How to Combine Nanotech with Business Success

Anthony Vicari
Lux Research, Inc.

NanoBusiness 2012

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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

Technology coverage

- Solar Components
- Solar Systems
- Grid Storage
- Electric Vehicles
- Alternative Fuels
- Bio-based Materials & Chemicals
- Formulation and Delivery
- China BioPharma
- Water
- Advanced Materials
- Printed, Flexible, and Organic Electronics
- Energy Electronics
- Sustainable Building Materials
- Efficient Building Systems
- China Innovation

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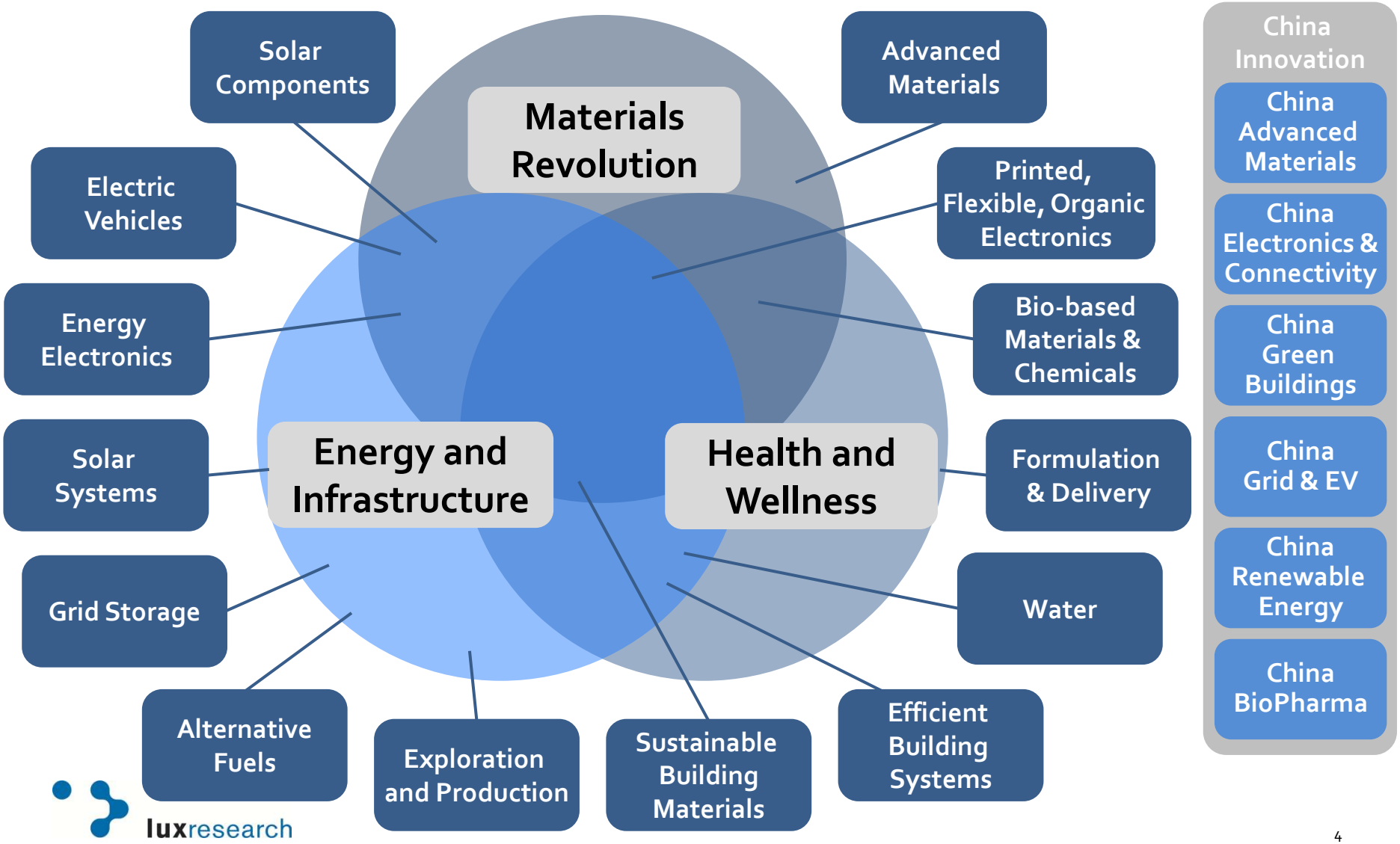
Lux coverage areas address key global megatrends



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Agenda

- The nanotechnology value chain: how to procure the most value as a nanotech developer
- Industry examples
  - Nanocomposite materials
  - Transparent conductive films
- Conclusion

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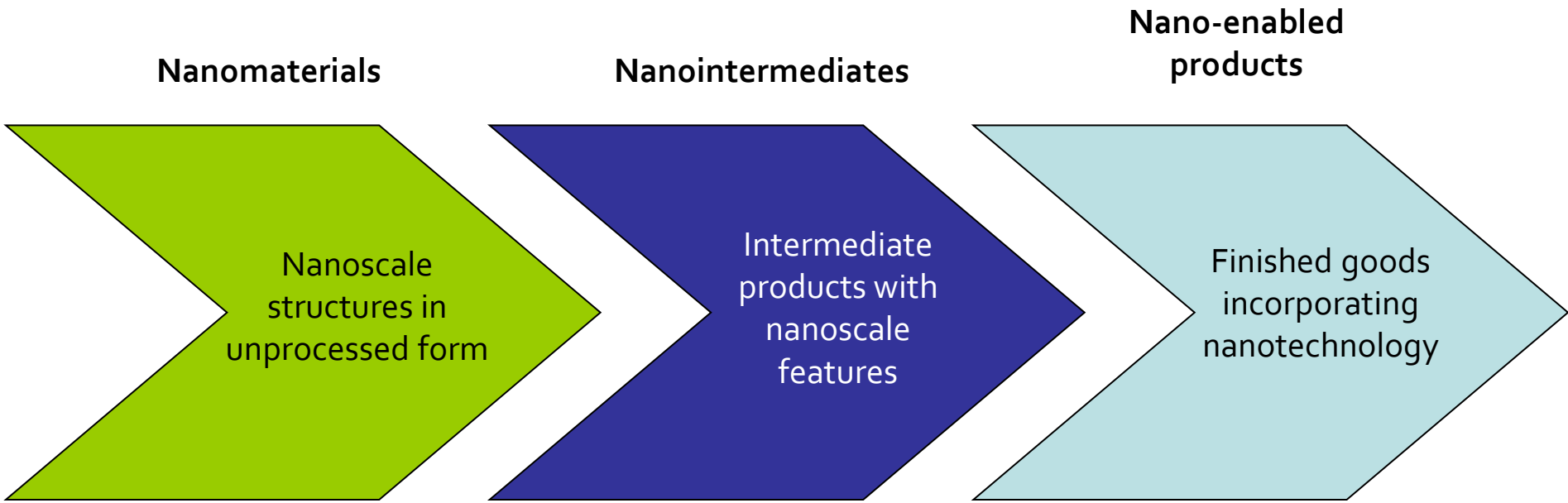
The value chain within nanotechnology



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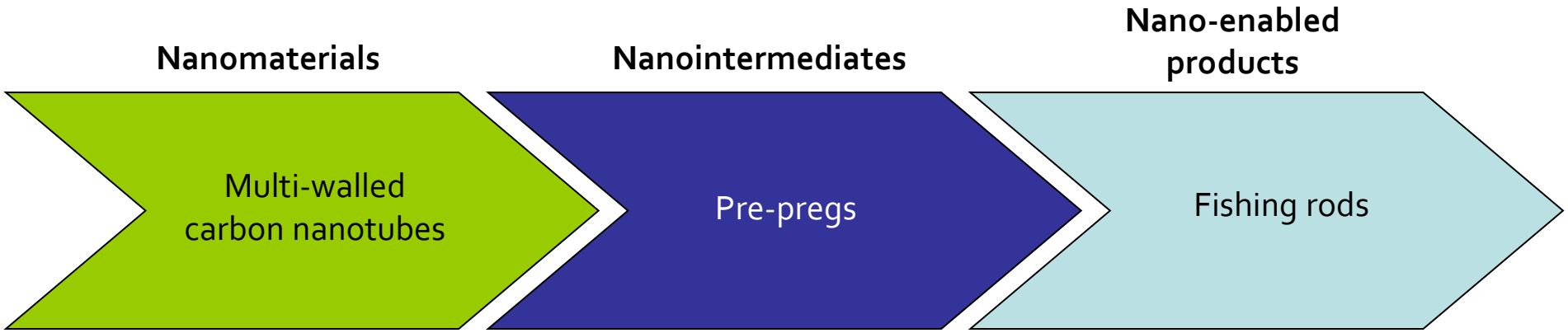
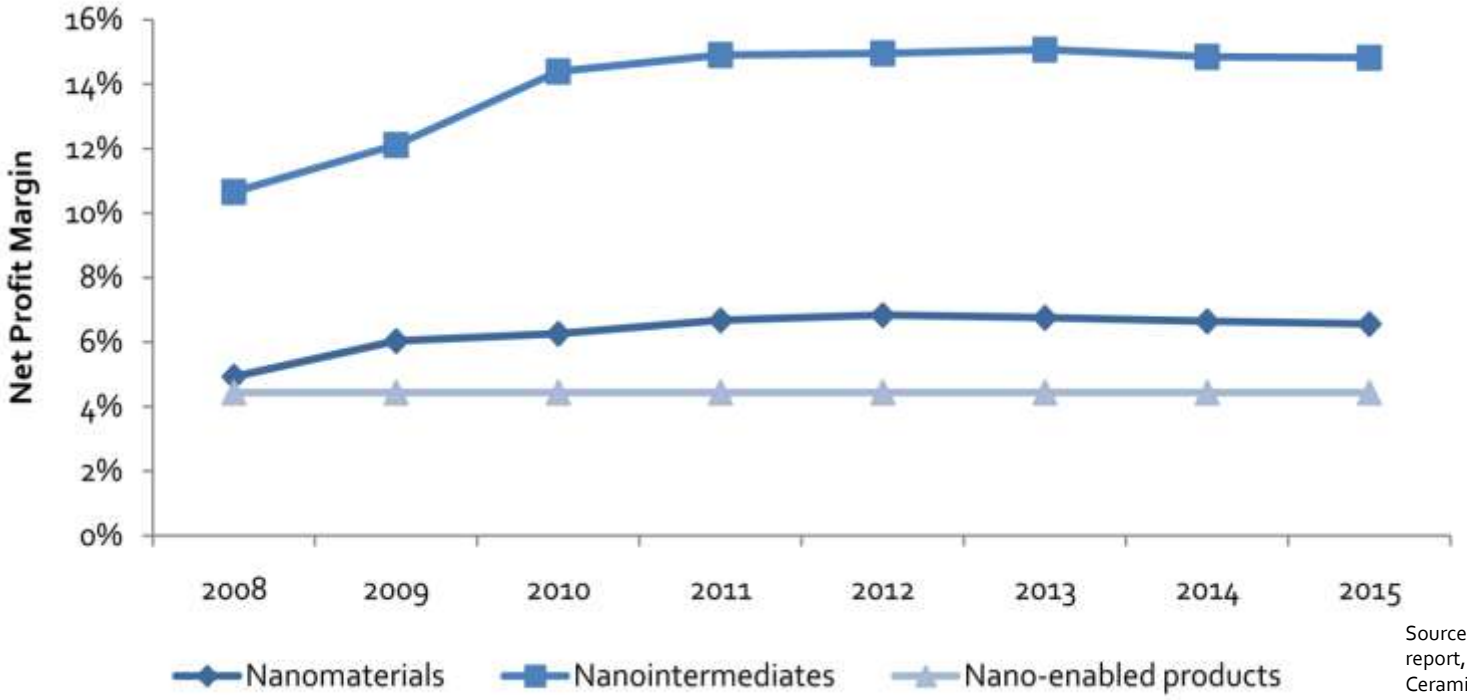
The value chain within nanotechnology



Source: Lux Research report, "The State of Ceramic Nanoparticles: A Decade Dominated by Metal Oxides", October 2010

Value of moving down the nanotech value chain



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- Nanointermediates command over twice the profit margin of nanomaterials
- Avanzare produces nanomaterials including silica nanoparticles, zinc oxide nanoparticles, and graphene. However, it also formulates them into dispersions, which it sells as higher value nanointermediates

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Value of moving down the nanotech value chain

TOTAL GLOBAL REVENUE	2004	2009	*2015*
Nanomaterials	$0.29 b	$1 b	*$2.9 b*
Nanointermediates	$2.5 b	$27 b	*$474 b*
Nano-enabled products	$16 b	$223 b	*$1960 b*

Italics indicate projected

- Due to naturally hefty price tags and large volumes, nano-enabled products garner the biggest share of revenue in the nanotech value chain
- Converting nanotechnology from a materials play into a solid investment, requires a keen focus on end applications

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  - Nanocomposite materials
  - Transparent conductive films
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What is a nanocomposite?

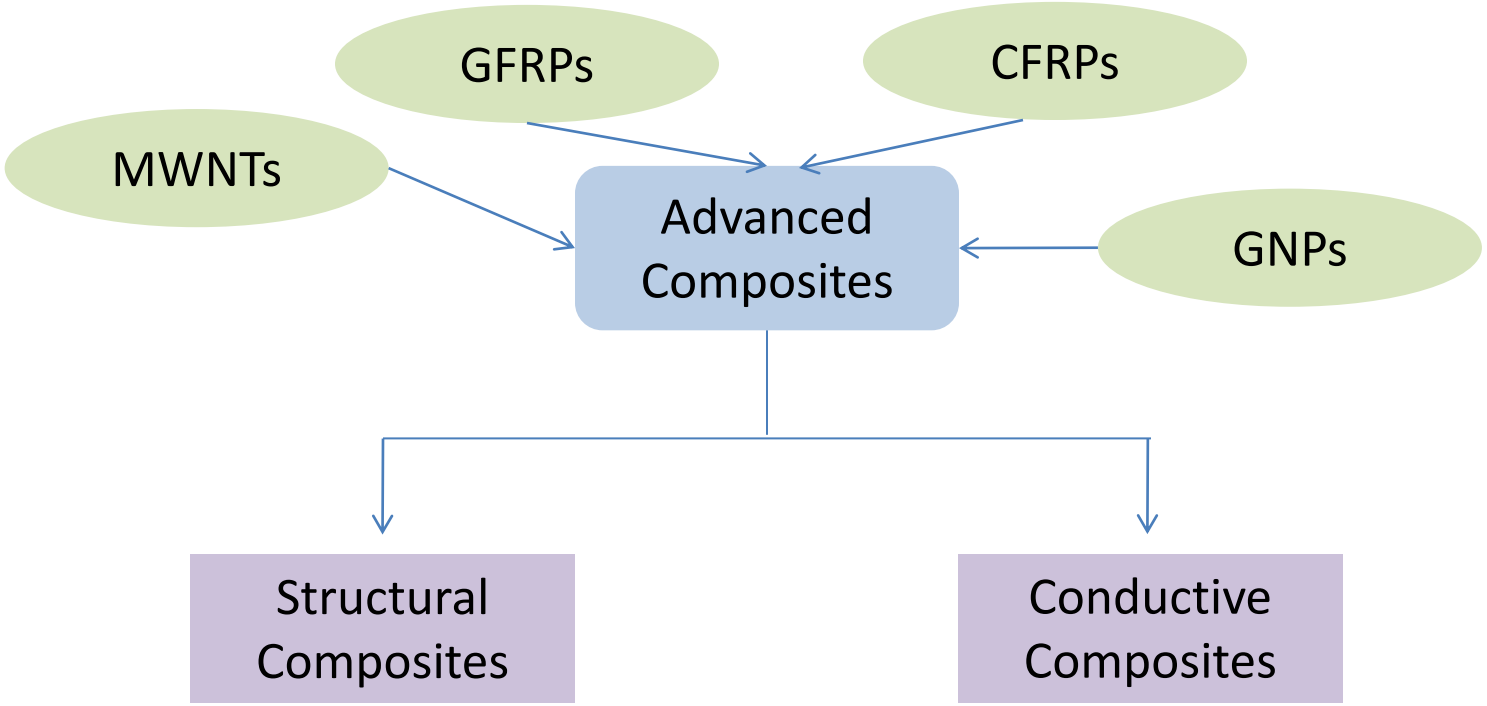
- Composite: a solid material composed of two or more constituent phases
  - Most commonly a polymer matrix surrounding reinforcement materials such as glass fiber or carbon fiber that give strength or functional properties to the polymer
- When the reinforcement is a nanomaterial such as multi-walled carbon nanotubes (MWNTs) or graphene nanoplatelets (GNPs), that is called a nanocomposite

Different advanced composite reinforcements offer different advantages

	Price	Specific strength (GPa/g/mL)	Specific modulus (GPa/g/mL)	Electrical resistivity
Glass fiber	$2/kg	1.4 to 1.8	28 to 33	10^{14} Ω-cm
Carbon fiber	$20/kg to $50/kg	1.8 to 3.0	127 to 380	10^{-3} Ω-cm
MWNT	$60/kg to $100/kg	129	714 to 1214	10^{-4} Ω-cm
GNP	$100/kg to $400/kg	7.1 to 14.3	714	10^{-4} Ω-cm

- MWNTs and GNPs boast **superior mechanical properties to carbon fiber**, but **dispersion issues limit them to low loading levels**

Putting MWNT and GNP applications in context



MWNTs must serve as a secondary reinforcement to enhance the strength of GFRP and CFRP due to dispersion and viscosity issues

GNPs can serve as the primary filler for EMI shielding in aerospace and ESD protection in automotive

We evaluated MWNT and GNP companies with the Lux Innovation Grid

TECHNICAL VALUE

- Technology score
- Market size
- IP
- Competitive landscape

BUSINESS EXECUTION

- Management team
- Barriers to growth
- Revenue per employee
- Partnerships
- Momentum

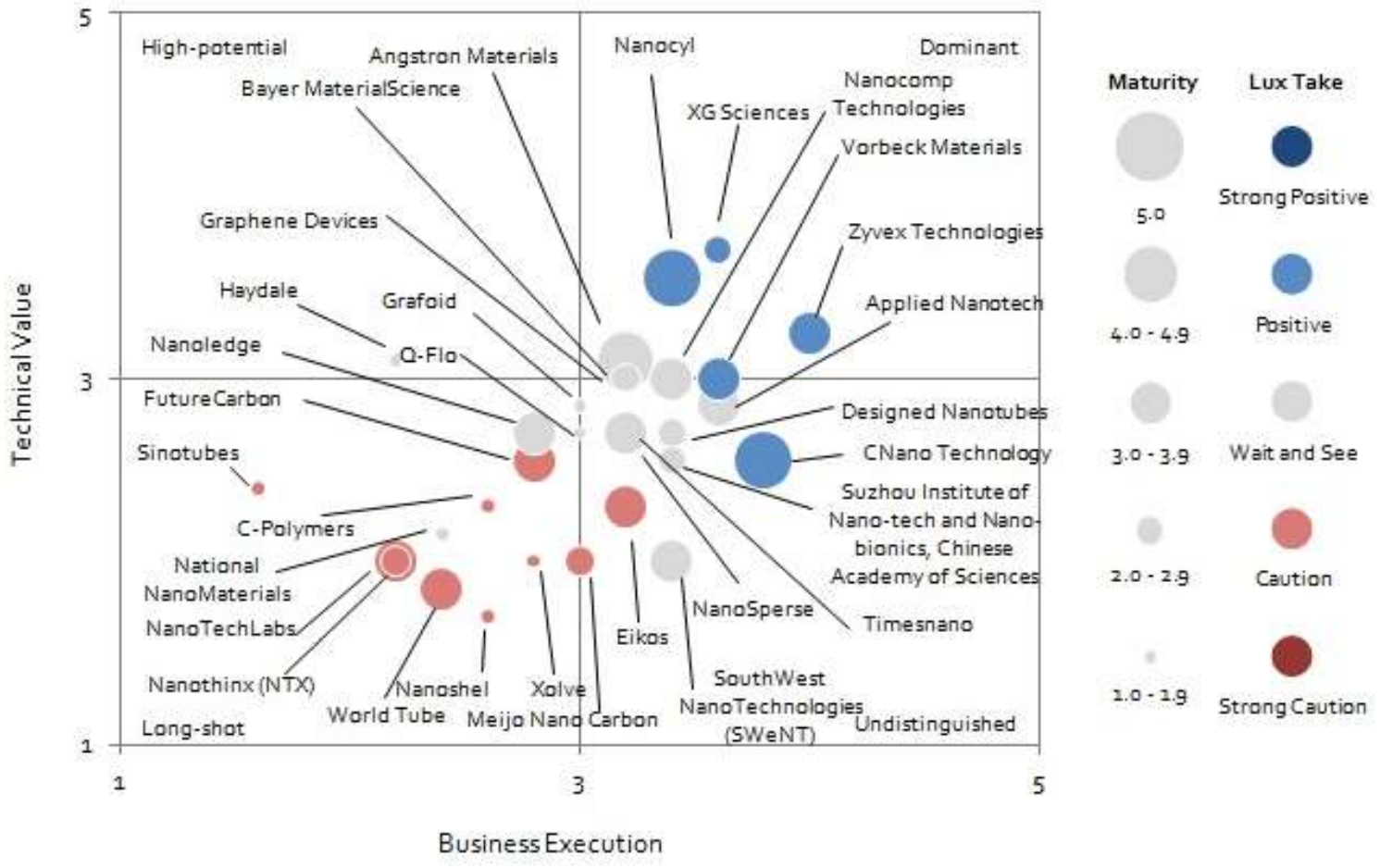
MATURITY

- Development stage
- Revenue
- Employee count

LUX TAKE

- Ranges from "Strong Positive" to "Strong Caution"

GNPs and MWNTs on the Lux Innovation Grid



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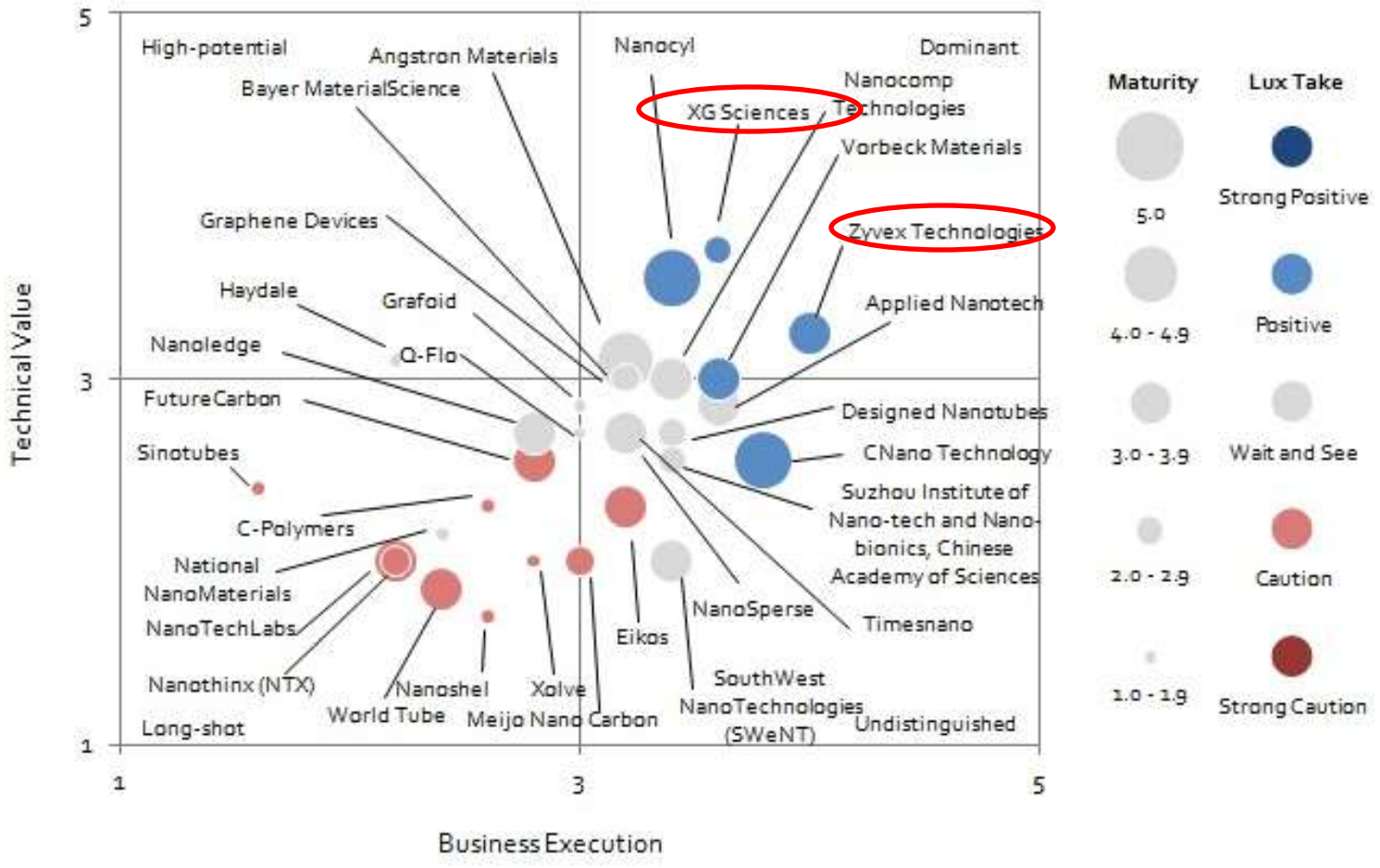
GNPs and MWNTs on the Lux Innovation Grid

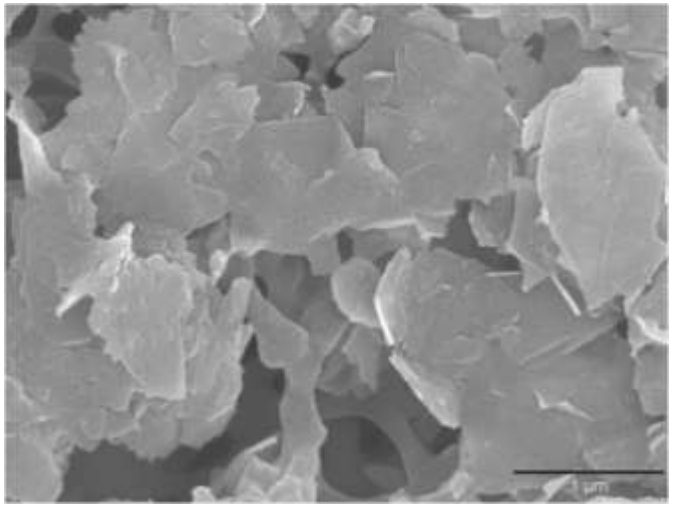


Source: Lux Research

XG Sciences

Graphene nanoplatelet supplier

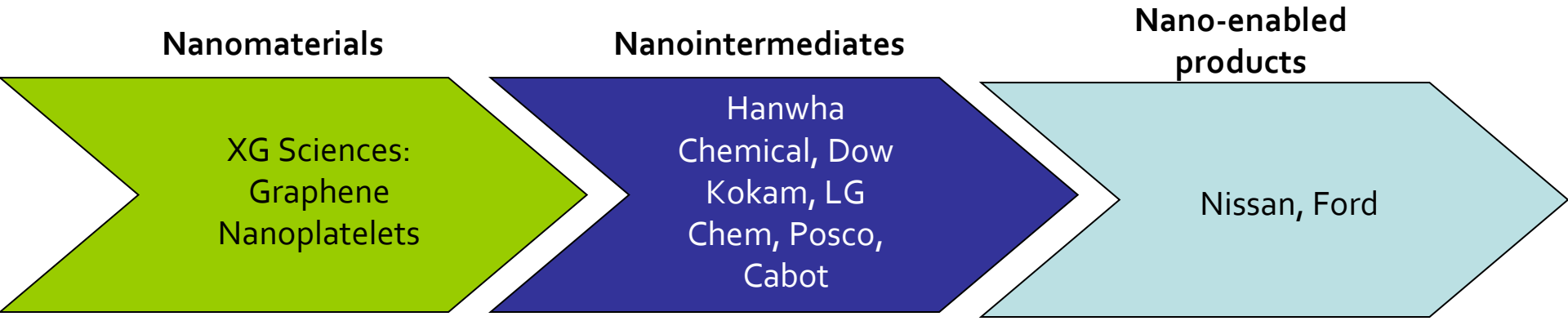
- One of the top three GNP producers
- Has over 300 customers looking at energy storage, composites, and coatings applications, though all but two are only R&D scale
- Major partnerships with – and investments from – Hanwha Chemical, Posco, and Cabot. It has also collaborated with LG Chem, Maxwell, Nissan, Ford, Umicore, and Dow Kokam
- **Positive.** XG is the low cost leader in the space, though overall GNPs offer higher performance at usually higher price than other material solutions



Employees: 30
Revenue: $250,000, 2011
Founded: 2006

XG Sciences

Graphene nanoplatelet supplier



Zyvex Technologies

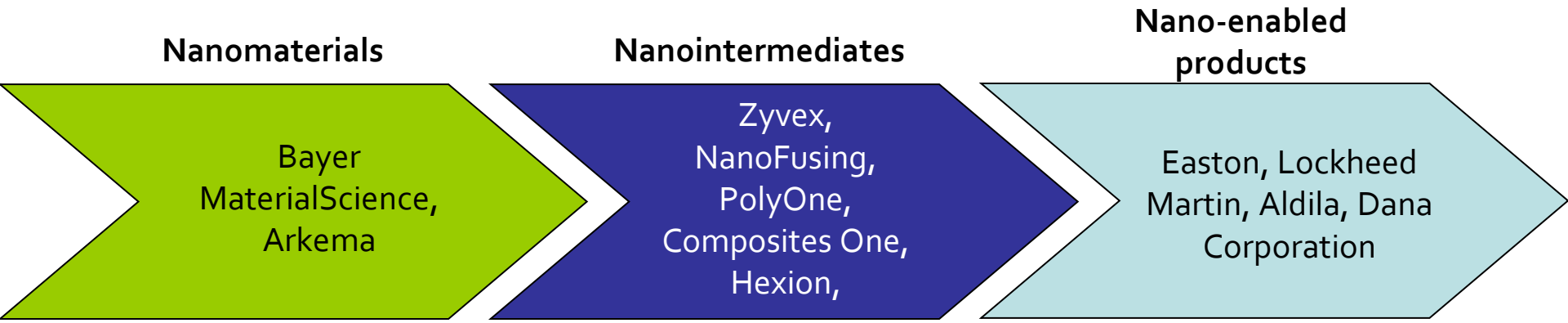
Nanoparticle-enhanced polymers, intermediates, and products

- Core technology is proprietary Kentera polymer in which it can more easily disperse MWNTs
- Offers two-part adhesives and pre-preg materials infused with carbon and glass fibers
- Partners include Lockheed Martin, NanoFusing, Arkema, Composites One, Hexion, and Polyone
- Demonstration products in marine, undisclosed aerospace, a tire maker, O&G gaskets, baseball bats
- **Positive.** Leading developer of thermoset nanocomposites

Employees: 40
Revenue: $5 million, 2011
Founded: 1997

Zyvex Technologies

Nanoparticle-enhanced polymers, intermediates, and products



Why do these leading companies follow different strategies?

- 0.5% MWNT loading in structural composites vs 3% to 10% for GNP in conductive composites
- % of final nanocomposite cost from raw nanomaterial:
  - 0.3% for MWNTs vs. 28% for GNPs
- Composite intermediates including dispersions, wovens, and prepregs command over 2/3 value of final composite
- XG leverages its partnerships further down the value chain, but may still need to move into nanointermediates as its markets mature

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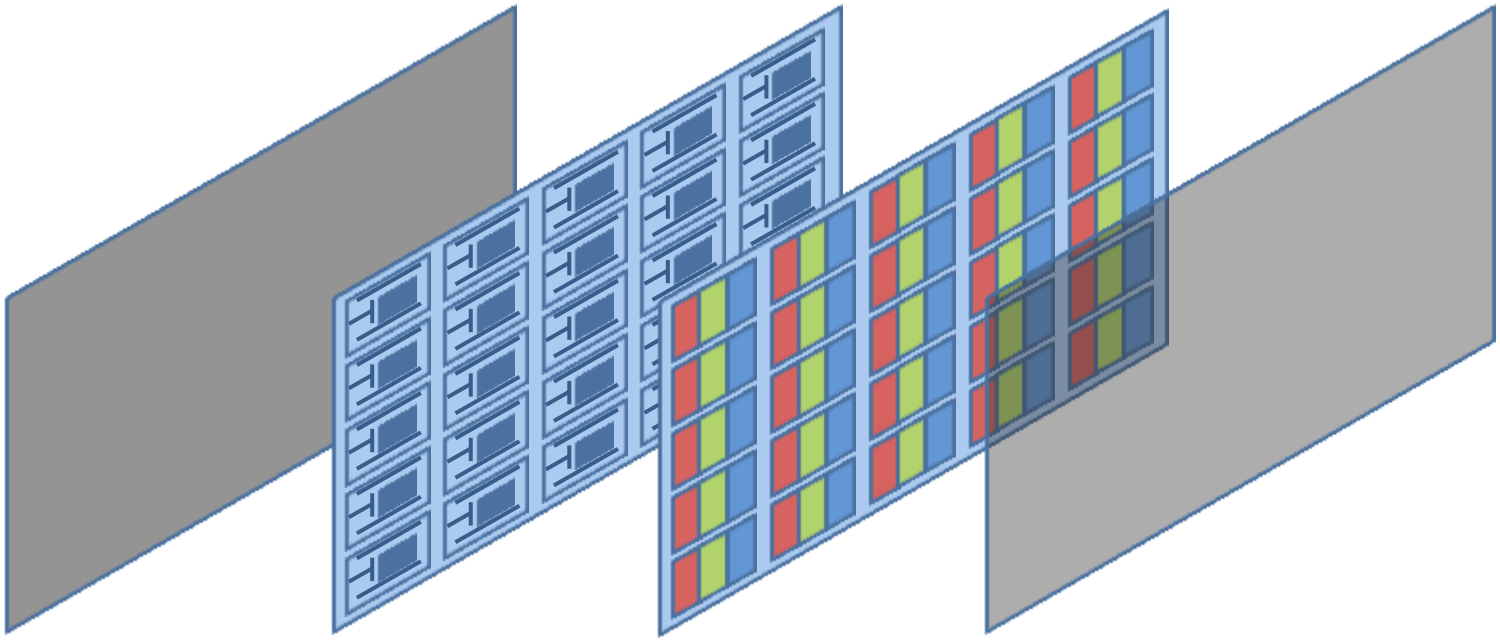
Transparent conductive films



Substrate
Current = Glass
- Plastic (PET, PEN, PI)
- Metal (steel)

Backplane (TFTs)
Current = PECVD a-Si
- Organic
- Printed Si
- Printed metal oxides
- Carbon nanotubes
- Epitaxial lift-off

Frontplane (active material)
Current = Liquid crystals
- Small-molecule OLED
- Polymer OLED
- Quantum-dot LED
- Electrophoretics
- Electrowetting
- Electrochromic

Transp. conductive film (TCF)
Current = Indium tin oxide (ITO)
- Metal nanoparticles
- Metal nanowires
- Carbon nanotubes
- Conductive polymers
- Graphene

The promise of nano-based transparent conductive films (TCFs): Nano is not enough

- Indium tin oxide (ITO) is the player to beat in solar cells, liquid crystal displays (LCDs), and touchscreens
  - Drive to replace indium due to cost, brittleness, and supply security concerns
- Nanomaterial alternatives allow for printable deposition and non-vacuum processing
  - Roll to roll manufacturing
  - Higher materials utilization
- Promise of low cost has spawned many start-ups

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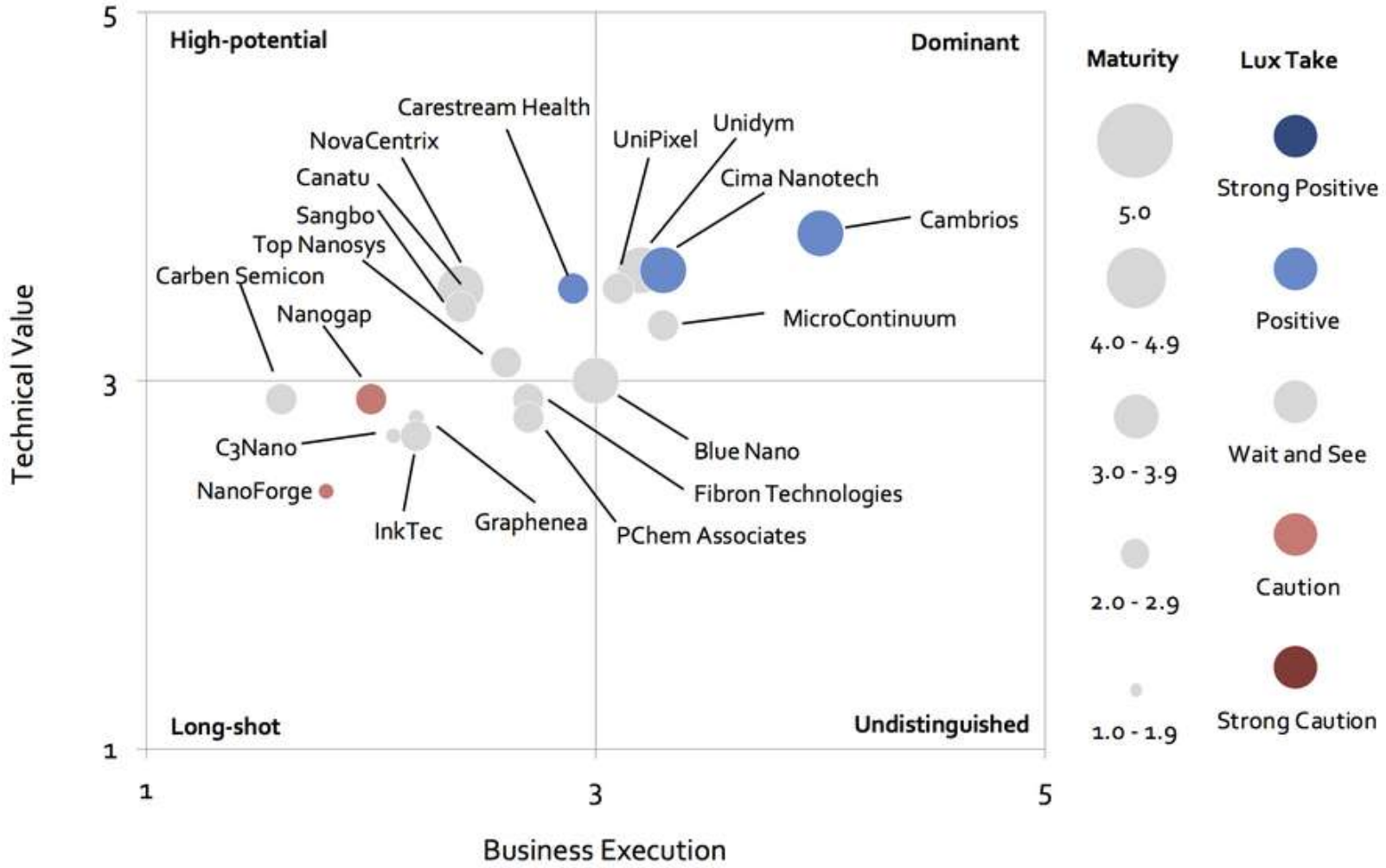
TCFs on the Lux Innovation Grid



Source: Lux Research Report, "Finding the Winning and Losing Companies in Printed, Flexible, and Organic Electronics," December 2011

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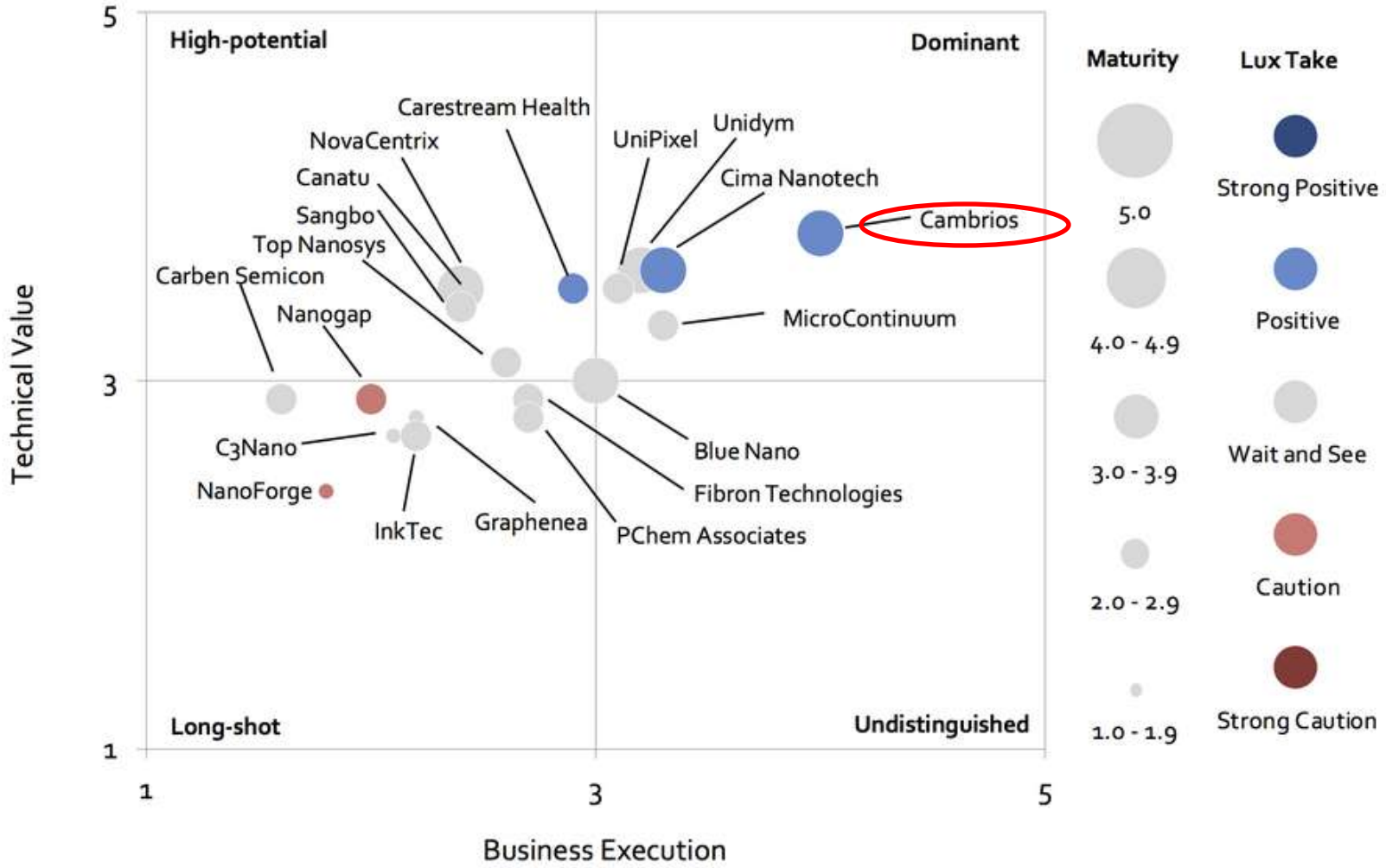

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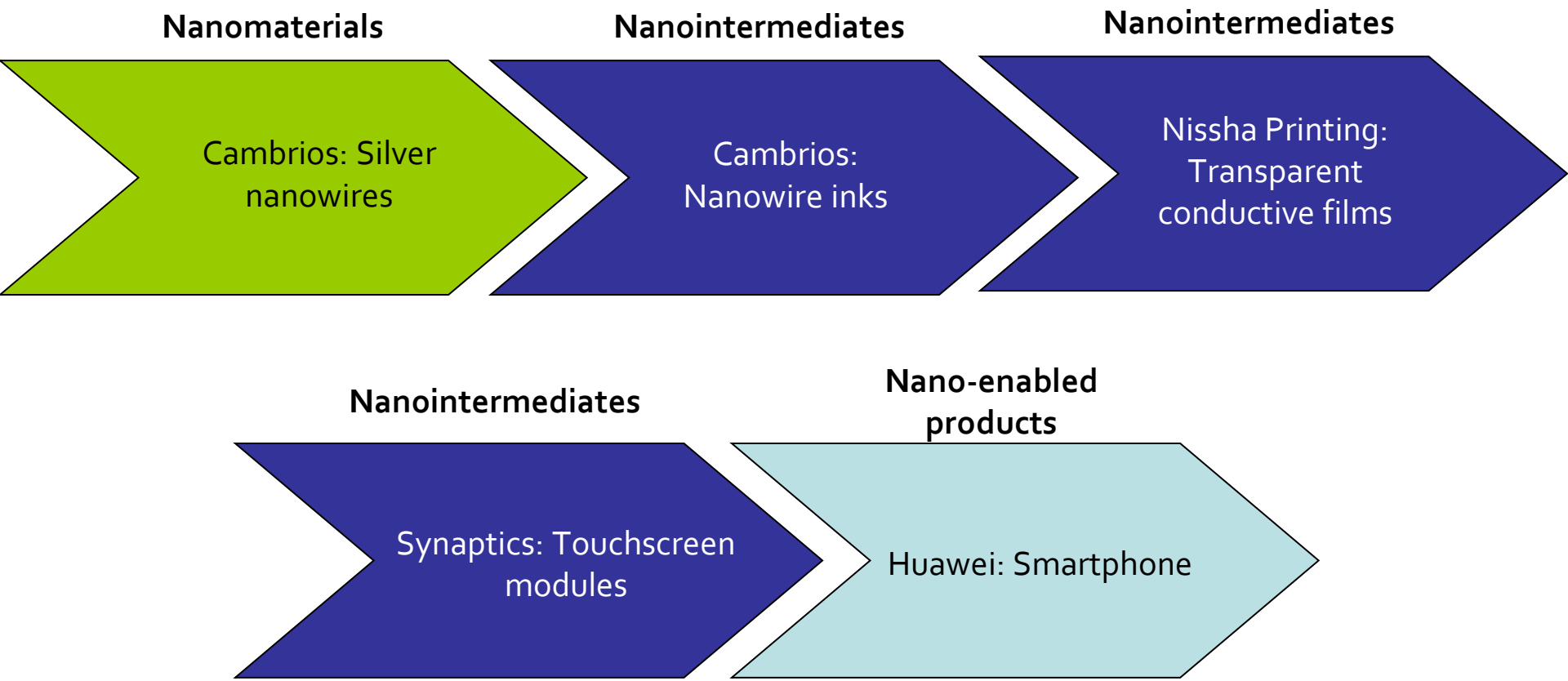
Cambrios Technologies

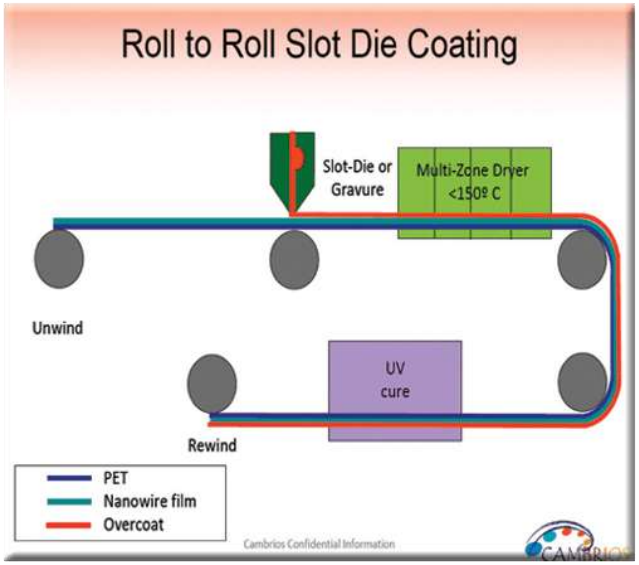
Silver nanowire inks for transparent conductive films



Cambrios Technologies

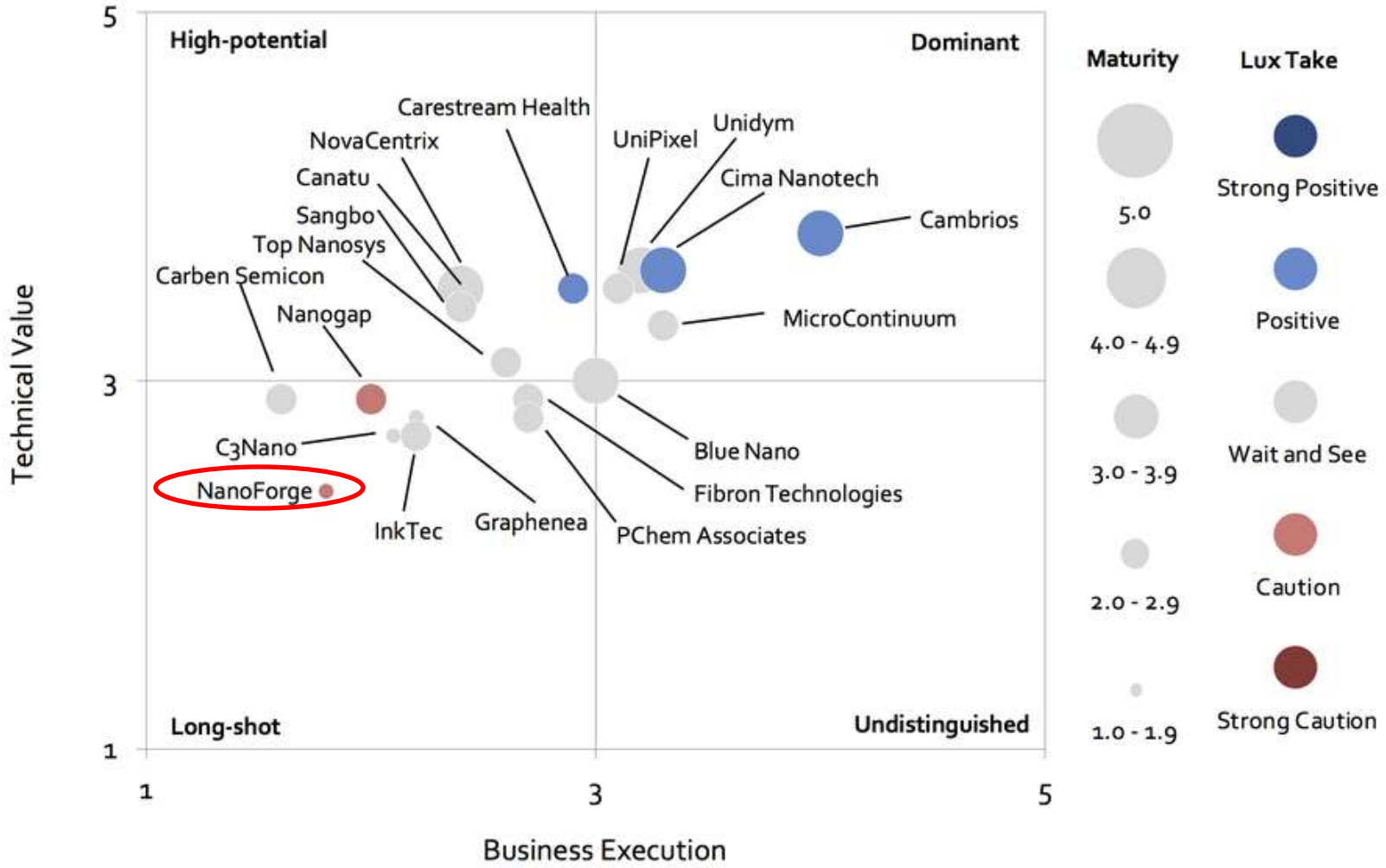
Silver nanowire inks for transparent conductive films

- Sells silver nanowire ink formulations, but leverages extensive partnership network further down the value chain to increase commercial penetration
- Partners include Sumitomo Corporation, Chisso, Nissha Printing, and Hitachi Chemical, and Synaptics
- First commercial product using its materials, the Huawei Ascend mobile phone, launched in 2011
- **Positive.** Films produced with its inks offer strong advantage over ITO on polymer films



Employees: 44
Revenue: $1.5 million, 2011
Founded: 2002

TCFs on the Lux Innovation Grid



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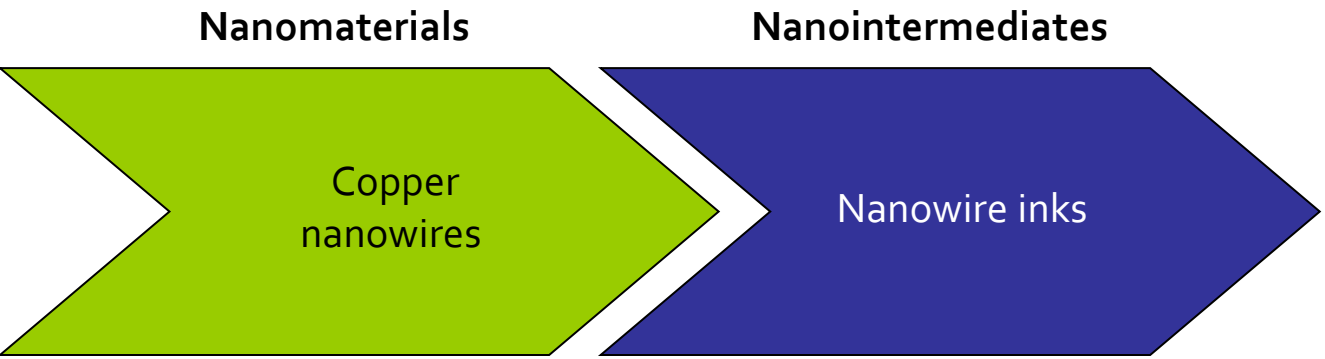
Nanoforge

NANOFORGE

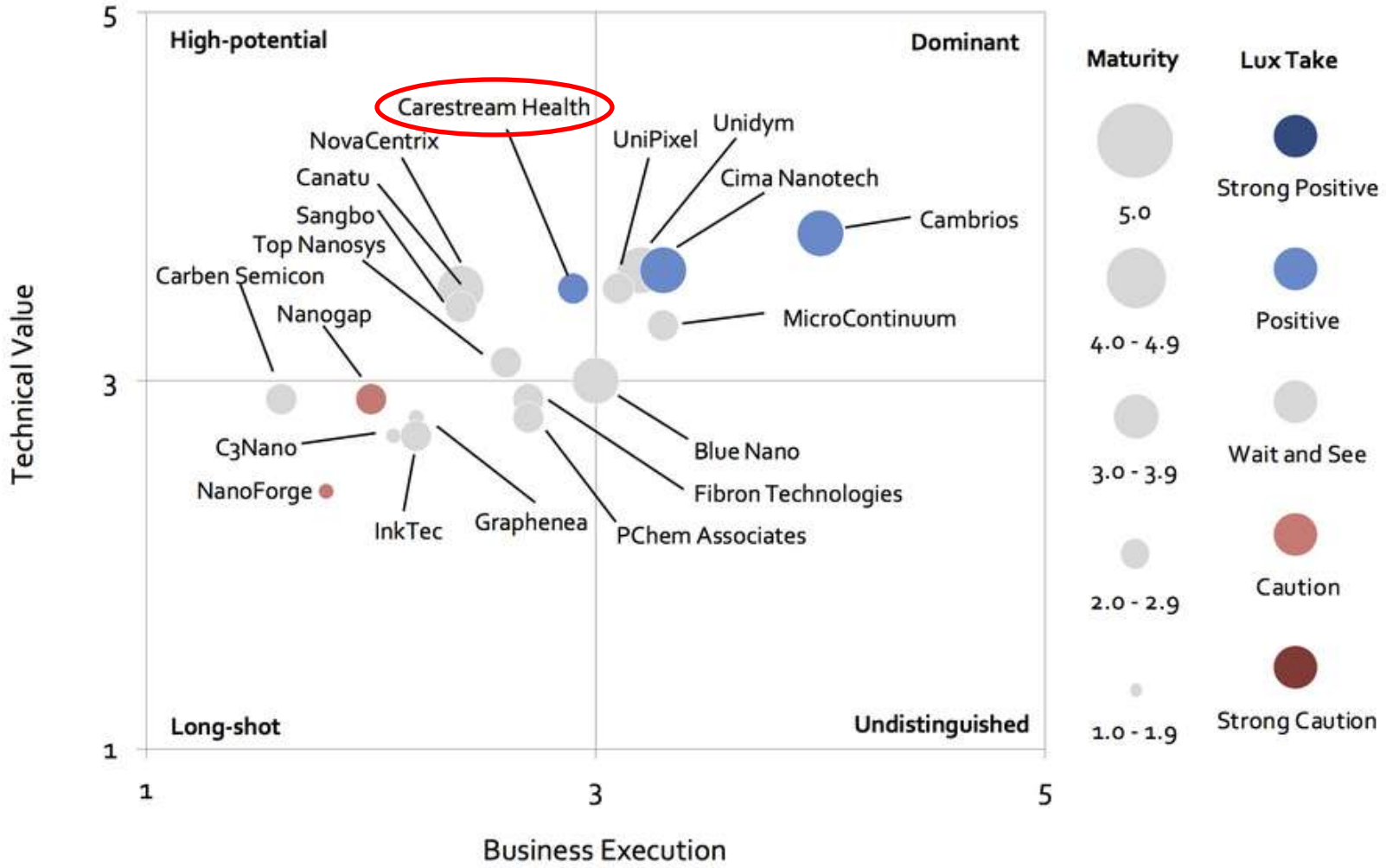
Pure copper and copper-nickel alloy nanowires for transparent conductive films

- Developing copper and copper/nickel nanowires and nanowire ink formulations
- Targeting TCF applications in displays and touchscreens, as well as conductive bulk material applications such as aerospace EMI shielding
- **Wait and See.** Copper offers potentially lower cost than silver, but the company faces a steep slope competing with more mature and well connected companies



Employees: 4
Revenue: $40,000, 2011
Founded: 2010

TCFs on the Lux Innovation Grid



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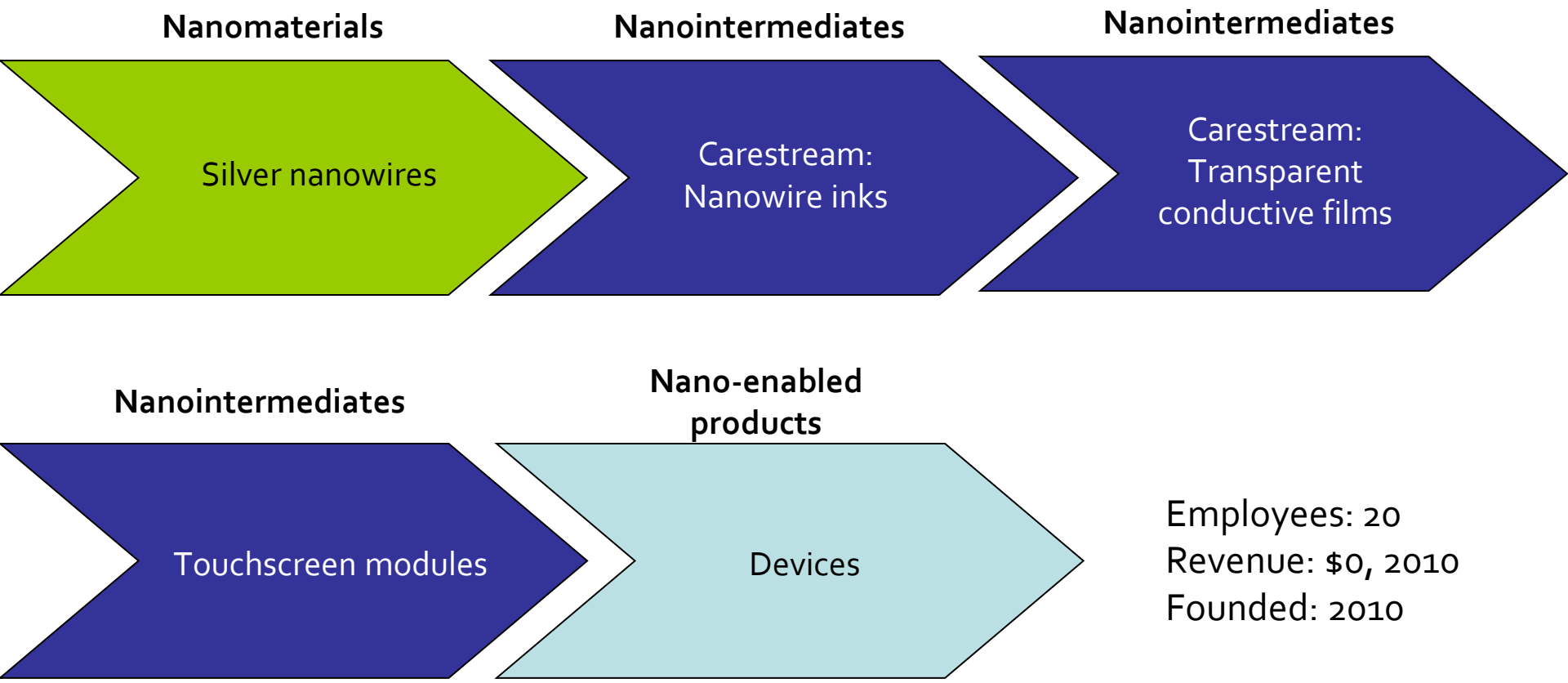
Case Study: Carestream Advanced Materials

Transparent conductive films based on silver nanowires



Employees: 20
Revenue: $0, 2010
Founded: 2010

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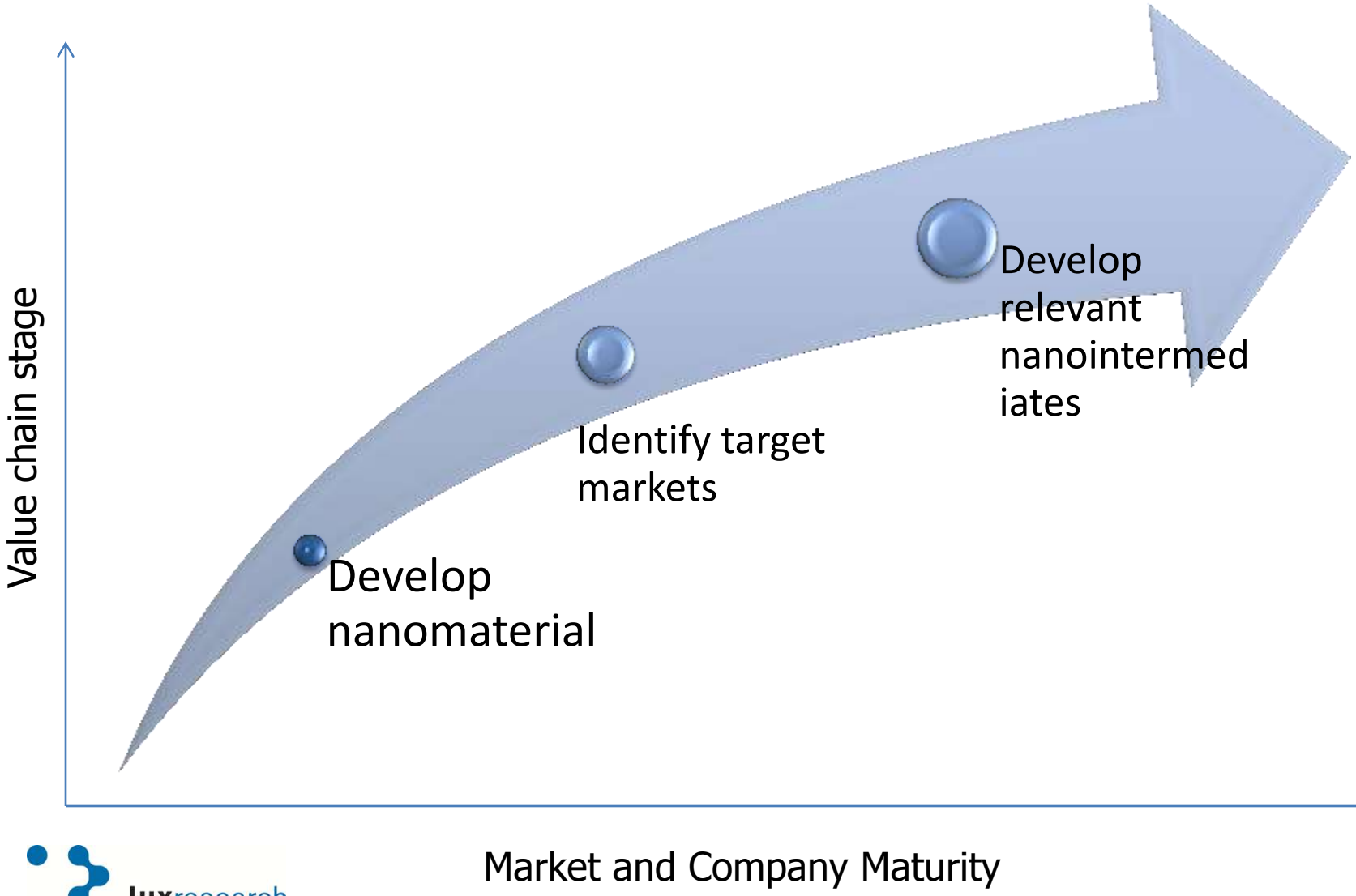
Conclusions

- Nanotech is not its own industry or market, but enables downstream products
- Nanomaterial suppliers must move or partner down the nanotech value chain to capture enough value to become and remain viable businesses
- Nanotech companies must know their markets and target applications– good nanomaterial properties and good engineering are essential, but not enough

Conclusions



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Thank you

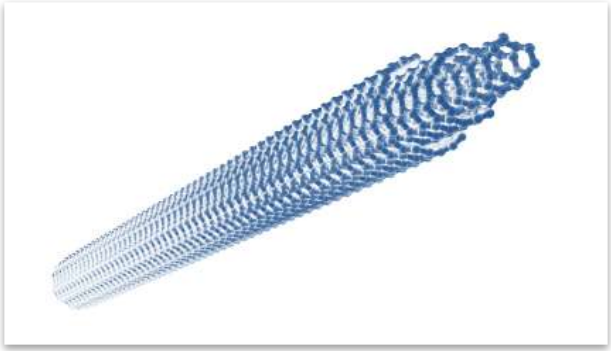
Anthony Vicari
Research Associate
+1 857-284-5688
anthony.vicari@luxresearchinc.com

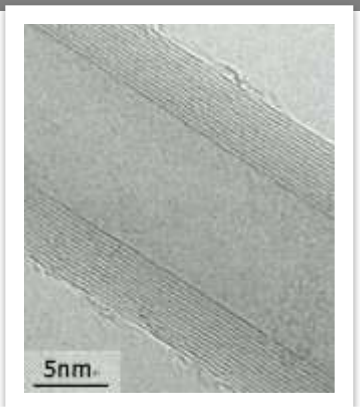
Applications vs. materials focus

- Impressive materials performance alone is not enough – makers need to develop applications, providing ready-made solutions
- A reminder: the value chain within nanotechnology

	Definition	Examples
Nanomaterial	Purposefully engineered structures with at least one dimension less than 100 nm, exhibiting size-dependent properties, that have been minimally processed	Carbon nanotubes, graphene, metal nanoparticles, ceramic nanoparticles, quantum dots, nanowires, fullerenes, dendrimers
Nanointermediate	These incorporate nanomaterials or are constructed from other materials to have nanoscale features,	Catalysts, catalyst supports, filters, fuel additives, fuel cells, hard drive components, logic and memory chips, lubricants, sensors, solar cells
Nano-enabled Product	Finished goods that incorporate nanomaterials or nanointermediates	Sporting goods, pharmaceuticals, aircraft, spacecraft, motor vehicles, consumer electronic devices

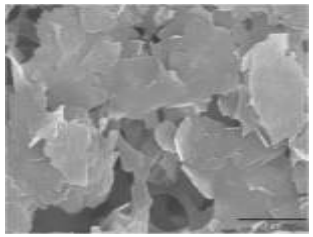
What are multi-walled carbon nanotubes (MWNTs)?

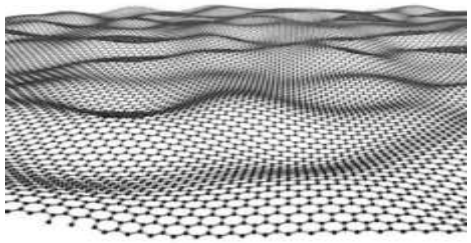




	MWNTs
What it is	Hollow tubes comprised of multiple concentric single-layer graphite sheets
Applications	Additives to resins/coatings, inks, electrodes for energy storage
Properties	Strength, modulus, and conductivity (electrical and thermal)

What are graphene nanoplatelets (GNPs)?





	GNPs
What it is	Flakes of graphene, one to hundreds of layers thick and nanometers to microns across
Applications	Additives to resins/coatings, inks, electrodes for energy storage
Properties	Strength, conductivity (electrical and thermal), gas barrier

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