation. E.g.:**
- **UK**: Designated “great technology”; National Graphene Institute; Graphene Engineering Innovation Centre; Royce Materials Institute (£300m +)
- **EU**: €1 billion Graphene Flagship (17 countries); Germany: €15m graphene electronics
- **South Korea** ($300m); **Singapore** ($32m) in graphene R&D
- **US**: graphene under nanotechnology and materials genome initiatives
- **China**: National R&D; Graphene Alliance; plus local government initiatives



National Graphene Institute, Manchester, UK



Graphene complex - Jiangnan (near Suzhou), China

Early graphene commercialization

- **Graphene materials**
  - Flakes, powders, nanoplatelets, solutions, graphene oxide, and CVD graphene

- **Intermediate products**
  - Graphene polymer masterbatch
  - Conductive ink for printed electronics (Vorbeck Materials, USA)
  - LITX™ G700 of Cabot Corporation: conductive additive that improves energy density of lithium-ion batteries

- **Graphene-enabled products**
  - HEAD YouTek™ Graphene™ tennis racquet

- **Graphene producing tools**
  - Black Magic Systems of AIXTRON (thermal and plasma-enhanced CVD)

Qurano 46 graphene-enhanced race wheel (Vittoria, Italy) $1.7K

Larger firms and smaller firms: Strategies, resources, capabilities, and market orientation.

Large Firms [1]

- ❑ Access to financial resources
- ❑ Established R&D Processes
- ❑ More patenting activity compared to smaller firms
- ❑ Well-defined knowledge acquisition and marketing channels
- ❑ *Open innovation (& acquisition) of SMEs*

SMEs: New Technology Based Firms (NTBFs) [2, 3]

- ❑ Younger firms may innovate more radically than larger firms
- ❑ Challenges of scale-up & acquisition of finances

Science-based →focused on "basic technologies" and to a lesser extent product innovations

Engineering-based →focused more on applications

1. OECD, 2010
2. Autio, 1997a and 1997b
3. Michael and Pearce II, 2009

Acknowledgements: Shapira, Youtie, Arora, 2011

Information Sources

CONVENTIONAL

- ❑ Publications
- ❑ Patents
- ❑ Surveys
- ❑ Interviews and case studies
- ❑ Secondary documents

NEW DATA METHODS

- ❑ Web mining
- ❑ Social media analysis

- *Unobtrusive*
- *Real-time promise?*

Web Mining

What is it?

- Mine current and archived web sites for key activity terms
- Use to reveal business strategies, products, finance, linkages, internationalization, and other factors
- Analyse terms using text mining algorithms and software

Use and interpretation

- Most technology companies have web sites
- Web-site information is self-reported, variety in type of information reported (but size is often large), often updated
- Companies use sites to promote – but incentives not to mislead
- Companies will not disclose all what they do ("go dark")
- Link to other data sources (business databases, pubs, patents, etc.)

ACTIVITY SEARCH: R&D KEYWORDS

Rule: (development[a-zA-Z]*activity OR development[a-zA-Z]*cent[a-zA-Z]* OR development[a-zA-Z]*cycle OR development[a-zA-Z]*efforts OR development[a-zA-Z]*facilit[a-zA-Z]* OR development[a-zA-Z]*phase OR development[a-zA-Z]*process[a-zA-Z]* OR development[a-zA-Z]*program[a-zA-Z]* OR development[a-zA-Z]*project[a-zA-Z]* OR development[a-zA-Z]*research OR lab[a-zA-Z]* OR product[a-zA-Z]*development[a-zA-Z]* OR R&D OR research[a-zA-Z]* OR research[a-zA-Z]*&[a-zA-Z OR *development OR Research[a-zA-Z]*development OR RnD OR science[a-zA-Z]* OR scientist[a-zA-Z]* OR technical[aA-Z]*development[a-zA-Z]* OR technological[a-zA-Z]*development[a-zA-Z]* OR technology[a-zA-Z]*development[a-zA-Z]*)



References: Shapira, Gök, Klochikhin, Sensier (2014). Probing "green" industry enterprises in the UK: A new identification approach, *Technological Forecasting and Social Change*. Gök, Waterworth, Shapira (2015) Use of web mining in studying innovation, *Scientometrics*. Arora, Youtie, Shapira, Li. (2015) Using the Wayback Machine to mine websites in the social sciences: A methodological resource, *Journal of the American Association for Information Science and Technology*

Example: R&D Activities in Green Goods Manufacturing SMEs

Variables	UK	US	China
Green Goods SMEs	**2004-2012**	**2008-2010**	**2002-2014**
Publications	**15%**	**10%**	**1%**
Patents	**5%**	**19%**	**19%**
R&D spend	17%		
R&D employees			92%
TSB awards	22%		
US contract registration		48%	
R&D web mentions	**68%**	**66%**	**97%**
N (companies)	296	271	300

Notes: Publications in Web of Science; Patents in Derwent patents; UK R&D spend from FAME; TSB = UK Technology Strategy Board; US active contract registrations with Sam.Gov; R&D web mentions (UK, US) & R&D employees (CN, N=213 in 2014) from web-mining.

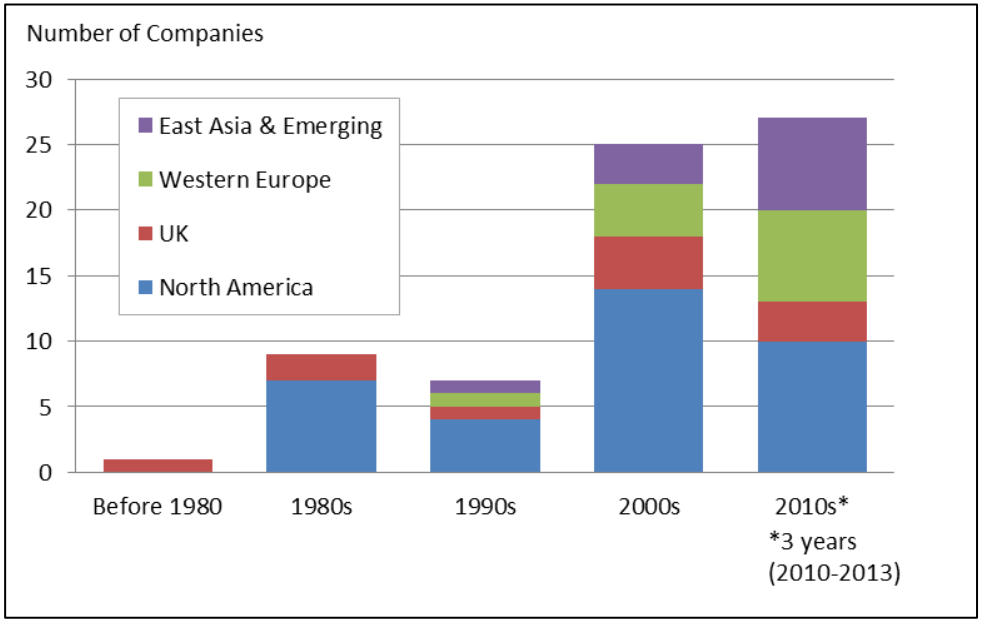
Source: Project on Sustaining Growth in Innovative New Enterprises
Sponsor: Economic and Social Research Council (ES/J008303/1). PI: P. Shapira

R&D in green goods SMEs

- UK firms – more publications but **relatively lower in patenting**
- UK firms **report more R&D activities on web** than would be expected from conventional data sources
- Web-based R&D mentions are frequently downstream (development, trials, test, pilot, demo, etc.)

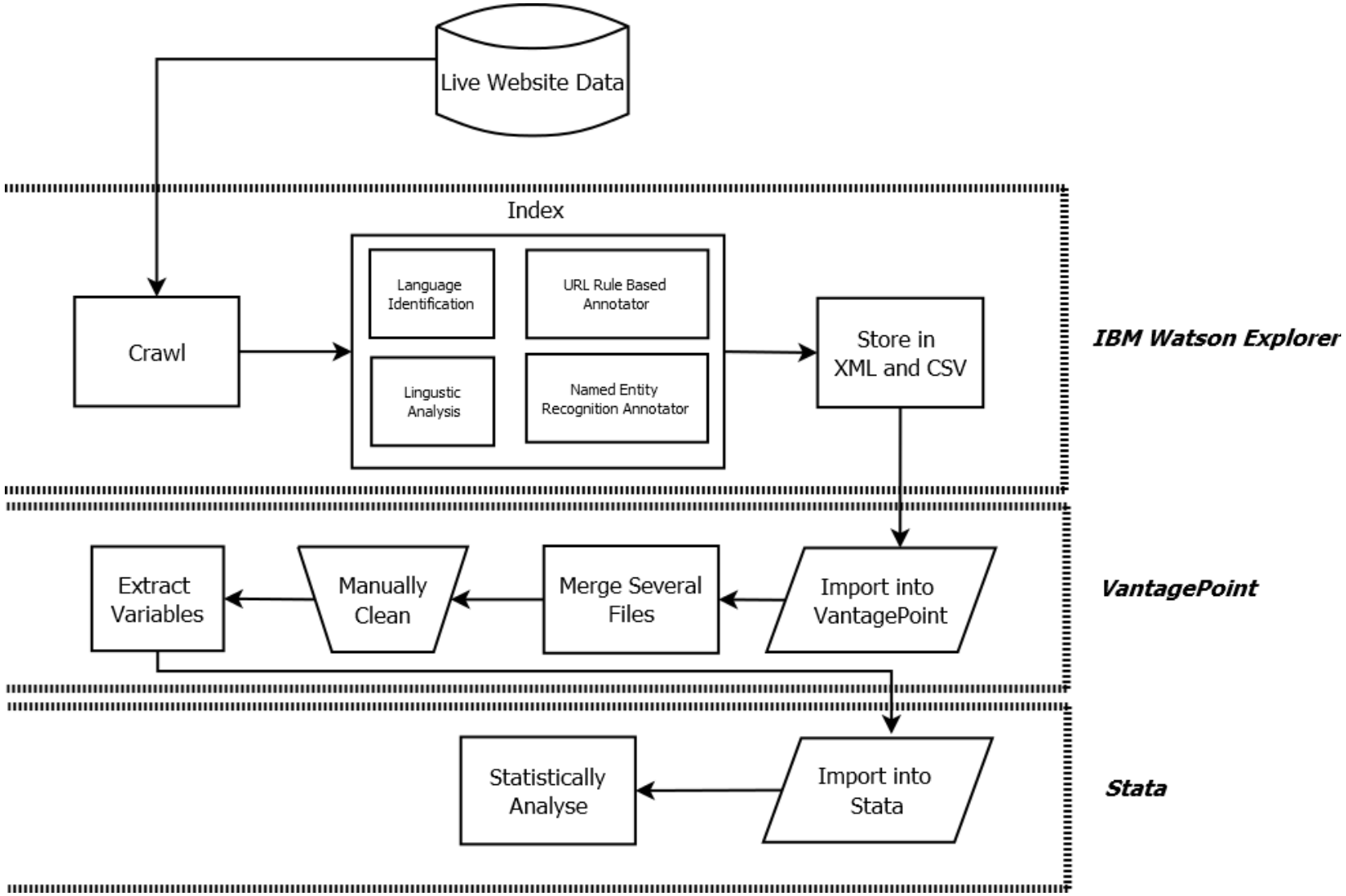
Application: Graphene SMEs

- **Search worldwide** for graphene SMEs (=87 in 2013) using social media, specialist websites, academic publications and grey literature.
- **65 graphene SMEs identified and followed** (excluded: services only companies or out-of-business)
- **16 countries represented**: 30 US; 10 UK; 6 ES; 3 CN; 2 CA, NO & SK; 10 others. 4 regional groups
- **SMEs established mostly since 2000s**
- **Not all graphene SMEs**, but a significant population sample.
- **11,285 web pages indexed**; counts normalized by # words per web site



Source: Web mining analysis of 65 graphene small and medium-sized enterprises (SMEs) in study data set.

Web mining process



Probes – Graphene SMEs

- ❑ Year of Establishment
- ❑ Location
- ❑ Lines of business
- ❑ Graphene targets and value-stream position
- ❑ Graphene functionality
- ❑ Graphene production method
- ❑ Other 2-D materials
- ❑ Graphene intensity

- ❑ Research and development
- ❑ Markets
- ❑ Government linkages
- ❑ Business linkages
- ❑ University linkages
- ❑ Finance
- ❑ Nobel prize mention
- ❑ Social media

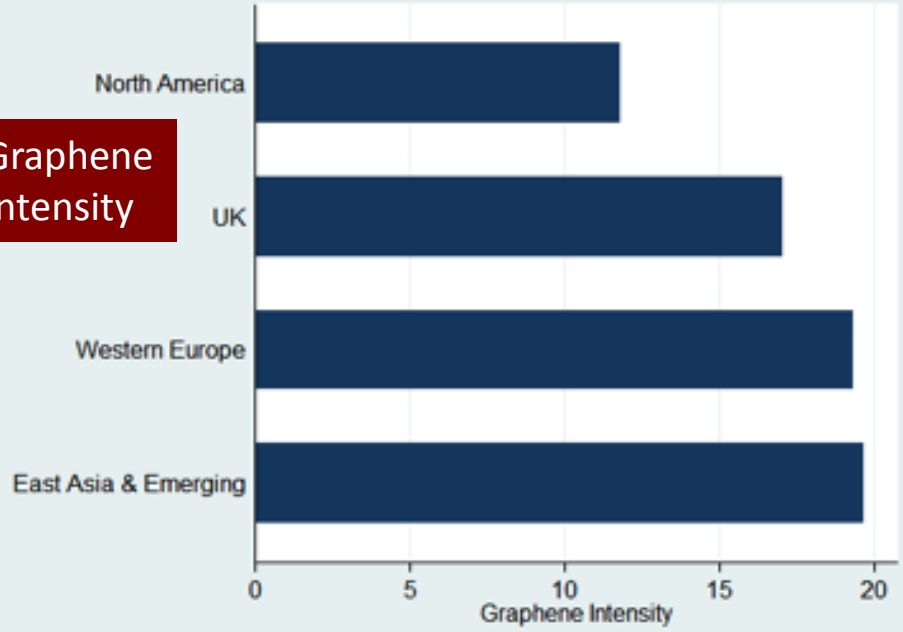
What graphene production method is being used?

CVD, chemical vapour deposition, SiC, sicon carbide synthesis, exfoliation, mechanical exfoliation, liquid-phase exfoliation, molecular assembly

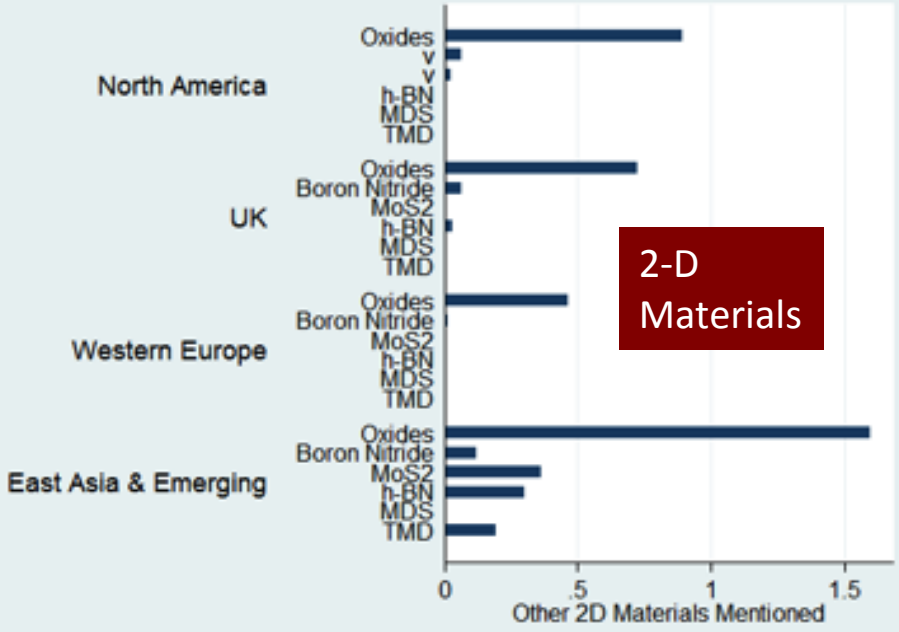
Rule: keywords:
[a-zA-Z0-9]*epitax[a-zA-Z0-9]*
[a-zA-Z0-9]*exfoliation
[a-zA-Z0-9]*intercal[a-zA-Z0-9]*
[a-zA-Z0-9]*molecular assembly[a-zA-Z0-9]*
[a-zA-Z0-9]*reductio[a-zA-Z0-9]*
[a-zA-Z0-9]*unzip[a-zA-Z0-9]*
[a-zA-Z0-9]*deposition
CVD
nanotube[a-zA-Z0-9]*

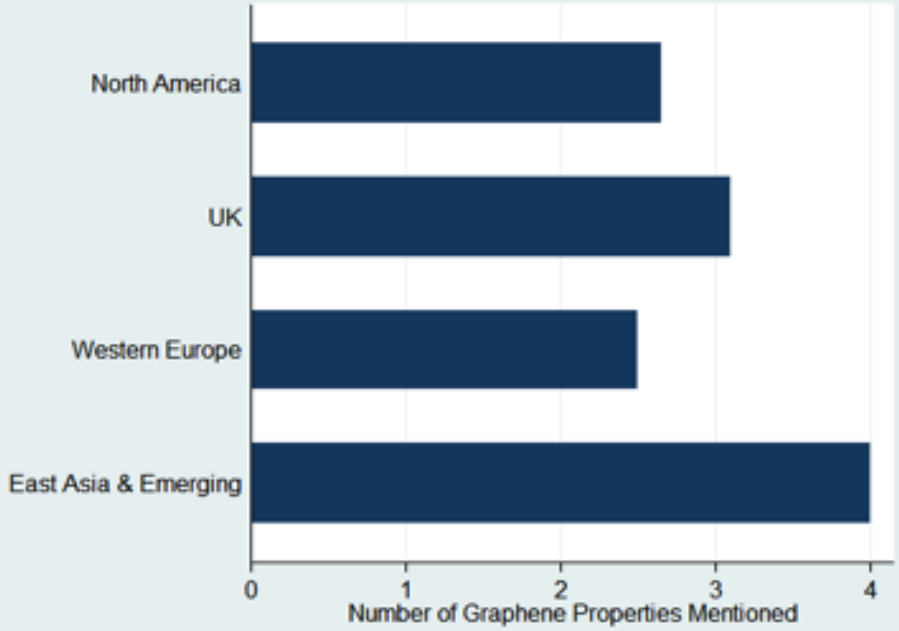
4.1 Case Study Findings: Webmining of Graphene SMEs

Graphene Intensity

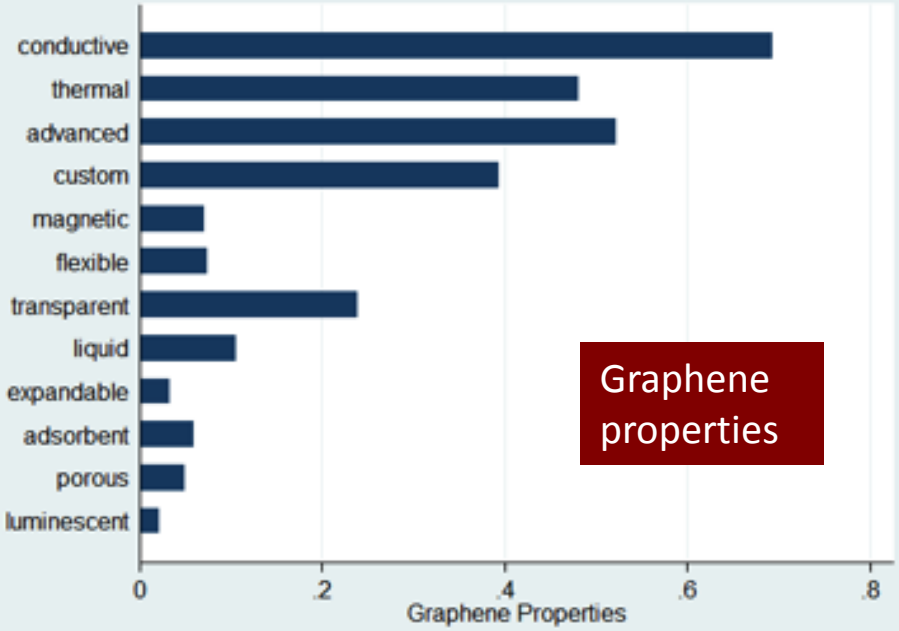


2-D Materials

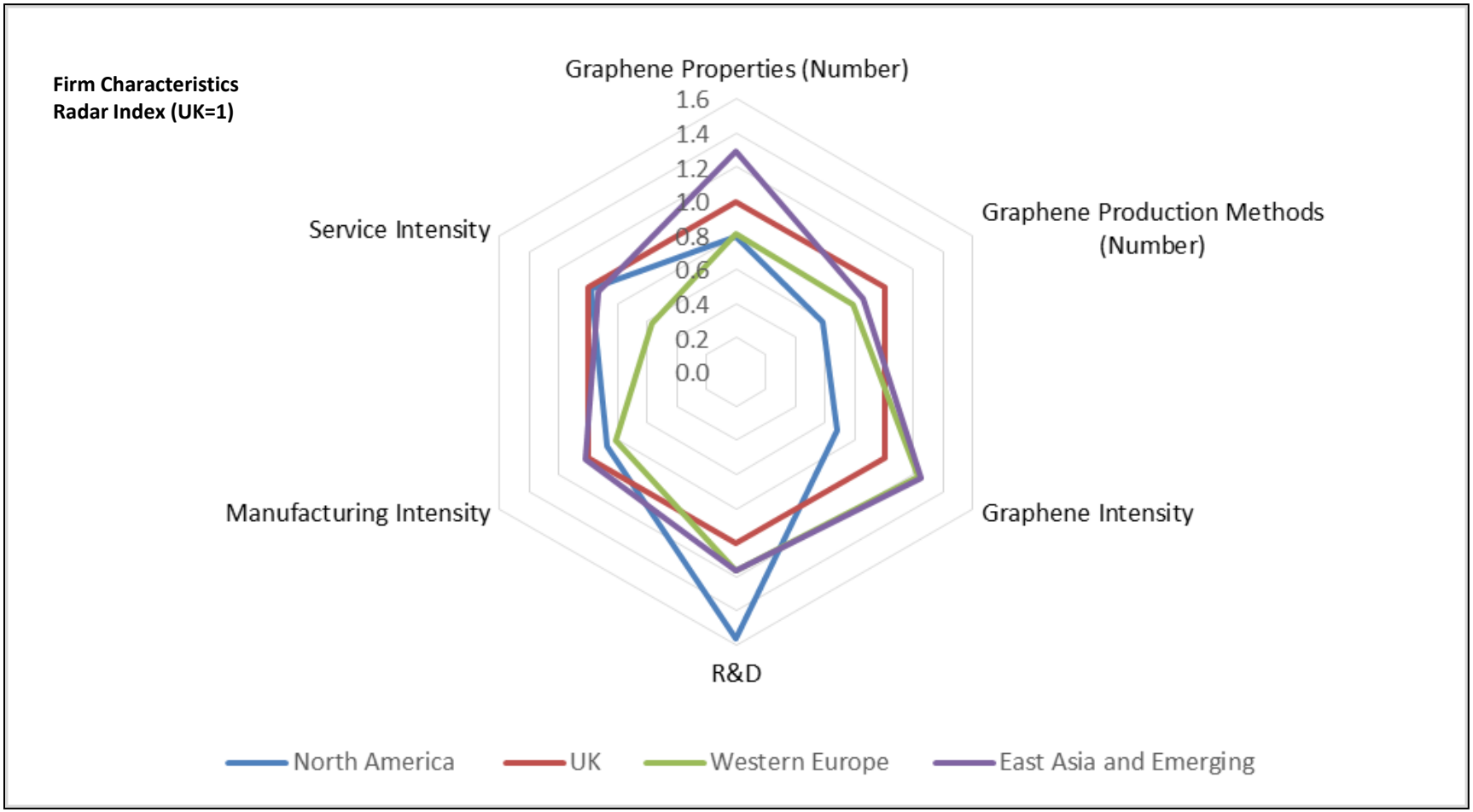




Graphene properties

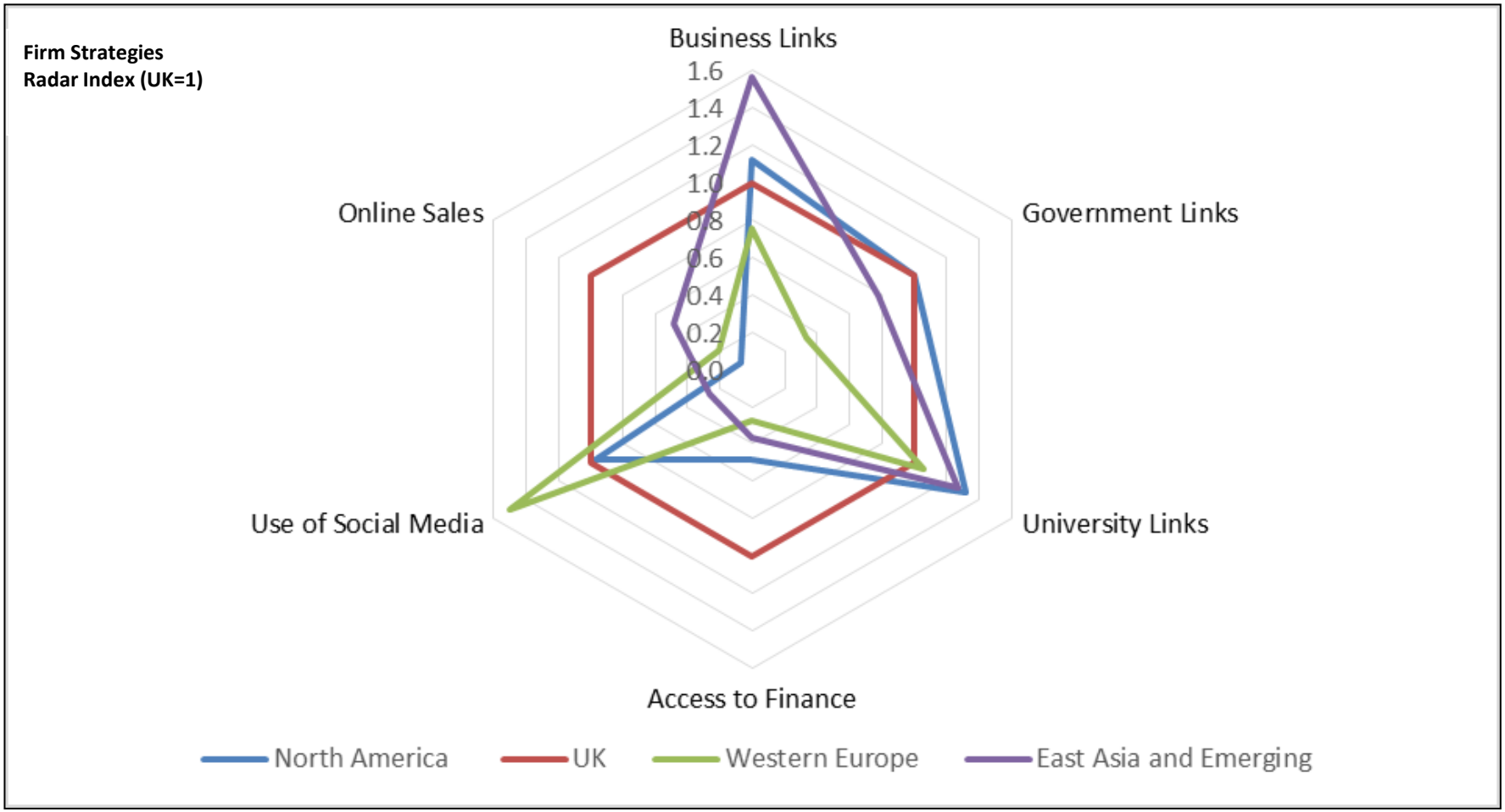


N. American graphene SMEs stress R&D
Asian SMEs stress # of graphene properties



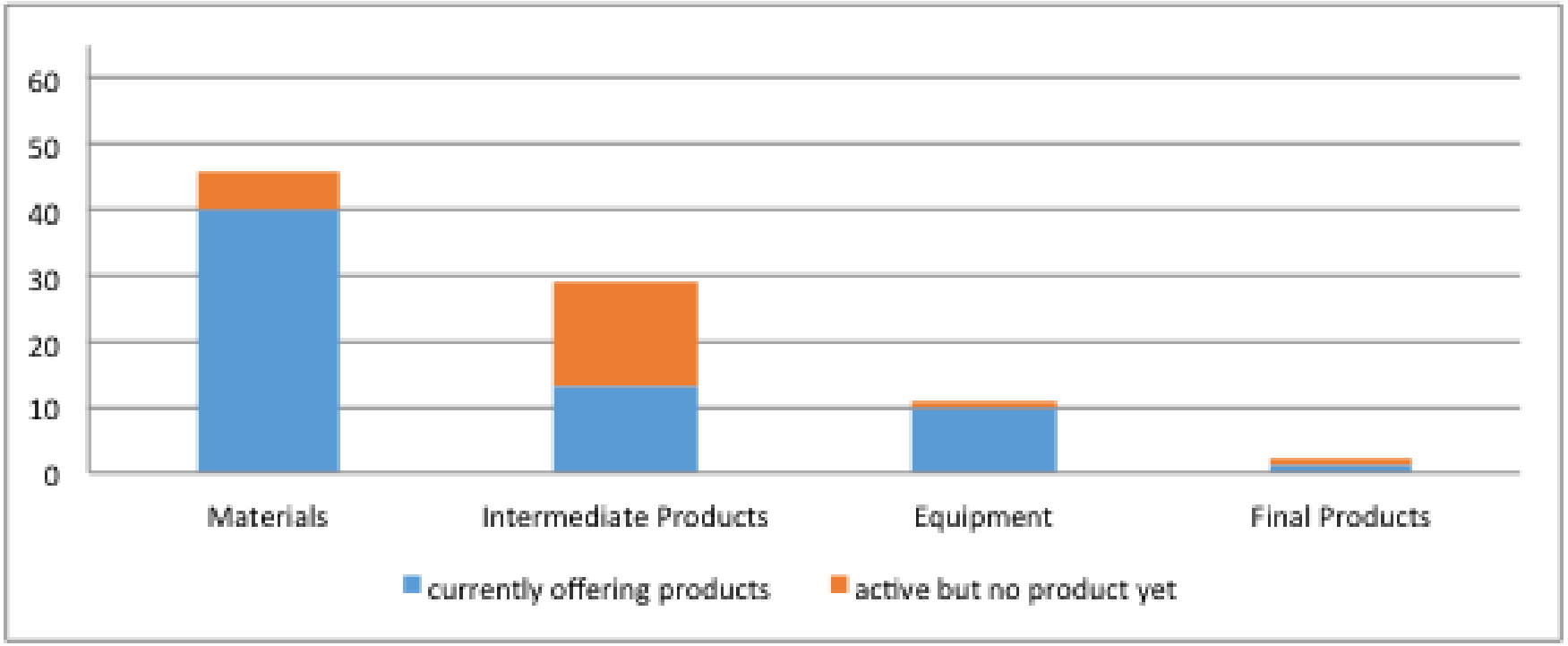
Source: Web mining analysis of 65 graphene small and medium-sized enterprises (SMEs) in study data set. Normalized to UK = 1.

Asian SMEs stress business links. UK firms more online sales.



Source: Web mining analysis of 65 graphene small and medium-sized enterprises (SMEs) in study data set. Normalized to UK = 1.

Most current SME products are upstream in value-chain



Source: Web mining analysis of 65 graphene small and medium-sized enterprises (SMEs) in study data set. Normalized to UK = 1.

Potential graphene products mostly similar to current products, and most are in electronics

Current Final and Intermediate Products	Potential Final and Intermediate Products
☐ Graphene field effect transistors ☐ Thin film transistors (TFT) ☐ Graphene field effect transistors ☐ Graphene-based paint ☐ Functionalized Graphene, inks and coatings ☐ Graphene ink ☐ Ultra capacitors / energy storage ☐ Ink and coatings for the printed electronics	☐ Anti-corrosive coatings used in electronics and electrical equipment/ Photovoltaic devices for solar cells / polymer composites for dental care ☐ Ultrafast photodetector ☐ Nano-composites ☐ Advanced graphene-hybrid admixtures ☐ Graphene ink ☐ Solid-state nano-pore sensing platforms ☐ Electrodes for super capacitors and batteries ☐ Composite of silicon and graphene for longer lasting, faster charging batteries ☐ Energy storage materials, inks and coatings ☐ Composites and film adhesives

Source: Web mining analysis of 64 graphene small and medium-sized enterprises (SMEs) in study data set.

4.6 Graphene SME Strategies – Cluster Analysis

1. Established Movers-In (23)

2. Graphene Materials Entrants (20)

3: Multi-Material Entrants (5)

4. Equipment Makers (9)

5. Science-IP Firms (N=8)

Source: 2-step cluster analysis, SPSS V 22. 65 graphene small and medium-sized enterprises (SMEs) in study data set. Clustering on the basis of strategies, value stream positions and basic characteristics (such as age). Silhouette measure of cohesion and separation: 0.25 (within acceptable range)

4.6 Graphene SME Strategies – Cluster Analysis

1. Established Movers-In (23)

- ❑ Most founded before 2000, mostly not based on graphene
- ❑ Graphene materials, intermediate products, final products
- ❑ Good access to finance, use social media.
- ❑ Produce scientific publications
- ❑ Half of these companies in UK

2. Graphene Materials Entrants (20)

- ❑ Almost all in graphene materials
- ❑ Linkages to universities, financial markets and government are relatively lower

3: Multi-Material Entrants (5)

- ❑ Varied 2D materials
- ❑ Report relatively less R&D
- ❑ Lower links to other businesses and financial markets
- ❑ More mentions of government
- ❑ Stress production methods
- ❑ Most based in North America

4. Equipment Makers (9)

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4. Equipment Makers (9)

- ❑ Majority are equipment manufacturers
- ❑ Some also producing graphene materials
- ❑ Good links with financial markets
- ❑ Mention relationships with other firms and universities (as customers)
- ❑ Most based in North America

5. Science-IP Firms (N=8)

- ❑ Most established after 2010.
- ❑ Research active
- ❑ High linkages universities & businesses.
- ❑ Underline the Nobel Prize in 2010.
- ❑ Highlight properties of graphene
- ❑ Most have not introduced products or revealed their plans for future releases.
- ❑ Diverse locations

Source: 2-step cluster analysis, SPSS V 22. 65 graphene small and medium-sized enterprises (SMEs) in study data set. Clustering on the basis of strategies, value stream positions and basic characteristics (such as age). Silhouette measure of cohesion and separation: 0.25 (within acceptable range)

Key Findings

- **Attention to graphene is associated with SME start-up**
  - Most graphene SMEs founded in 2000s
  - Five clusters of Graphene SMEs: Movers-in; Graphene materials entrants; Multi-materials entrants; Equipment makers; Science-IP firms
- **Technology strategies**
  - SMEs do not always patent but often reveal their activities and graphene technologies through their websites
  - Some publish – especially Movers-In
- **Linkages**
  - SME links vary – university-business links highest for Science-IP firms;
- **Globalization – with one new player**
  - US, European countries, Japan, Korea, and China
  - Research leadership (UK) does not guarantee commercial leadership – although multiple SME graphene firms now operating in UK
- **Slow widening of potential SME application funnel**
  - Most current graphene products are upstream; few SMEs have final products
  - Materials ➔ composites, inks ➔ displays, batteries, transistors
  - Bio-materials, other transformative applications still yet to emerge from SMEs

Some Implications

- **Still in first stage of exploitation of graphene**
  - Exploitation of graphene R&D is taking many years (progress but not so fast?)
  - What will second stage commercialization look like?
- **Graphene innovation models**
  - Materials innovations may not follow the "garage start-up-venture capital scale-up" model
  - Is the pattern: SMEs make the materials and intermediate innovations, but large firms will undertake scale-up and large-scale final applications?
  - Large firms "waiting game" – invested in incumbent technologies, open to collaboration, but not yet acquiring graphene SMEs?
- **Policy implications**
  - Need to complement graphene R&D with translation, scale-up support for SMEs?
  - Case for support of wider array of potential applications?
- **Research implications**
  - Value in web mining as a source of intelligence – though more work needed in validation
  - Next stages: Expand (more SMEs, Large Firms); extend questions (open innovation; EHS)
  - Inclusion of other online data sources (social media) and links with established data sources

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Manchester Business School
University of Manchester, UK

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