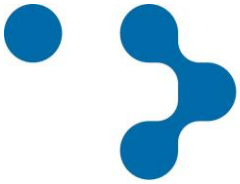

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Searching for Profits at the Intersection of Nanotech and Electronics

Lux Research, Inc.

Ross Kozarsky

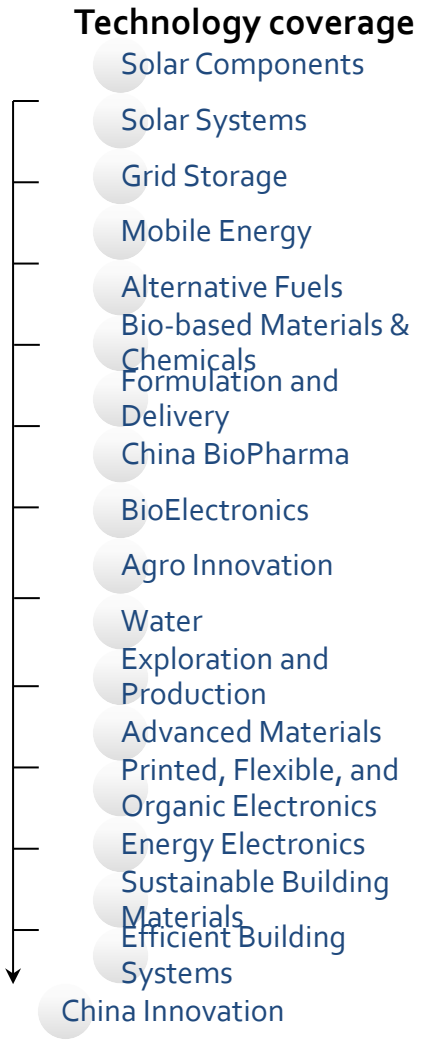
Senior Analyst

Prepared for IEEE

January 28, 2014

About Lux Research

- Helps clients find **new business opportunities** from emerging technologies in physical and life sciences
- Offers ongoing **technology and market intelligence**, as well as market data and consulting services
- Over **250 clients on six continents** – multinational corporations, investors, governments, and SMEs
- **Global reach,** with over 80 employees in Boston, New York, Amsterdam, Singapore, Shanghai, Seoul, and Tokyo
- Combines deep **technical expertise** with **business analysis** to support strategic decisions



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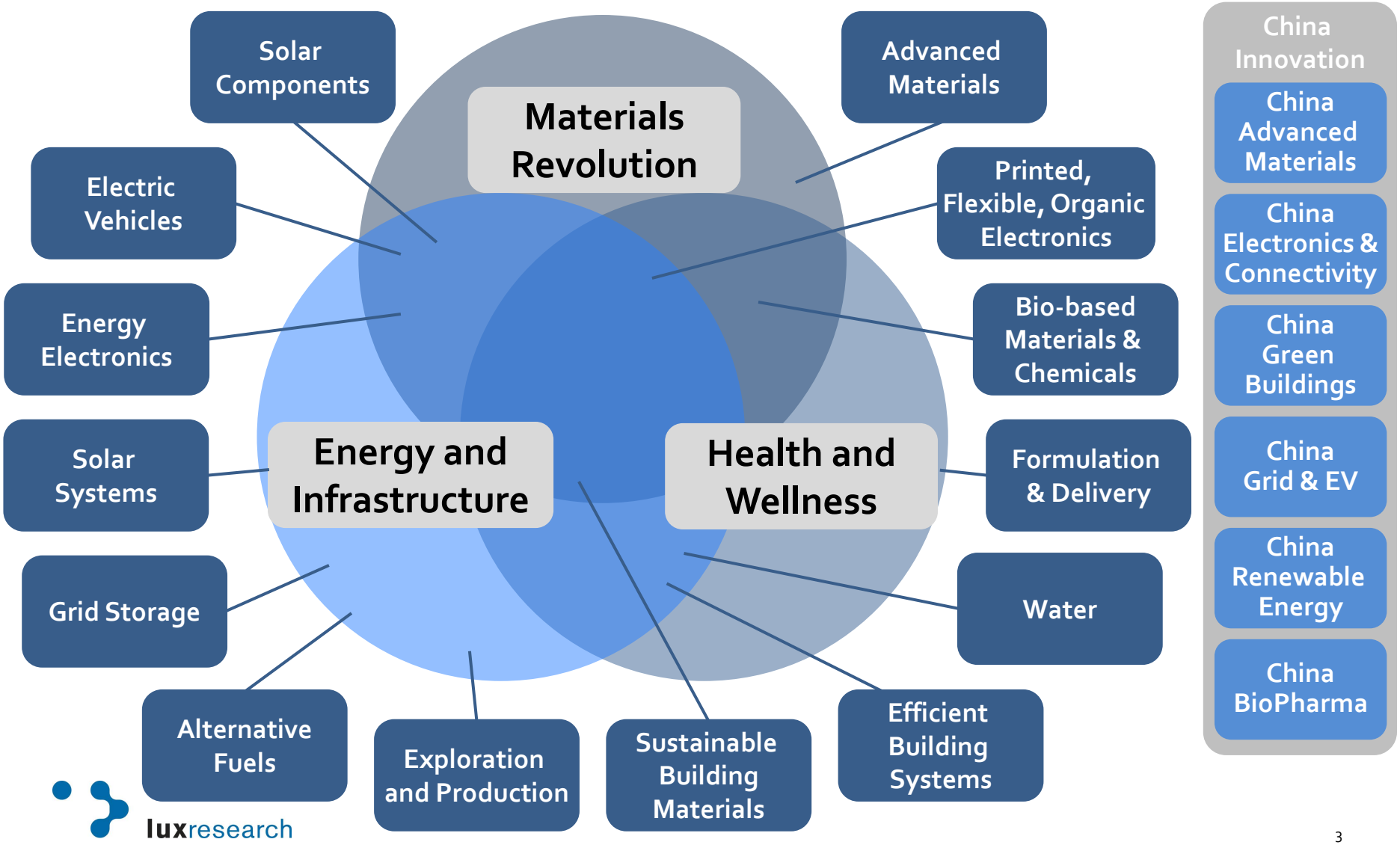
Why no nano?

Lux coverage areas address key global megatrends



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Agenda

- Nanotech market update
- Carbon CNTs: a tale of woe and oversupply (aka: what not to do)
- Is graphene the next carbon nanotube?
- Searching for opportunities in TCFs

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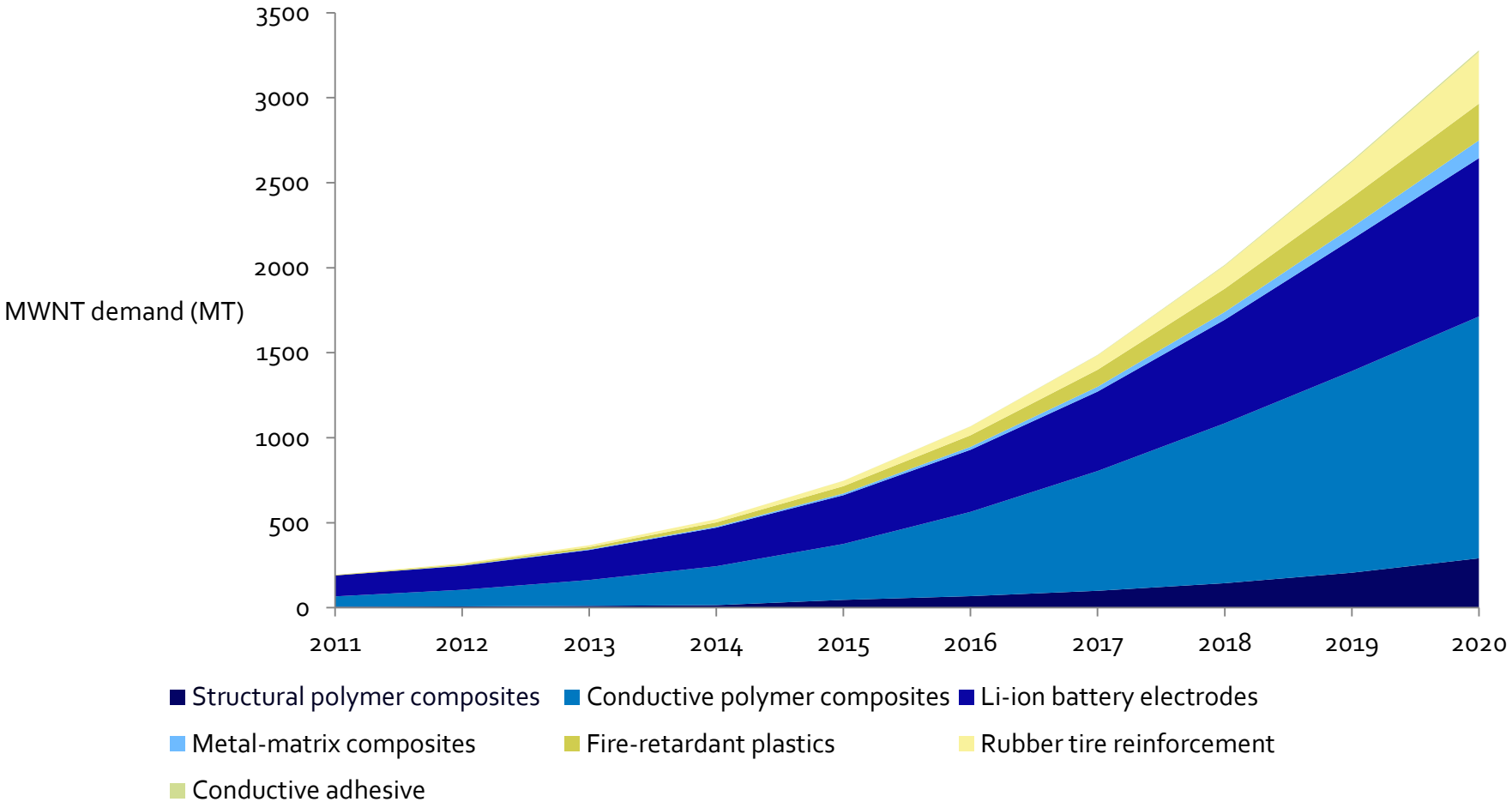
Total MWNT market will reach 3,728 MT by 2020



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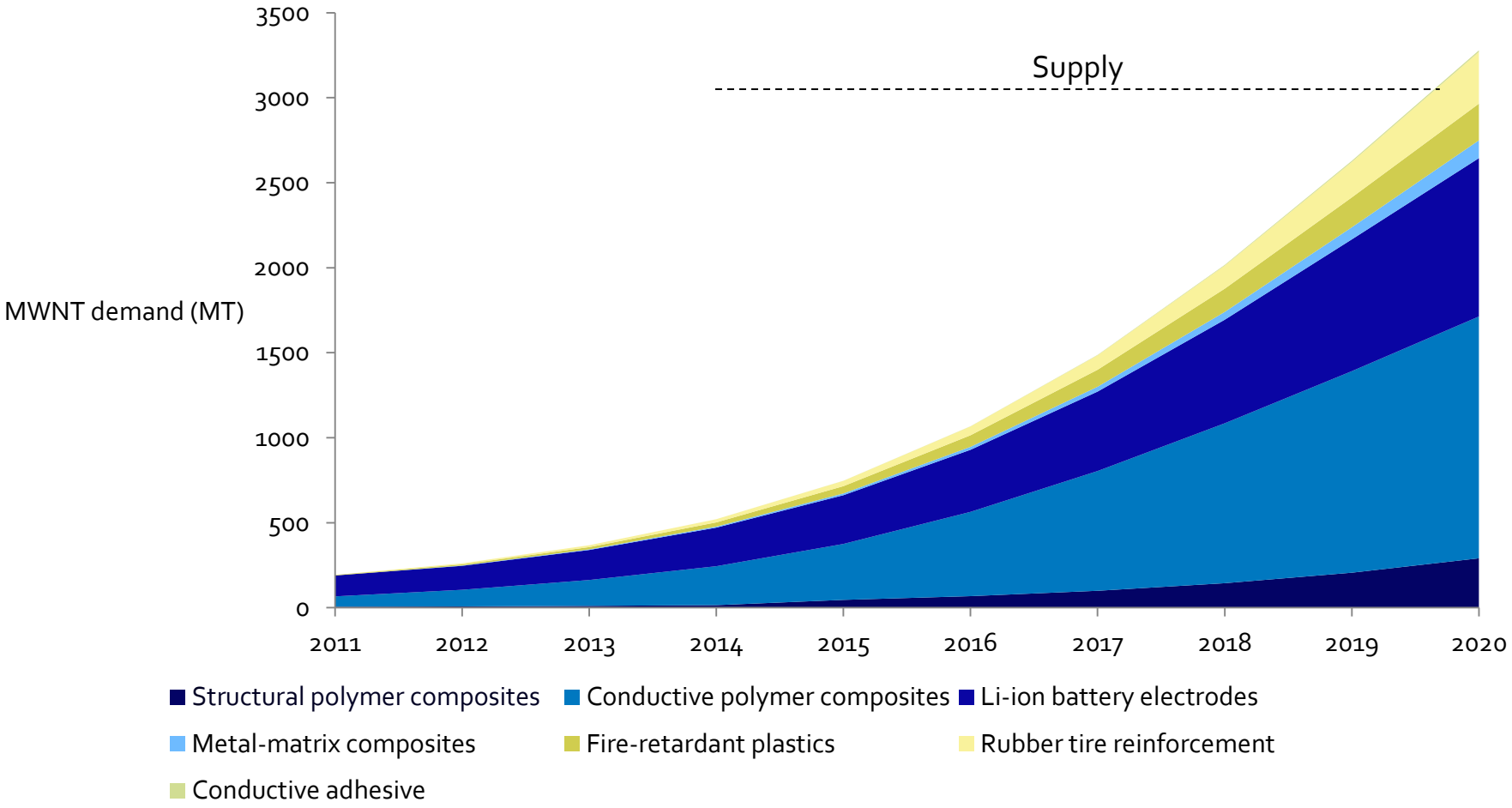
MWNT market remains in oversupply for the foreseeable future



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Bayer MWNTs for… solar-powered planes?

MWNT powders and dispersions

- BMS is a leading material company and previously one of the most reputable sources for MWNTs
- However, MWNT market currently in oversupply; large sources of demand hard to find
- BMS was forced to focus on "long-shot" projects like building the first solar-powered aircraft to circumnavigate the globe
- Prospects and timing for profitability of MWNT unit long unclear…Bayer shut down its CNT activities last week
  - *"…the potential areas of application that once seemed promising from a technical standpoint are currently either very fragmented or have few overlaps with the company's core products and their application spectrum."* (BMS CEO)

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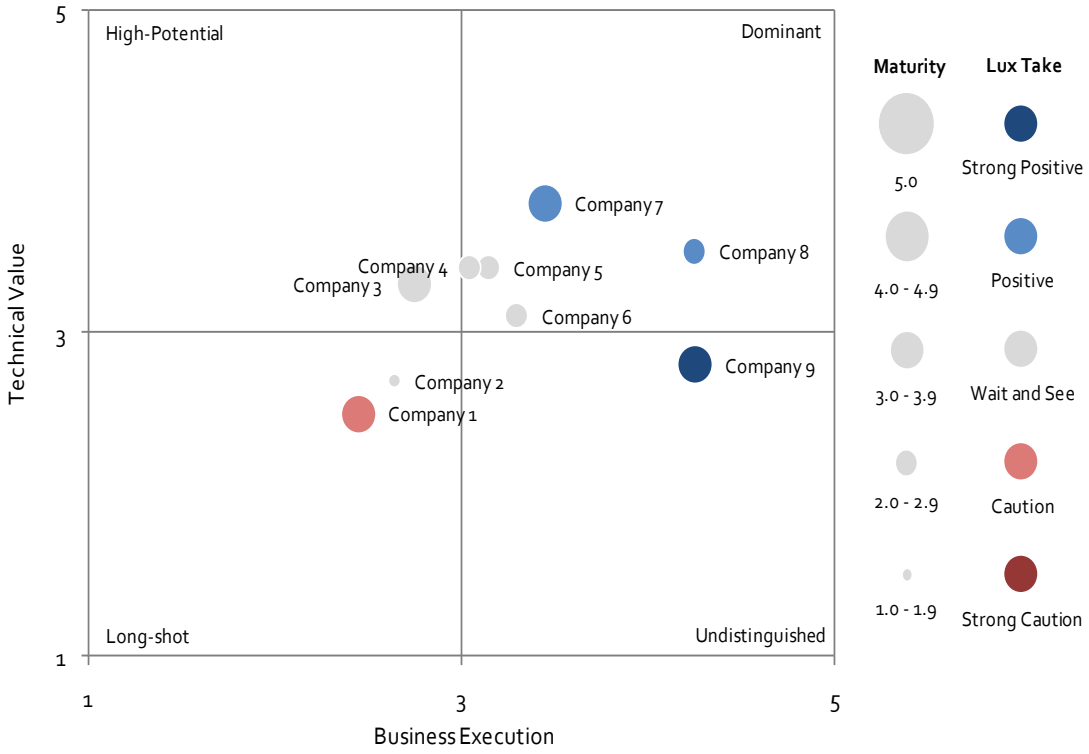
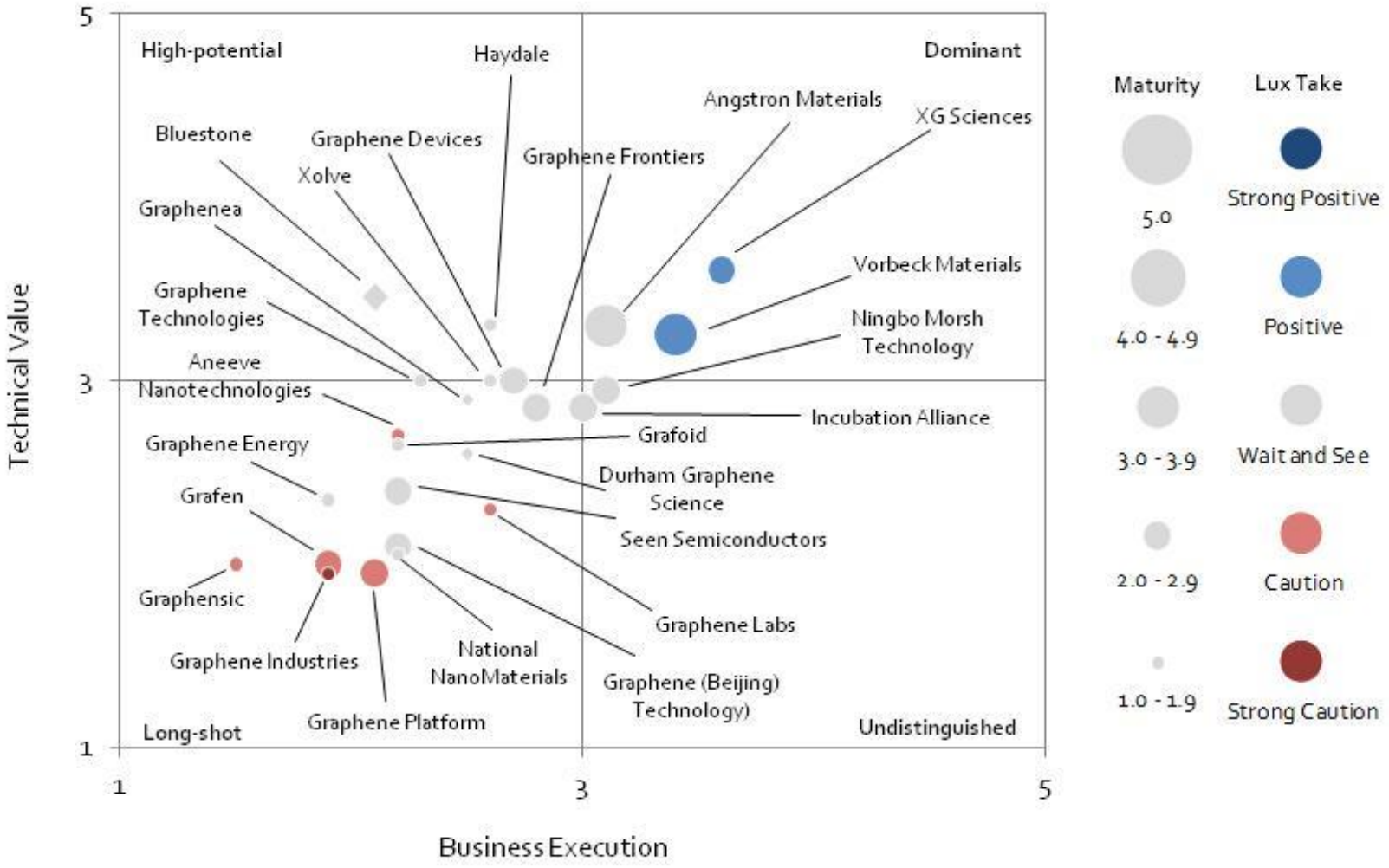
Lux Innovation Grid provides a framework to assess graphene developers

- **Technical value**: the strength and value of a company's technology determines its technical value score
- **Business execution**: a company's ability to perform and achieve success determines its business execution score
- **Maturity**: the completeness of a company's development reflects its maturity
- **Lux Take**: a company's success is measured holistically by the Lux Take



Findings of the Lux Innovation Grid illuminate key graphene companies and the dynamics of the field



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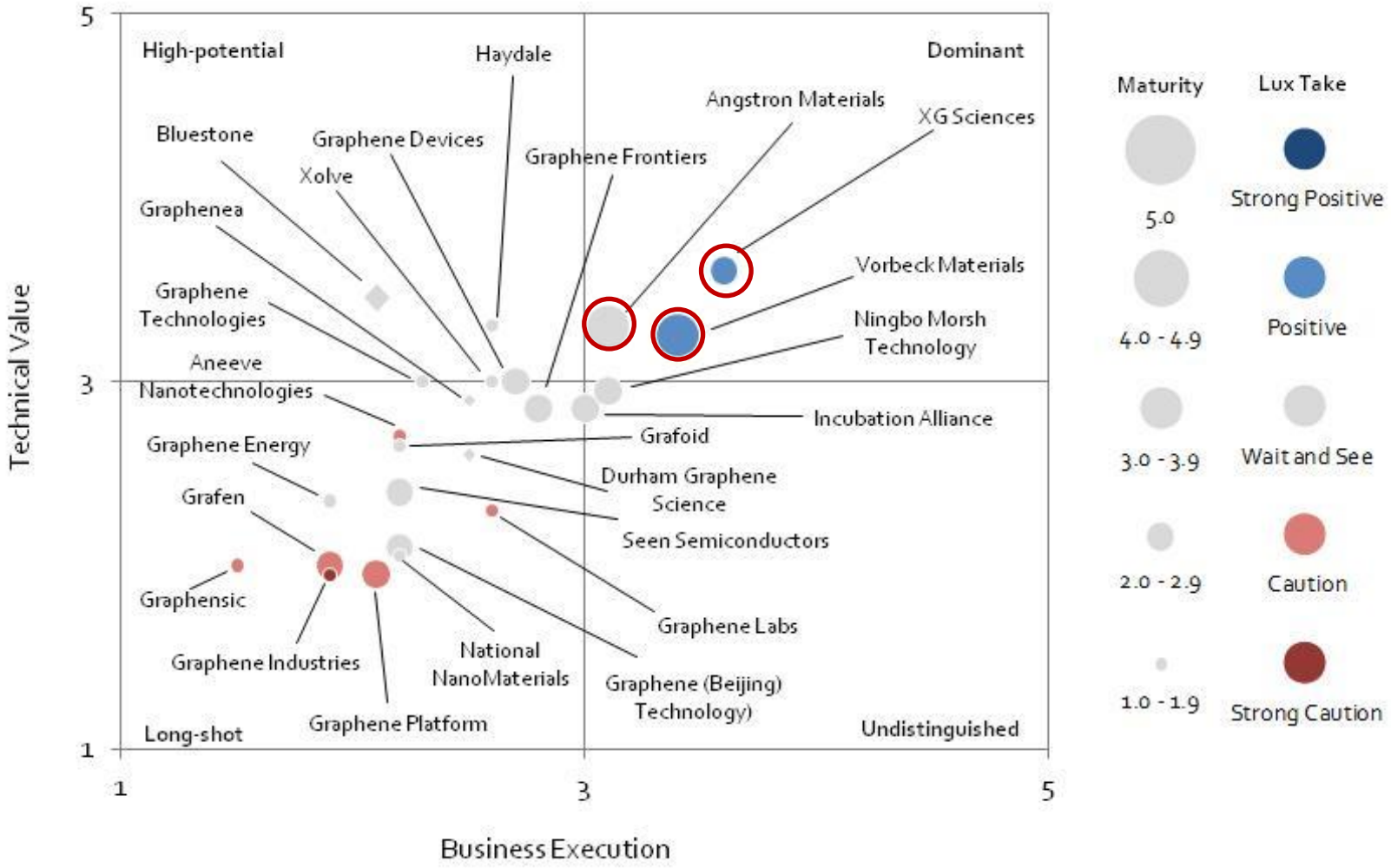
First wave of developers continue to assert their dominance



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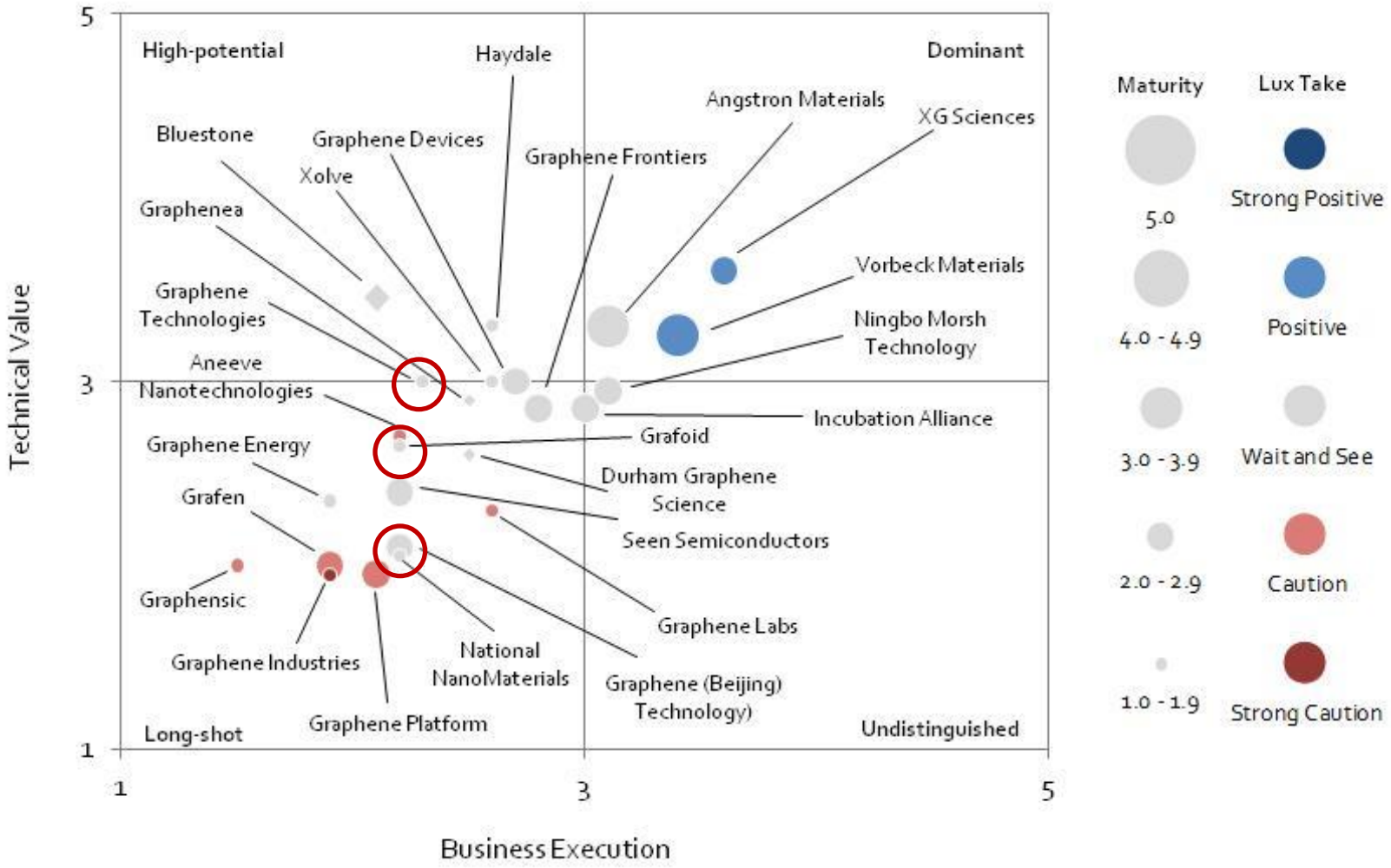
Second wave of developers: alternative precursors



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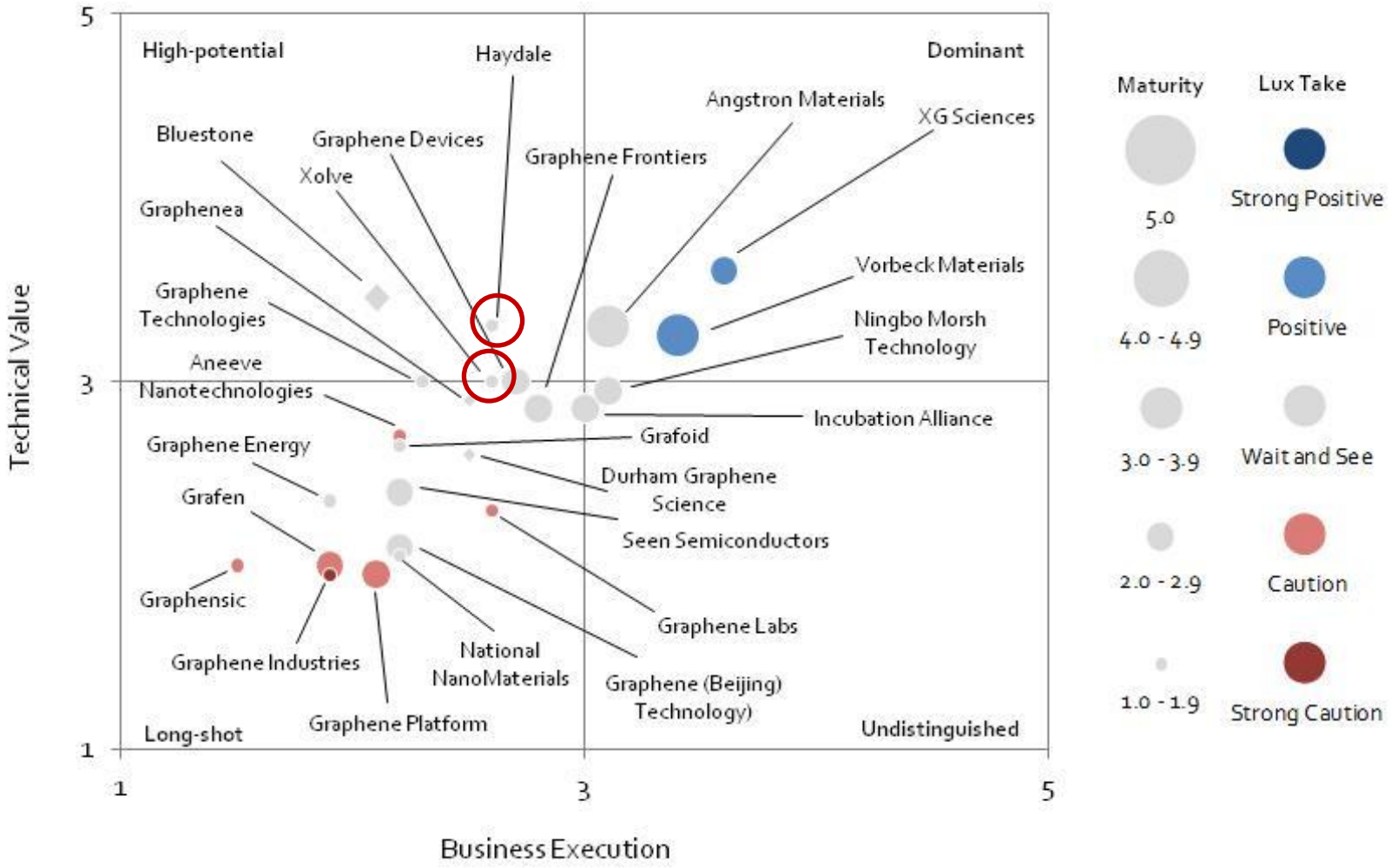
Second wave of developers: alternative processes



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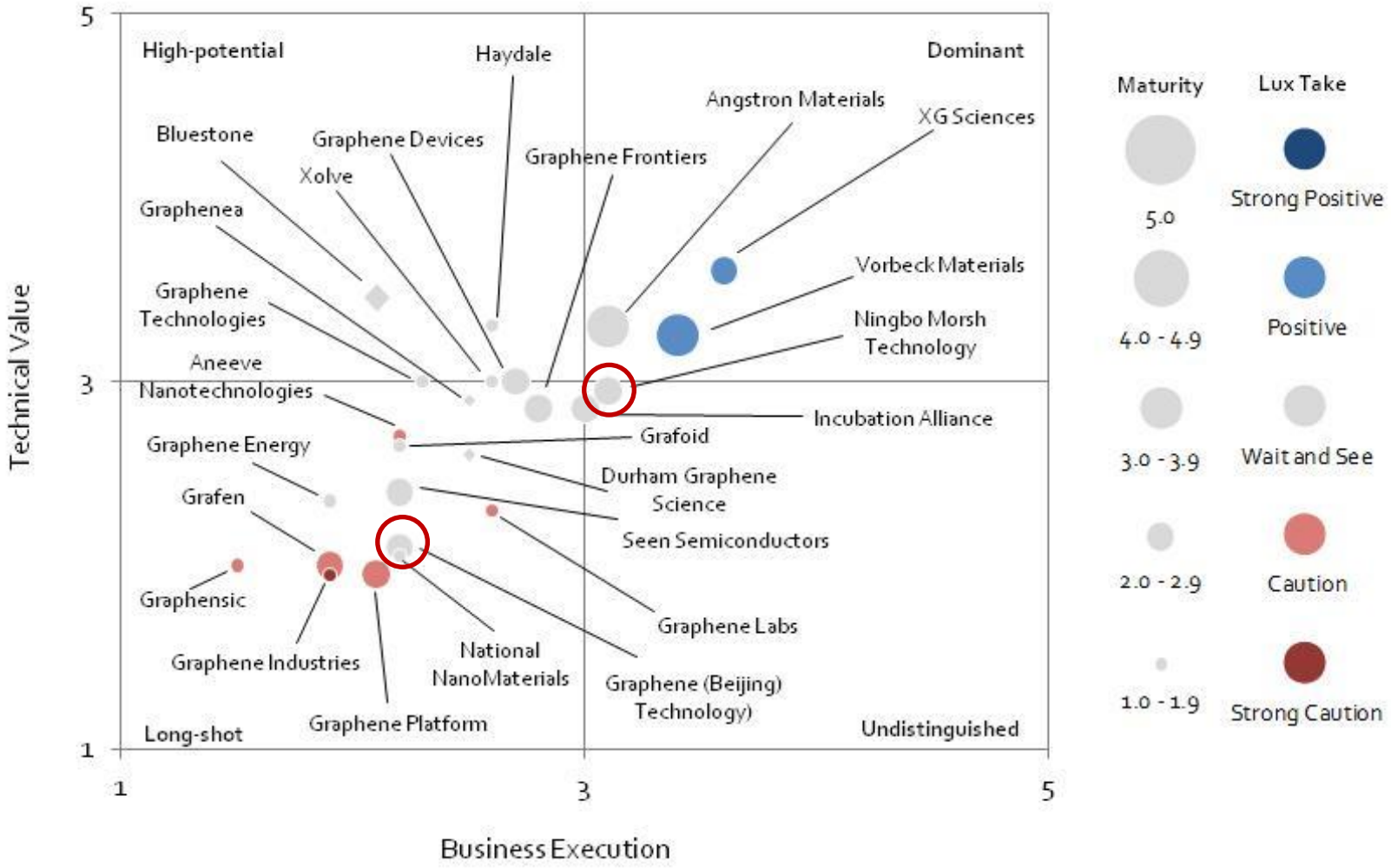
Chinese capacity expansions threaten to throw the space into oversupply



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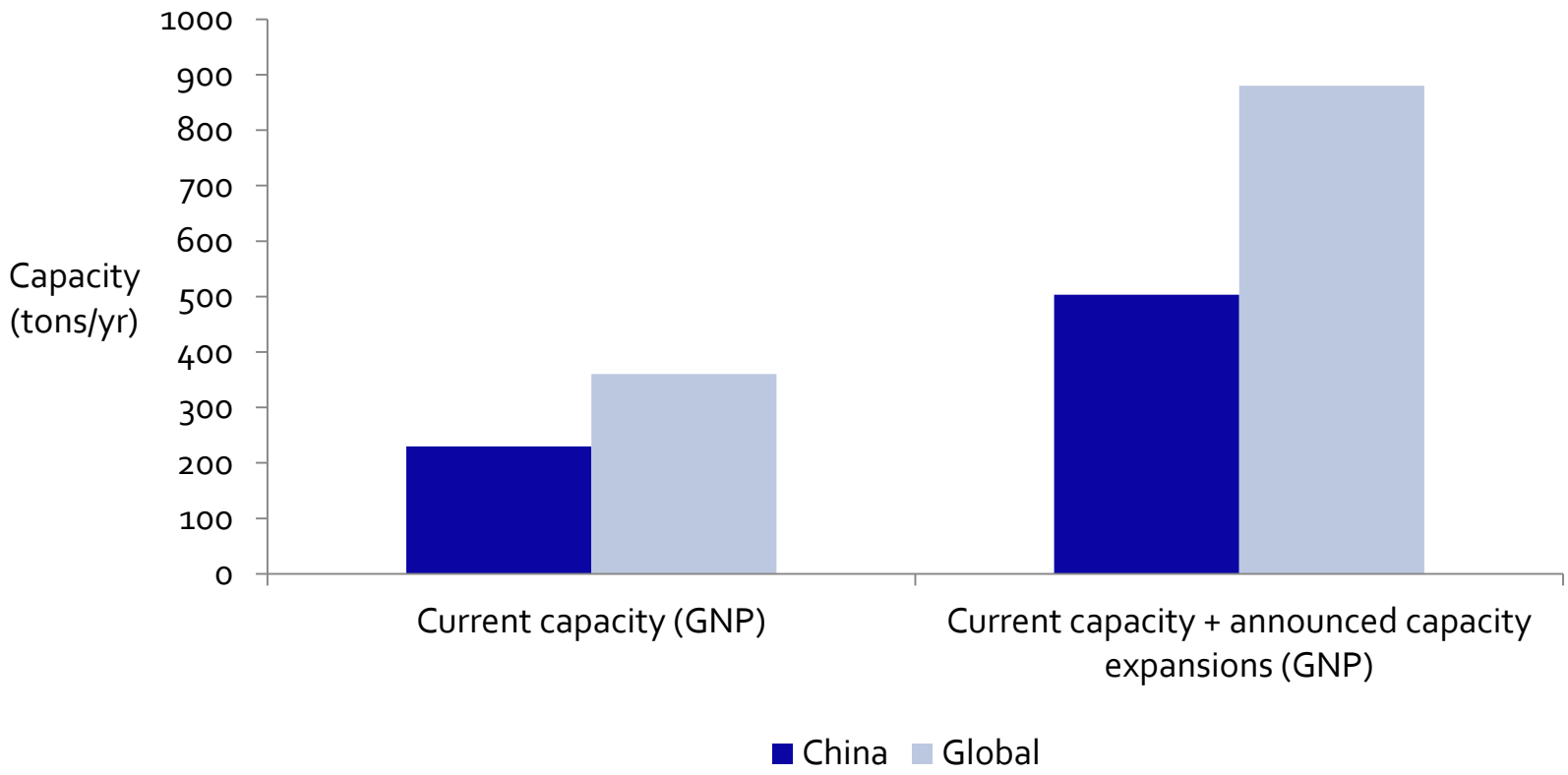
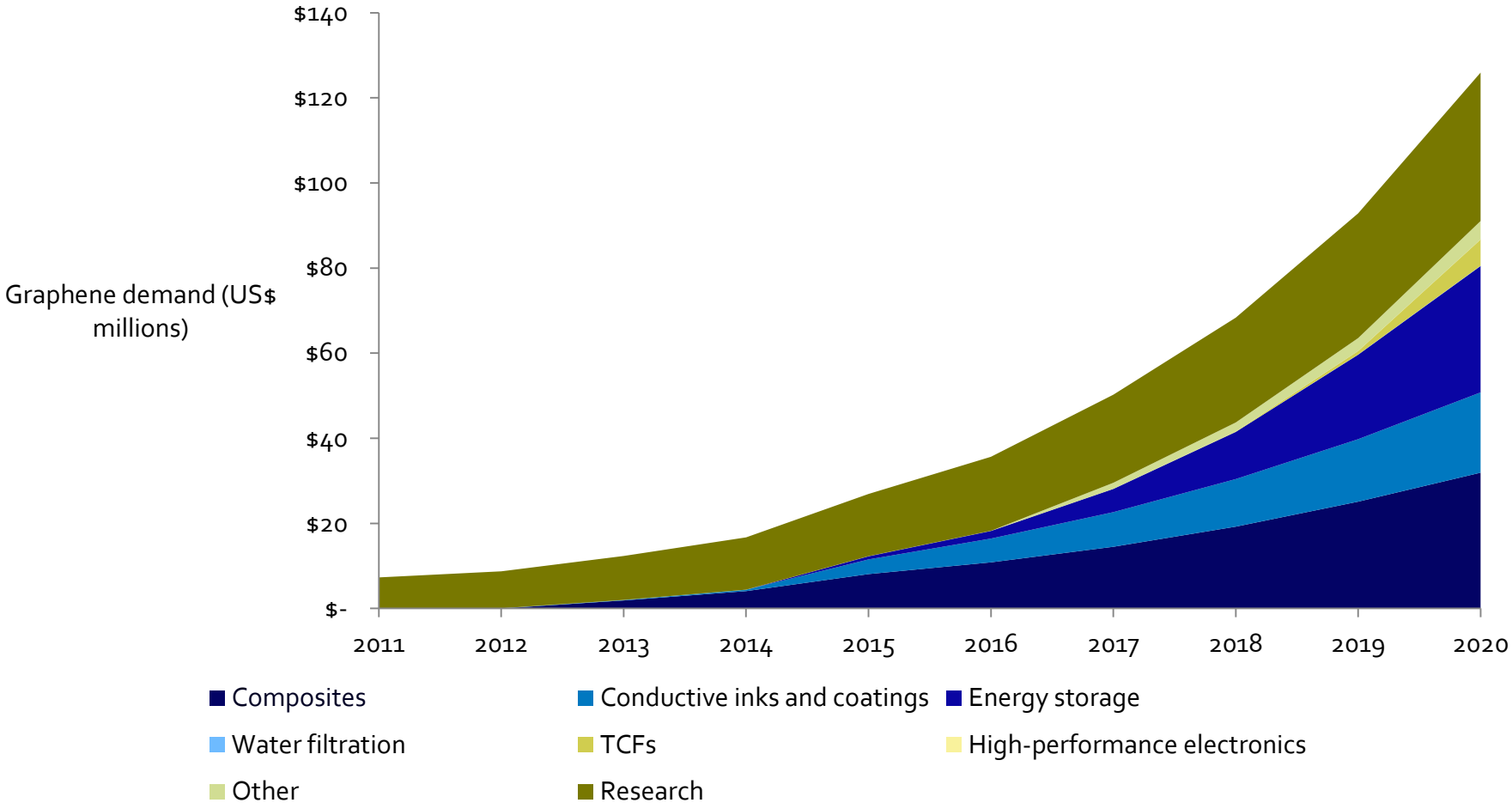
Aggressive capacity expansions by Chinese companies driving space towards oversupply



- In Nov 2013 The Sixth Element commissioned the 2nd phase of its project to expand capacity to 100 tons/yr, making China the global GNP capacity leader
- Other developers have even more ambitious scale-up plans: Ningbo Morsh anticipates ramping to 300 tons/yr in 2014

Total graphene market will reach $126 million in 2020



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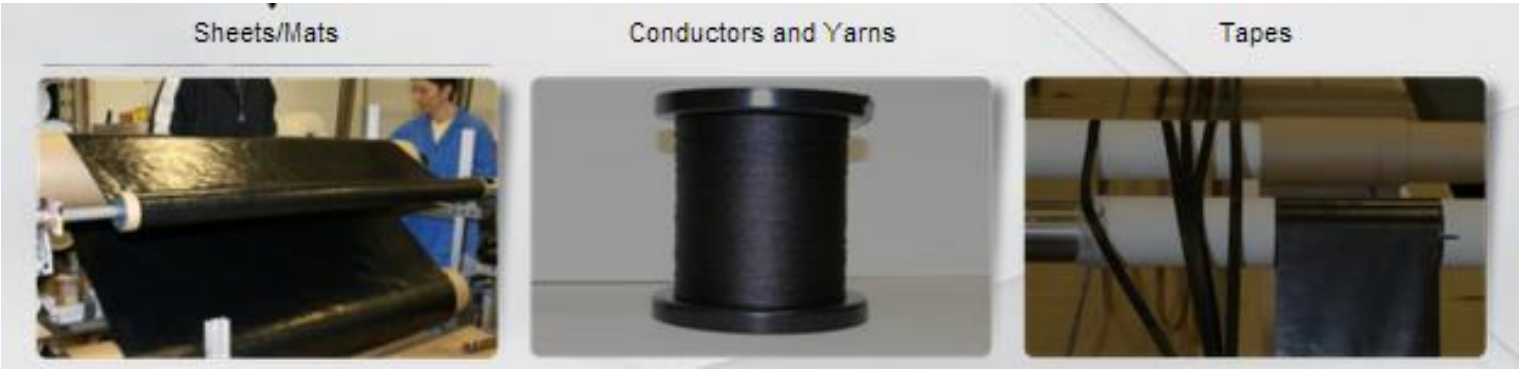
- Is graphene the next carbon nanotube?
- "Ross, stop being such a downer…tell me something positive!"
- Searching for opportunities in TCFs

Nanocomp Technologies

CNT yarns and sheets



- Produces CNT yarns and sheets using CVD process; directly spins synthesized CNTs into yarns or lays them onto a translating belt as nonwoven sheets
- Sells yarns as multi-kilometer spools; contracts Cytec and Tencate for converting sheets to pre-pregs
- Targeting EMI shielding, electrical wiring, and data cable applications in aerospace; products used on Juno spacecraft
- In June 2012 announced strategic partnership with DuPont to develop armor products (includes $25 million investment); recently secured additional $18 million from U.S. DoD

Vorbeck

Single layer graphene inks and coatings

VorbeckMaterials
realizing graphene's possibilities

- **Technology**: Develops opaque conductive single sheet GNP graphene inks for screen, flexographic, and gravure printing, as well as wire-rod and slot-die coating. Manufactures graphene and inks in-house.
- **Barriers**: Scale-up required to drop costs and open up markets; recent setbacks and delays have slowed momentum.
- **Other**: Formerly partnered with MeadWestVaco for retail security packaging. However, MeadWestvaco has scaled back its smart packaging initiatives, ceasing development (see the February 20, 2013 LREJ).
- **Lux Take:** Positive. Clients targeting graphene inks should approach, as Vorbeck is a leader in this space; medical applications remain farther off.
- https://portal.luxresearchinc.com/research/profile/Vorbeck_Materials

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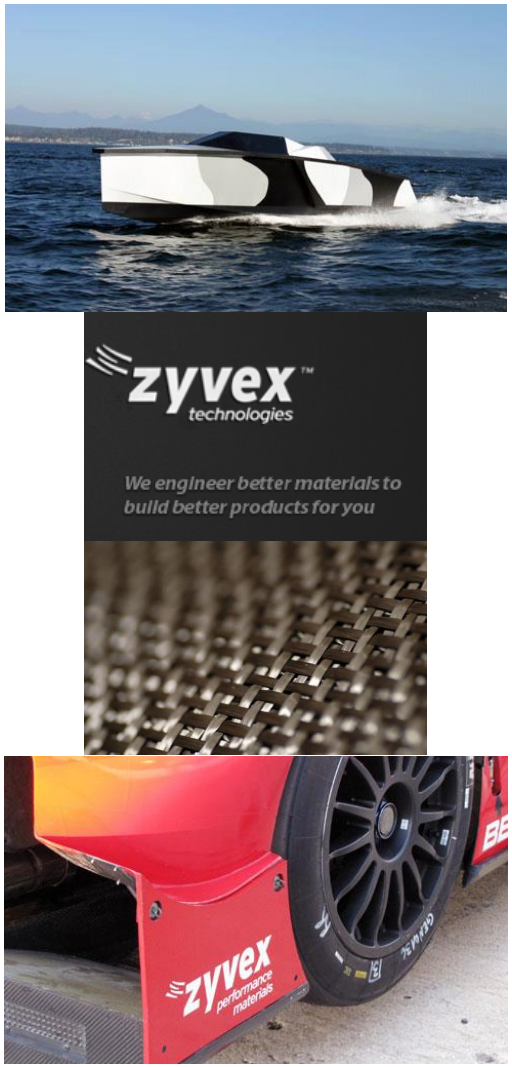
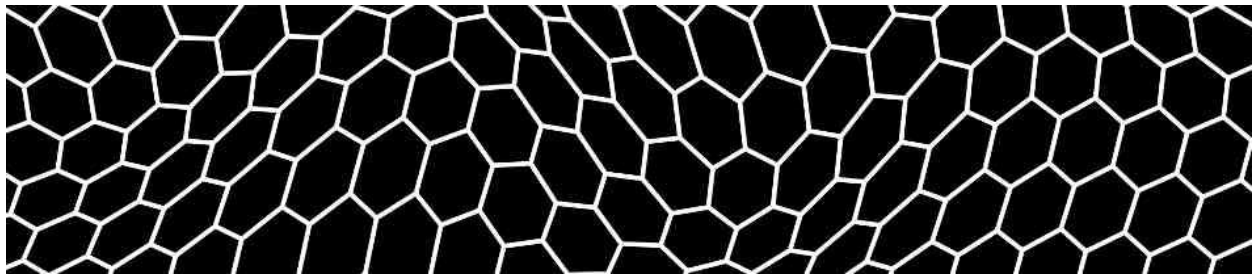
Zyvex Technologies

Nanoparticle-enhanced polymers, intermediates, and products

- Produces MWNT/polymer nanocomposite adhesives and prepregs in an epoxy matrix
- Core technology is proprietary Kentera polymer, which enhances MWNT dispersion in and bonding to a polymer matrix
- Primary business models are to license technology and sell intermediate products, but also manufactures end products as demonstrations of its materials' capabilities
- Partners and customers in aerospace, automotive, sporting goods, tire, oil and gas, maritime security, and chemical industries
- Focused primarily on CFRP prepregs, but also developing MWNT-reinforced GFRPs for automotive applications
- **Positive.** Clients interested in thermoset CFRPs should consider partnering with Zyvex, as its materials offer improved mechanical properties and only slightly increased cost



Seek out university relationships to refine and enhance syntheses



- Founded in 2010 with initial funding of S$40 million from NUS, has since received an additional S$60 million from the Singapore government
- Primarily a research institution, but also interested in exploring commercial value of research
- Working on different chemical exfoliation, intercalation, and sonication methods to convert graphite precursor to GNPs; no partners for this work, but spun out Graphite Zero
- Grows graphene films using surface-catalyzed CVD on metal foils; can transfer material to glass, polymer, and quartz substrates
- Working towards JDAs with BASF, Fuji Electric, and ST Kinetics for graphene film application development; currently seeking business partners who can help scale production
- **Wait and see.** Rich funding makes it an attractive development partner, though scale-up efforts are premature as value proposition of its wares is unproven

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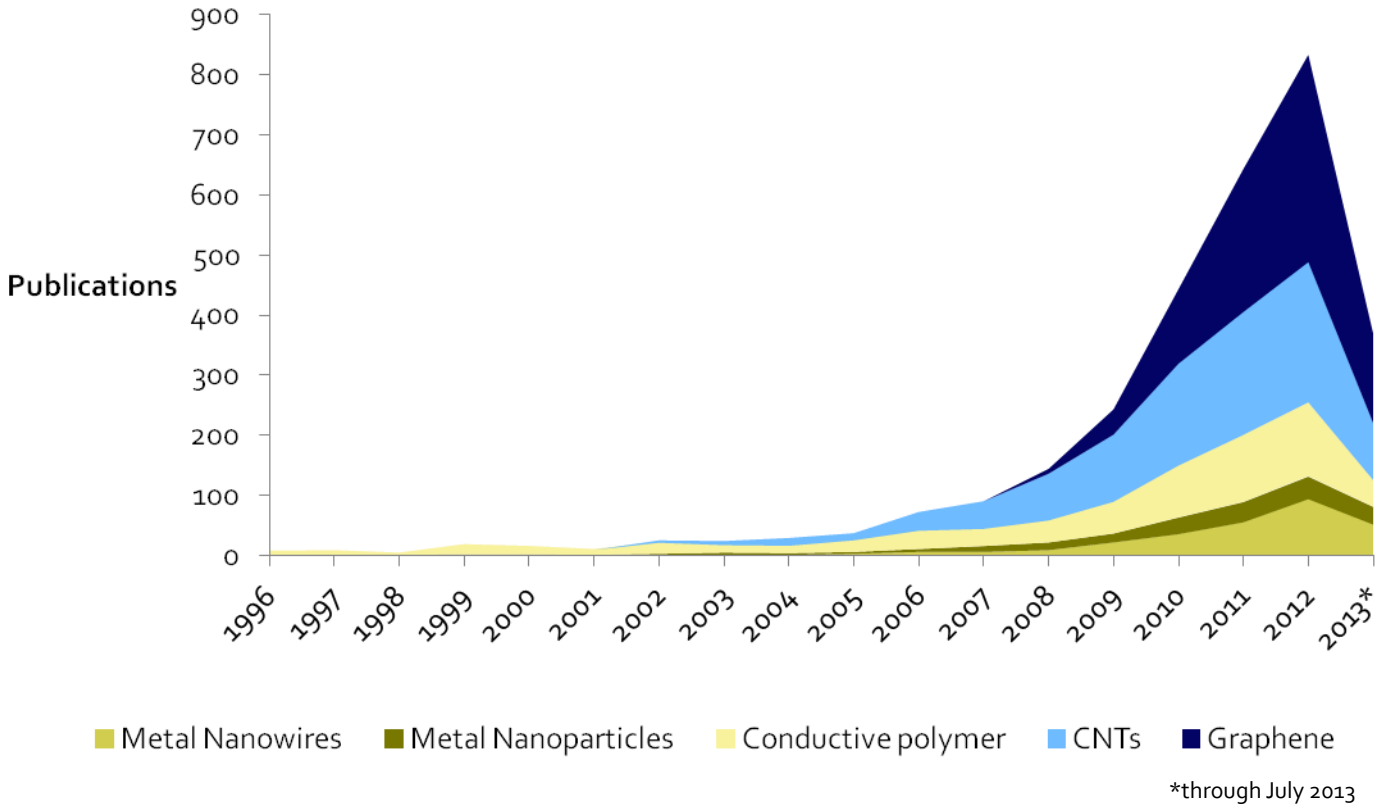
CNTs are Top Academic TCF Technology, but Graphene is Hot Recently



Source: Lux Research
Getting Full Credit from Academic Partnerships: The Top Technologies, Regions, and Universities, September, 2013

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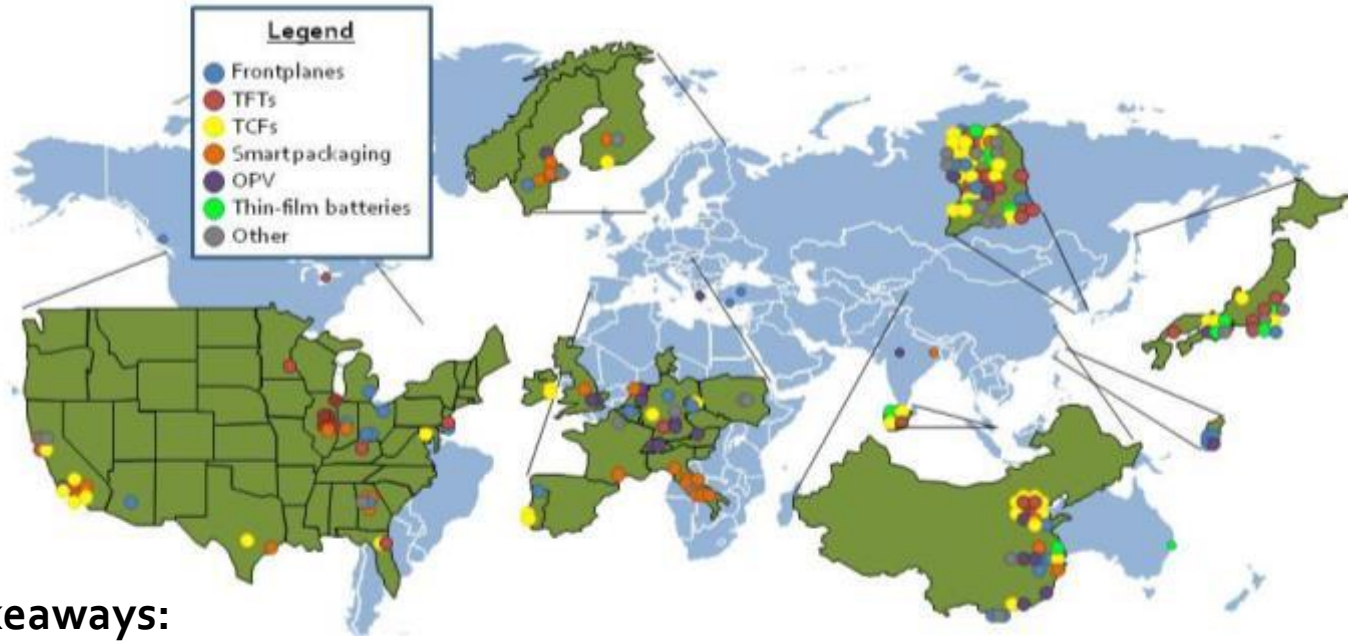
Effective academic partnering through finding the top technologies, regions, and universities



Key takeaways:

- We evaluated 36,000 publications in printed, flexible, and organic electronics, where academic research has increased 25% annually since 1996.
- Seoul is the top regional hotspot, with 61 of the top 213 researchers.
- Seoul National University, Stanford, UCLA, and the University of Tokyo top the list of 30 candidates for forming master agreements.

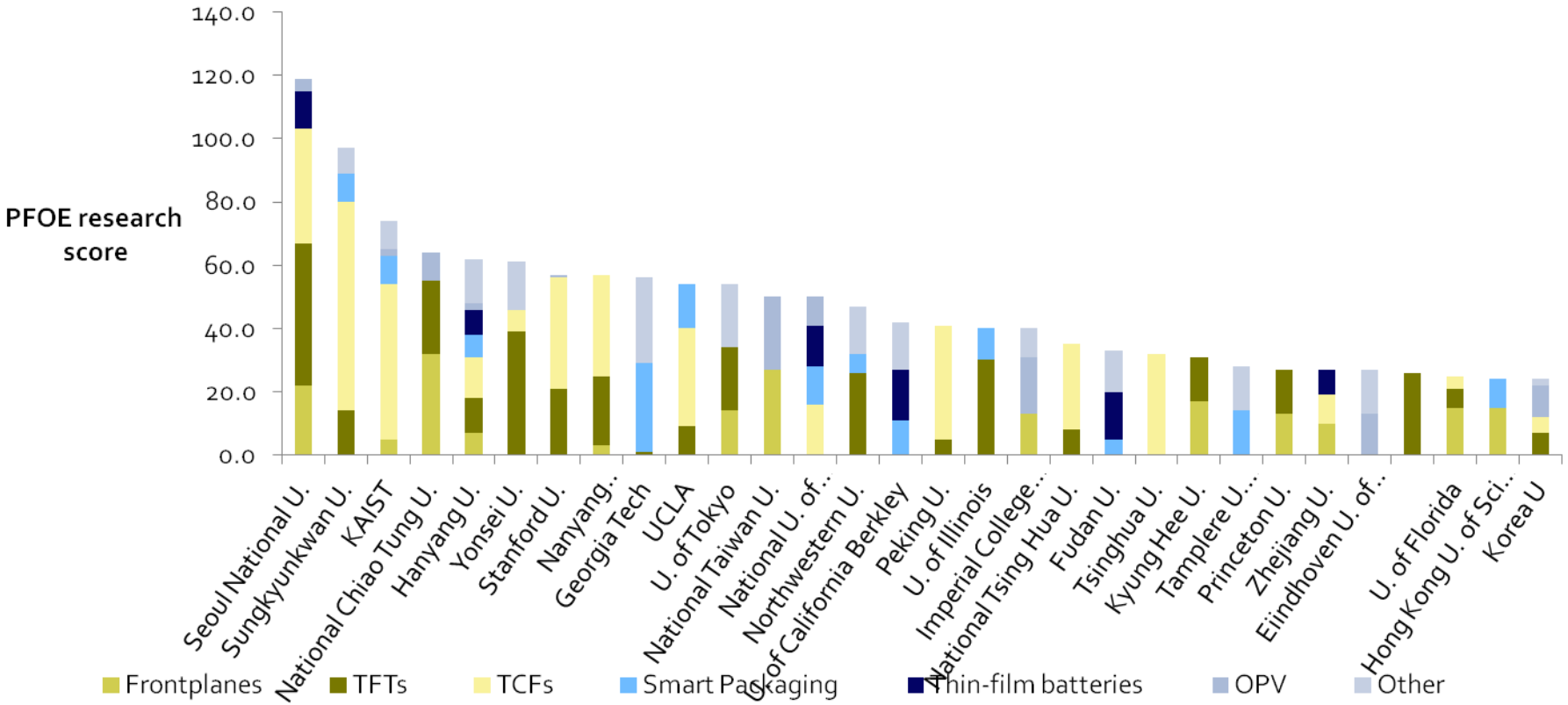
luxresearch

Source: Lux Research report "Getting Full Credit from Academic Partnerships: The Top Technologies, Regions, and Universities"

South Korea is the Top Global Region across all Technologies, but particularly in TCFs and TFTs

	Technology Family	Technology: Research group (School)
South Korea	TCFs	**Graphene:** Minhyeok Choe (Gwangju Institute of Science & Technology); Byung Hee Hong (Sungkyunkwan University); Takhee Lee (Gwangju Institute of Science & Technology); Young Hee Lee (Sungkyunkwan University); Jong-Hyun Ahn (Sungkyunkwan University); Hakseong Kim (Konkuk University) **CNT:** Seil Kim (Hanyang University); Joo-Hyung Kim (Chosun University); Siegmar Roth (Korea University); Jong-Heun Lee (Korea University) **Polymer:** Hakkoo Kim (Korea University); Jegon Lee (Seoul National University); Jungyoon Kim (Korea Institute of Science & Technology); Ji Min Kim (Chungnam National University) **Nanowire:** Sanghyun Ju (Kyonggi University); Jaebeom Lee (Pusan National University); Sang-Woo Kim (Sungkyunkwan University); Ju-Hyun Lee (Kyung Hee University) **Nanoparticle:** Hee-Tae Jung (KAIST); Jung-Yong Lee (KAIST)
	TFTs	**Metal oxide:** Sunyoung Lee (Chungbuk National University); Hyun Jae Kim (Yonsei University) ; Jingon Jang (Seoul National University); Soo-Yeon Lee (Seoul National University); Jiwoong Kim (Sungkyunkwan University); Jung-Hee Lee (Kyungpook National University); Chi-Sun Hwang (ETRI) **Organic:** Jin Jang (Kyung Hee University) ; So Han Kim (Chungbuk National University); Chan Eon Park (Pohang University of Science & Technology); Ji-Hoon Kim (Pusan National University); Yun Ho Kim (Korea Research Institute of Chemical Technology); Ju-Hyun Lee (Kyung Hee University) **Printed silicon:** Kyung-Ju Lee (Korea Research Institute of ChemicalTechnology); Hong Seung Kim (Korea Maritime University); Jong-Hyun Ahn (Sungkyunkwan University) **CNT:** Seok Ju Kang (Yonsei University)
	Other	**Conductive ink:** Jaehwan Kim (Inha University); Ju Hyun Lee (Inha University); Donghwan Kim (Sunchon National University); Jooho Moon (Yonsei University); Sunho Jeong (Korea Research Institute of Chemical Technology) **Deposition:** Junseok Kim (Sunchon National University); Seung Hwan Ko (KAIST); Jaewon Chung (Korea University) **Haptics:** Jihyung Yoo (Sogang University)
	OPV	**DSSC:** Nam-Gyu Park (Sungkyunkwan University); Ji Hye Kim (KAIST)
	Smart packaging	**Memory/logic:** Tae Whan Kim (Hanyang University)

U.S., South Korean, and Chinese Universities Control the Top 30 PFOE Universities



Source: Lux Research

Getting Full Credit from Academic Partnerships: The Top Technologies, Regions, and Universities, September, 2013

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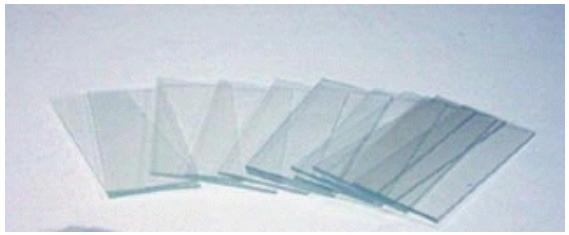
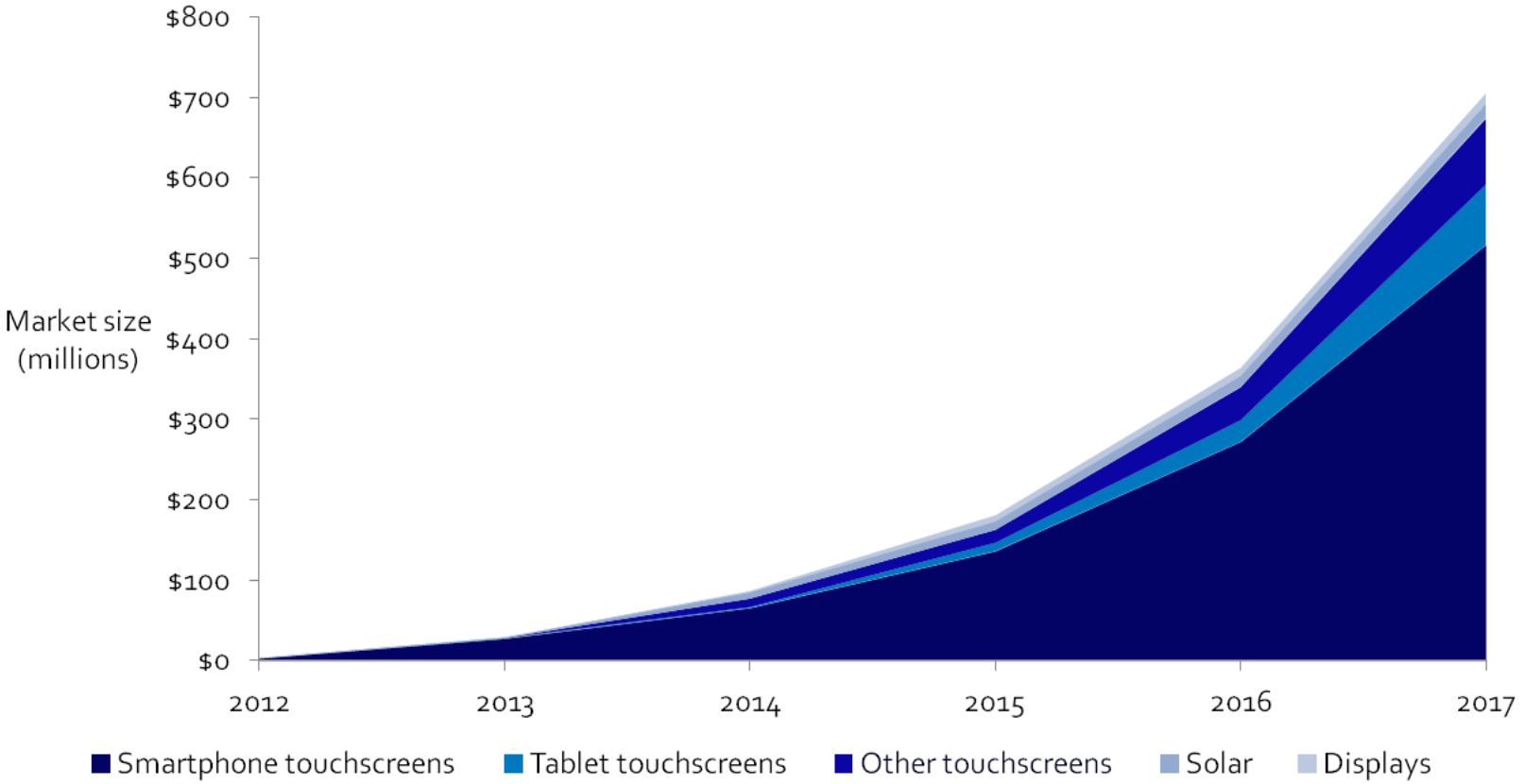
Indium tin oxide (ITO) is the Incumbent

- Advantages
  - Excellent conductivity and high transparency
  - Familiar materials properties and processing methods
  - Large installed infrastructure in the display and PV industries
- Disadvantages
  - Deposited limits material usage
  - Etching
  - Indium supply is unreliable
  - ITO is brittle, cracking and degrading over time
  - Performance (transparency/ conductivity) on flexible substrates



ITO replacement films will rise to $705 million



Source: Lux Research 2012

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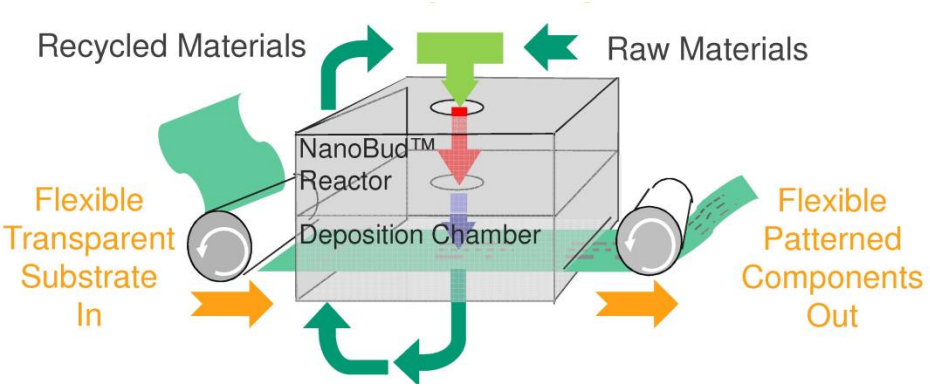
Case Study: Canatu

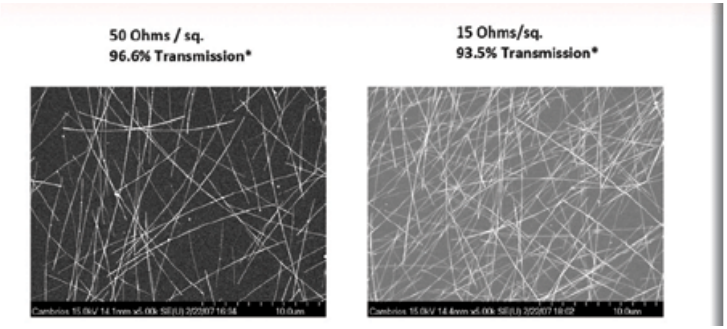
Nanotube-fullerene hybrid materials for electronic and optical applications

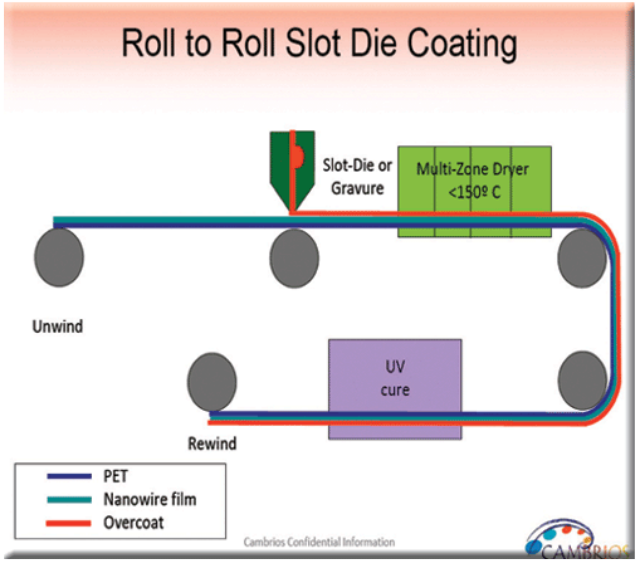


- **Technology:** Creates semiconducting and conducting fullerene derived nanotubes dubbed "NanoBud,"in one pot synthesis without need for purification
- **Applications:** Touchscreens, capacitors, transistors, transparent conductors, OPV active layers, logic circuits and more
- **Momentum:** Recently raised $12 million for further R&D and to build a roll-to-roll production line to replace its manual process
- **Lux Take:** Wait and see: Offers higher performance than conductive polymers, but still a dark horse for TCFs, TFTs, and touch sensors, behind more established metal-based technologies
- **Lux Profile:** https://portal.luxresearchinc.com/research/profile/Canatu

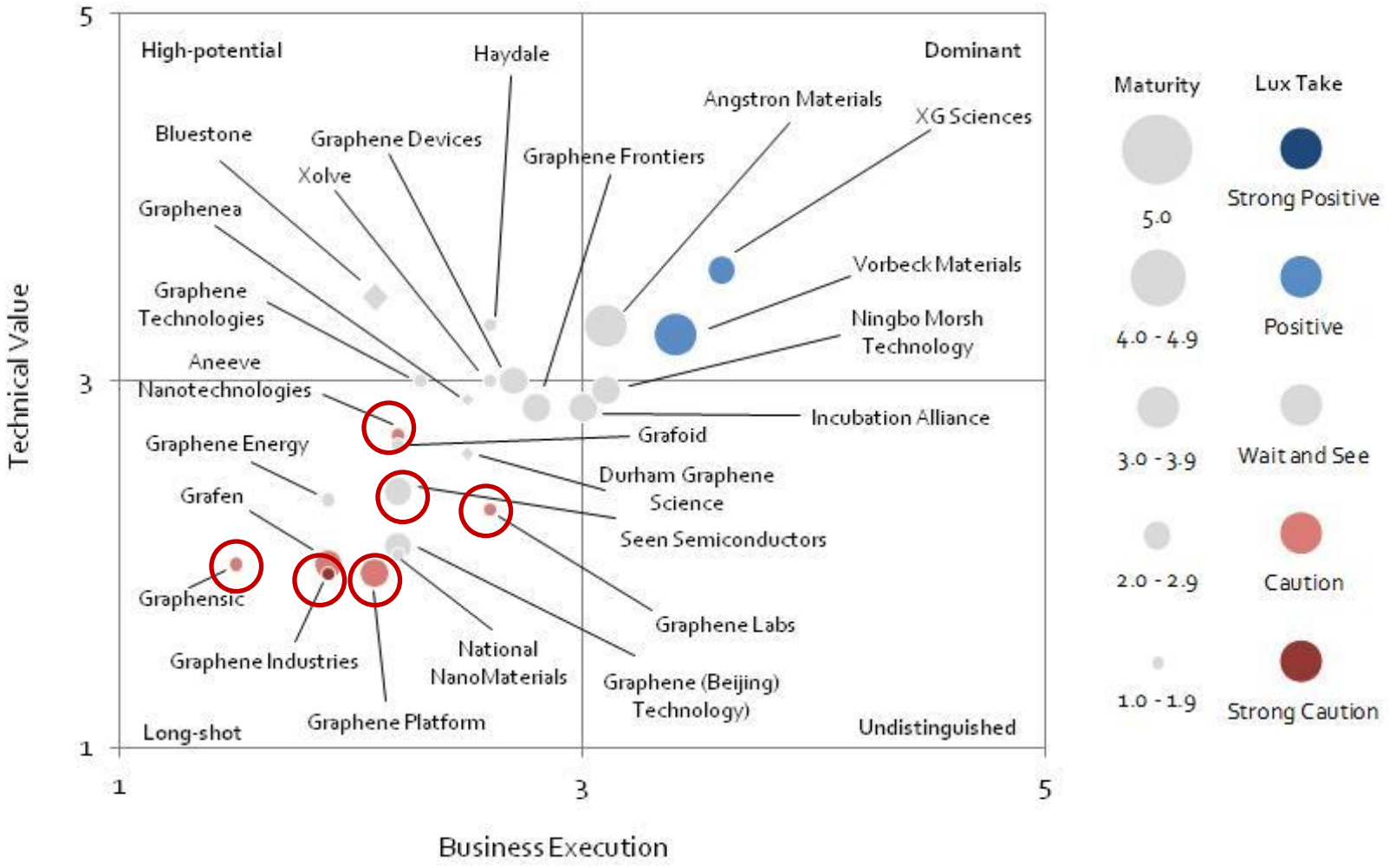
Silver Nanowire Case Study: Cambrios

- **Technology**: Silver nanowire dispersions and coated PET substrates with 85% to 92% transparency and 10 Ω/sq to 250 Ω/sq sheet resistance, sold under the name ClearOhm
- **Barriers**: Gaining commercial traction for touchscreens: first consumer product to use its films, the Huawei Ascend, came to market in 2011. Competition with ITO on glass will still be a big challenge.
- **Other**: Extensive partnership network includes Sumitomo Corporation, Chisso, Nissha Printing, and Hitachi Chemical
- **Lux Take:** Positive: Demonstrated value proposition in touchscreens, but most value will come when it moves away from slot-die coating and towards additive processing





Many graphene film developers appear content selling to research customers



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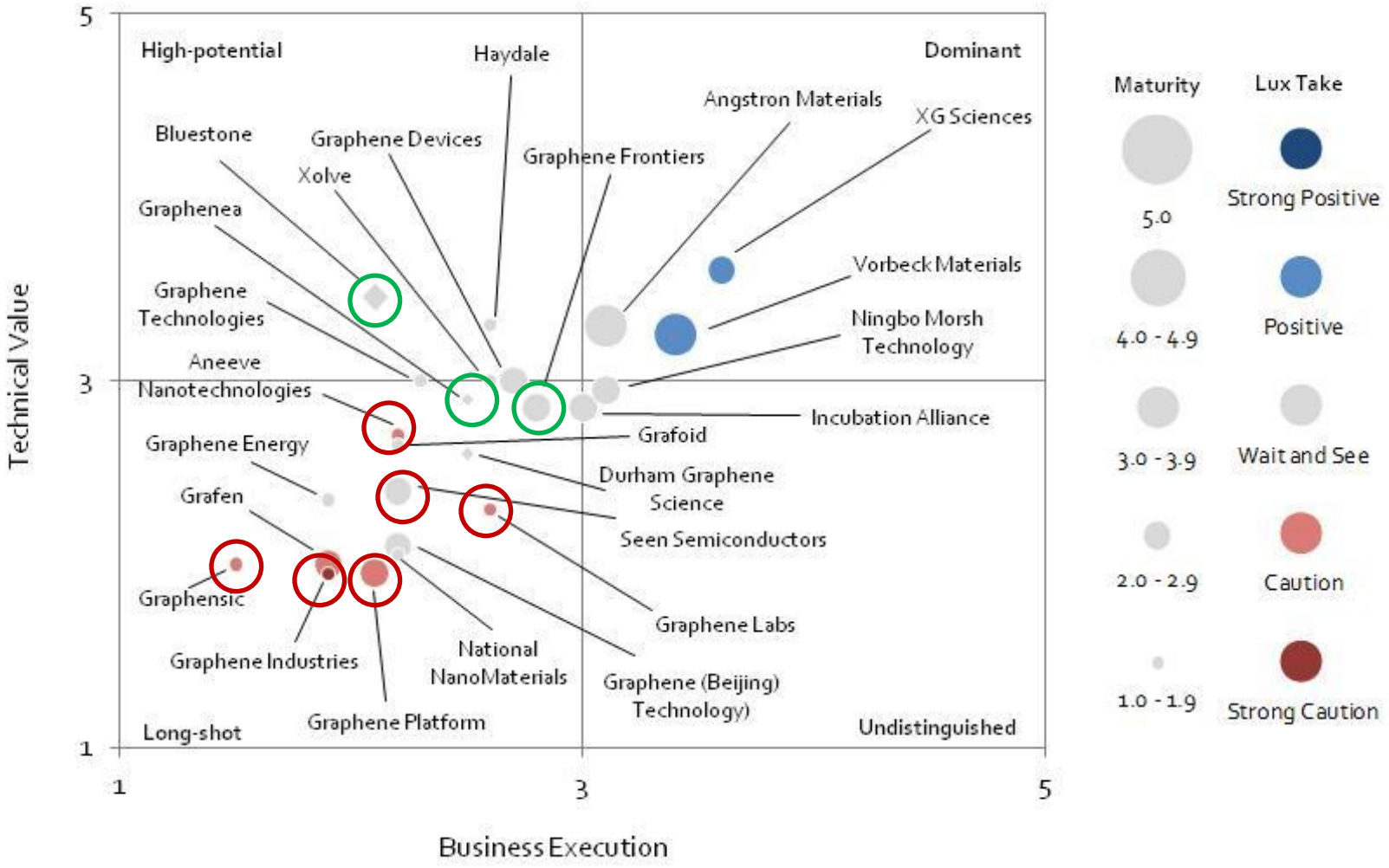
Select handful working on large area scale up, roll to roll processing, and Cu recycling



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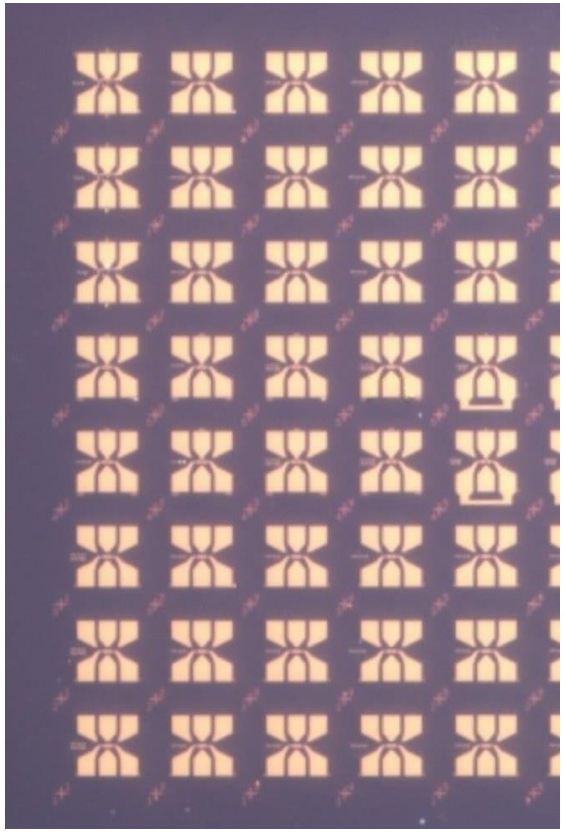
Bluestone Global Tech

Graphene films

Employees	2012 revenue
33	$0

- Develops graphene films using surface-catalyzed CVD on copper foil; transfers material to silicon, silicon dioxide, quartz, and PET substrates
- Currently able to produce 36-in x 300-in films using roll-to-roll production process and copper recycling method
- **Recently released new product called "Grat-FET", a graphene field-effect transistor (FET) based on its high mobility graphene**
- Grat-FET can be applied to a wide variety of applications, including gas and chemical sensors and high frequency electronics
- **While company still pursuing TCFs, it believes costs are still too high for that segment**
- **Believes sensors employing Grat-FET will be its primary revenue source in the near term because such applications are more cost tolerant and allow customers to purchase graphene already integrated into a device rather than just the raw material.**
- **Wait and see.** Performance and large area deposition capabilities make it one of the more promising start-ups in the graphene film space

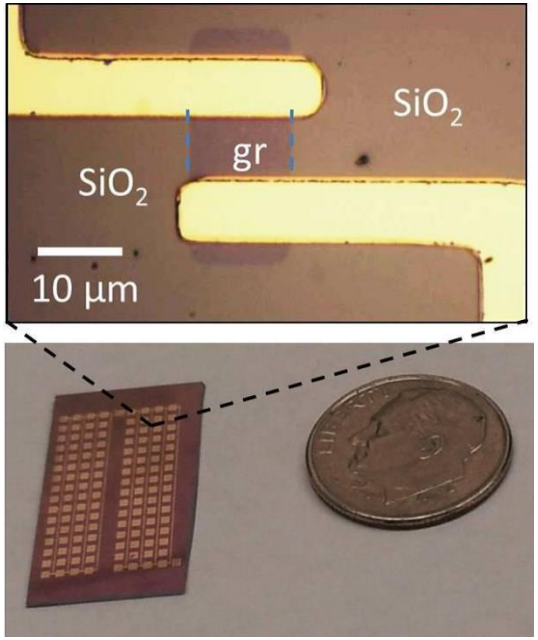


Graphene Frontiers

Graphene films

Employees	2012 revenue
4	$500,000

- Uses CVD process with methane feedstock on copper foil to create graphene films
- Mechanical transfer method that avoids need for harsh acids to dissolve copper substrate distinguishes it from other graphene developers
- Current business model is to seek out joint development and licensing agreements with big material suppliers in the electronics value chain
- **While it employs a material supply business model in other applications, it plans to make sensors "all by ourselves"**
- **Currently working on graphene FETs for biosensor applications**
- **Wait and see.** Non-vacuum process and transfer method make it a player worth watching



Graphenea

CVD-grown graphene films

Employees	2011 revenue
10	$50,000

- Grows graphene films from methane precursor using copper foil as catalytic layer and transfers to silicon, glass, quartz, and polymer substrates
- Targeting electronics, touch screen, LED, solar, and energy storage applications
- **Supplying Nokia for some sensor applications**
- **Working with Infineon on MEMS and graphene sensors**
- "To be honest we have a strong position on the graphene synthesis but not so much on the sensor side"
- CVD graphene will remain a small market for at least the next few years, thus it will likely need to rely on small product sales for cash in the near term
- **Wait and see.** Cost and performance on par with competition, but wider substrate transfer expertise make it unique and worth watching in this increasingly active space

At least graphene film developers have "learned the lesson"

- Sentiments of graphene film start-up CEOs regarding commercialization challenges in TCFs are refreshing
- Despite the material's low sheet resistance, high transmittance, and superior mechanical strength and flexibility compared to incumbent ITO, reducing costs, overcoming current deposition area limitations, and besting other emerging material solutions – such as silver nanowires, metal nanoparticles, and single-walled carbon nanotubes (SWNTs) – will be major hurdles and delay adoption in the near future
- Unlike demand elastic TCF applications, sensors and high performance electronic devices are less cost sensitive
- Selling a graphene intermediate rather than raw material reduces product integration complexities and should accelerate customer adoption

Conclusions

- Don't let GNPs become the next MWNT!
- Nano is not enough: nanomaterials are just materials and need to compete with incumbent solutions
- Nanotechnologies need to compete on cost, performance, availability, recyclability, reliability, EHS, compatibility with existing infrastructure, etc.
- Savvy developers will move down the value chain
- Partnerships are critical:
  - Assure a customer base at every step of development
  - Consider alternative models such as first focusing on end applications and then working backwards
- Nanotech developers need to become intimate with their target markets

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Thank you…Questions?

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