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Lux Research

- We help clients capitalize on **science-driven innovation**
- We focus on **emerging technologies** in the chemicals and materials sector and the energy and environment sector (cleantech)
- We have practices in **Water**, **Printed Electronics**, **Green Buildings**, **Advanced Materials**, **Solar Components**, **Solar Systems**, **Smart Grid & Grid Storage**, **Electric Vehicles**, **Alternative Fuels**, **Bio-based Materials & Chemicals**, **Targeted Delivery, and China Innovation**
- We have clients on **six continents** – blue-chip corporations, government agencies and laboratories, universities, investors, and SMBs
- We source our intelligence from **direct interaction** with CEOs, CTOs, CSOs, and R&D execs at cutting-edge technology firms in our sectors of focus
- We draw on our **network** to:
    - Continuously monitor emerging technologies
    - Identify discontinuities in technology commercialization
    - Assist with company and technology evaluation
    - We have global reach, with 50 employees in New York, Boston, Singapore, Amsterdam, and Shanghai
- Research team combines deep **technical expertise** with **business analysis**; 60% hold advanced science or engineering degrees

Suntech solar factory, China

Qatar Science and Technology Park

Svalbard Global Seed Vault, Norway

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How to Combine Nanotech with Business Success

Ross Kozarsky

Lux Research, Inc.

NanoBusiness 2011

Boston, MA

September 26, 2011

Agenda

- The Nanotech value chain

- Nanocomposite structural materials: how to procure the most value as a nanotech developer

- A solar case study: when nano is not enough

Research Intelligence Domains – why no nano?

- Solar Components
- Solar Systems
- Smart Grid and Grid Storage
- Electric Vehicles
- Alternative Fuels
- Bio-Based Materials and Chemicals
- Targeted Delivery
- Green Buildings
- Water
- Advanced Materials
- Printed Electronics
- China Innovation

Applications vs. materials focus

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

	Definition	Examples
Nanomaterial	Purposefully engineered structures of matter, with at least one dimension of less than 100 nm, exhibiting size-dependent properties that have been minimally processed; the base of the nanotechnology value chain	Carbon nanotubes, ceramic nanoparticles, dendrimers, Fullerenes and POSS, metal nanoparticles, nanoporous materials, nanoscale encapsulation, nanostructured metals, nanowires, quantum dots, graphene
Nanointermediate	Intermediate products are neither the first nor the last step in the value chain. Nanointermediates either incorporate nanomaterials or have been constructed from other materials to have nanoscale features. Typically, nanointermediates will serve as individual components of a final nano-enabled product.	Agriculture chemicals, batteries and capacitors, biological labels, catalysts, CMP slurries, coatings, composite materials, diagnostics, displays, drug delivery carriers, fabrics, filters, food ingredients, fuel additives, fuel cells, hard drive components, logic chips, lubricants, medical devices, memory chips, optical components, personal care ingredients, sensors, solar cells
Nano-enabled Product	Finished goods at the end of the value chain that incorporate nanomaterials or nanointermediates	Pharmaceuticals, motor vehicles, aircraft and spacecraft, power tools, sporting goods

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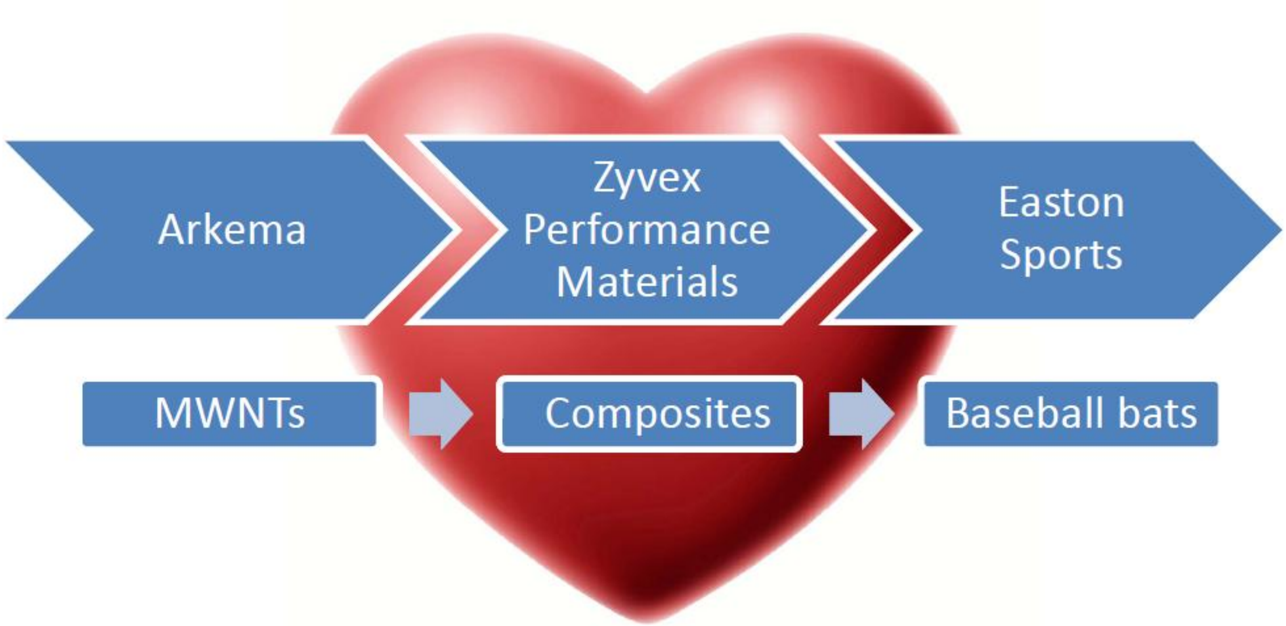
A reminder: the value chain within nanotechnology

Nanomaterials	Nanointermediates	Nano-enabled products
Nanoscale structures in unprocessed form	Intermediate products with nanoscale features	Finished goods incorporating nanotechnology



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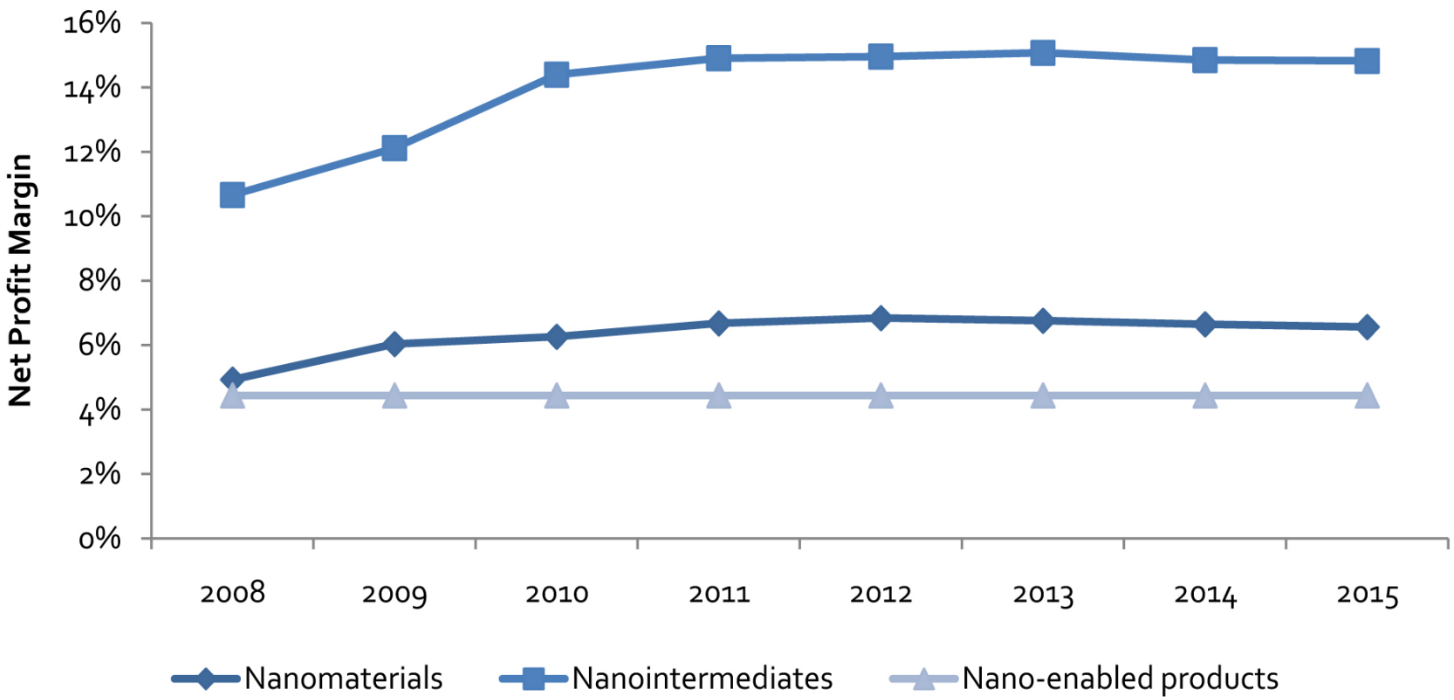
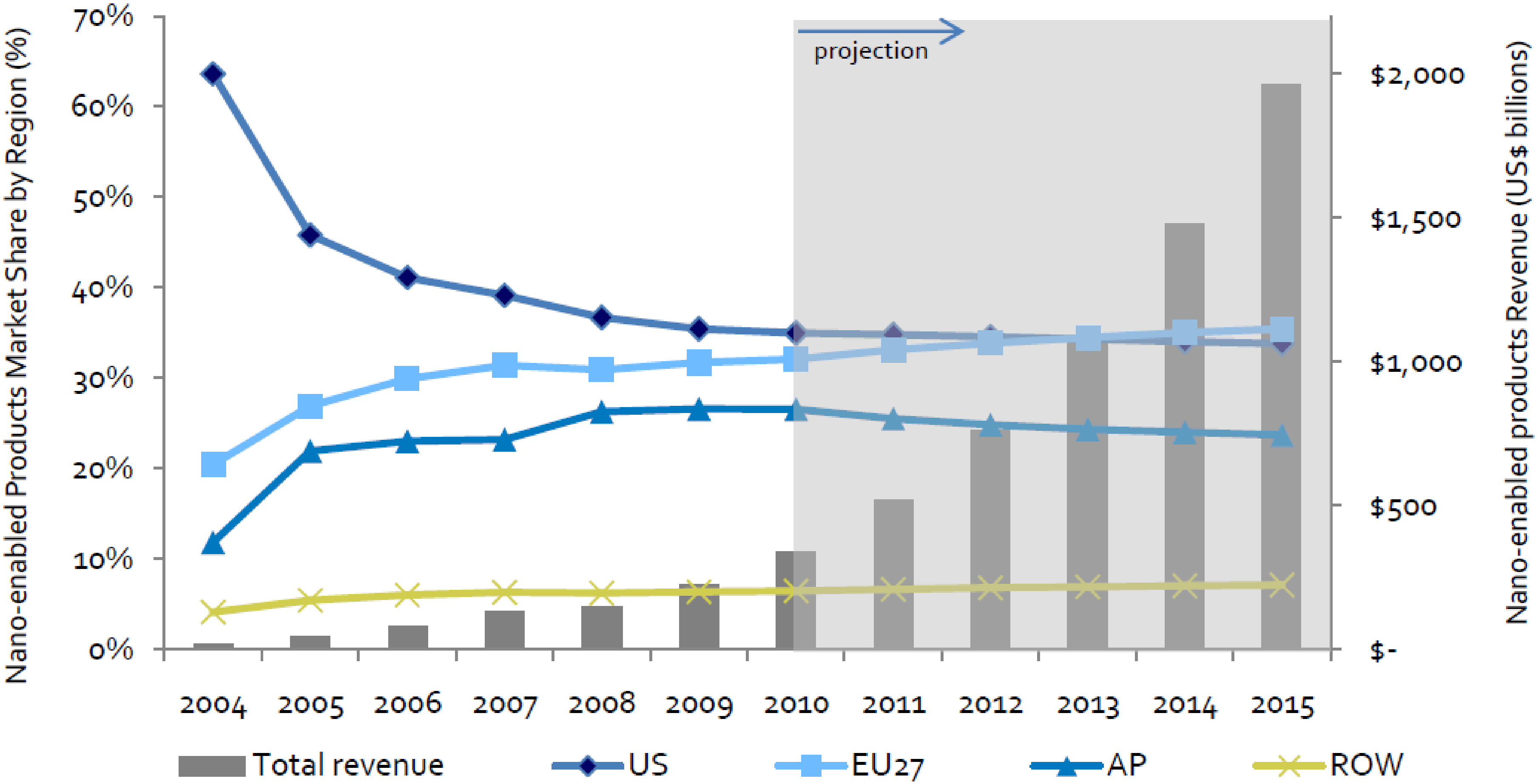
Value of Moving Down the Nanotech Value Chain



- Nanointermediates command over twice the profit margin of nanomaterials
- Bayer now offering MWNT-enabled polymer and solvent dispersions
- Vorbeck offers graphene in nanointermediate form only – either as printable ink, coating formulation, slurry, or polymer dispersion

Emerging nano-enabled products revenue: Europe will pass the U.S. well before 2015



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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

- Nanomaterials contribute the smallest portion of revenue
- Due to naturally hefty price tags and large volumes, nano-enabled products garner the biggest share of revenue in the nanotech value chain
- A keen focus on end applications is required to convert nanotechnology from a materials play into a solid investment.

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Nanocomposite structural materials: how to procure the most value as a nanotech developer

Composites offer several advantages over metals

- Composite: a solid material composed of two or more distinct constituent phases
  - Most commonly a polymer matrix surrounding reinforcement materials that give strength to the polymer while maintaining its light weight
- Composites are finding their way into new applications as industries demand new materials with ever higher strength-to-weight ratios, resistance to corrosion, and workability

Advantages	Disadvantages
High specific strength and stiffness	Material costs run high
Ability to mold complex shapes and consolidate parts	Created by craft, which slows production throughput and limits consistency
Resistance to corrosion	Steel bends + dents, but composites crack + shatter, complicating inspection/repair

Industry-specific dynamics both spur and slow composite adoption

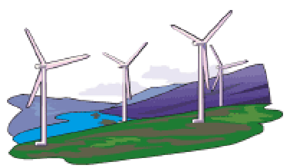
HIGH

Willingness to pay for advanced composites

LOW

- Use MWNTs as reinforcement at low loading (~0.5%) to epoxy resins in composite racquets, shafts, bats, etc. **Customers' ability to pay** for performance stimulates early adoption; Brand builder but **not a volume driver**

- Industry is shifting towards composites to **lower aircraft weight, decrease fuel consumption**, reduce required maintenance, and improve passenger comfort. Jet fuel cost goes directly to bottom-line; Boeing's 787 Dreamliner and Airbus' A350 XWB use > 50% CFRP



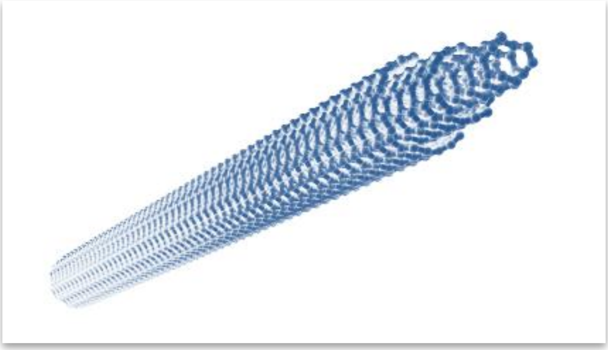
- Trend towards offshore favors bigger blades to improve efficiency and improve economics and **necessitates stiffer and lighter materials**; 2-3 year development cycles allow for aggressive materials approach

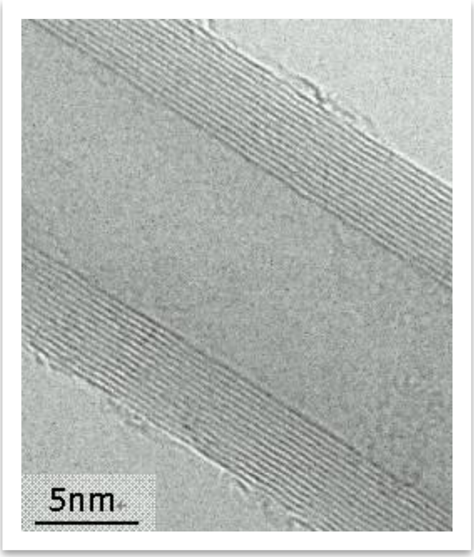
- Risers subjected to dynamic ocean environment; conservative industry with **slow adoption pace**

- Composites can **cut weight in half and improve fuel economy**. Regulations demand **conductive materials in fuel system** to eliminate sparking and accidental combustion. Security of supply chain and recycling become significant issues at these volumes; standard product development is incremental

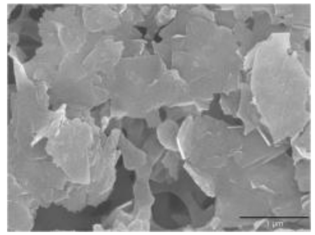
What are MWNTs?

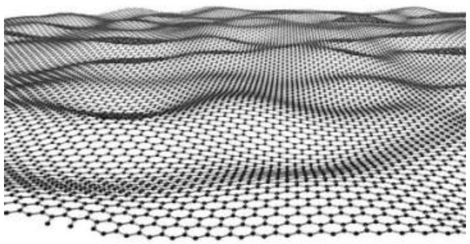
- MWNT = multi-walled carbon nanotube
- Hollow tubes comprised of multiple concentric single-layer graphite sheets
- Typically have extremely high aspect ratios
  - Diameter: 5 nm - 150 nm
  - Length: 1 µm - 1 cm





Graphene: Two very different materials





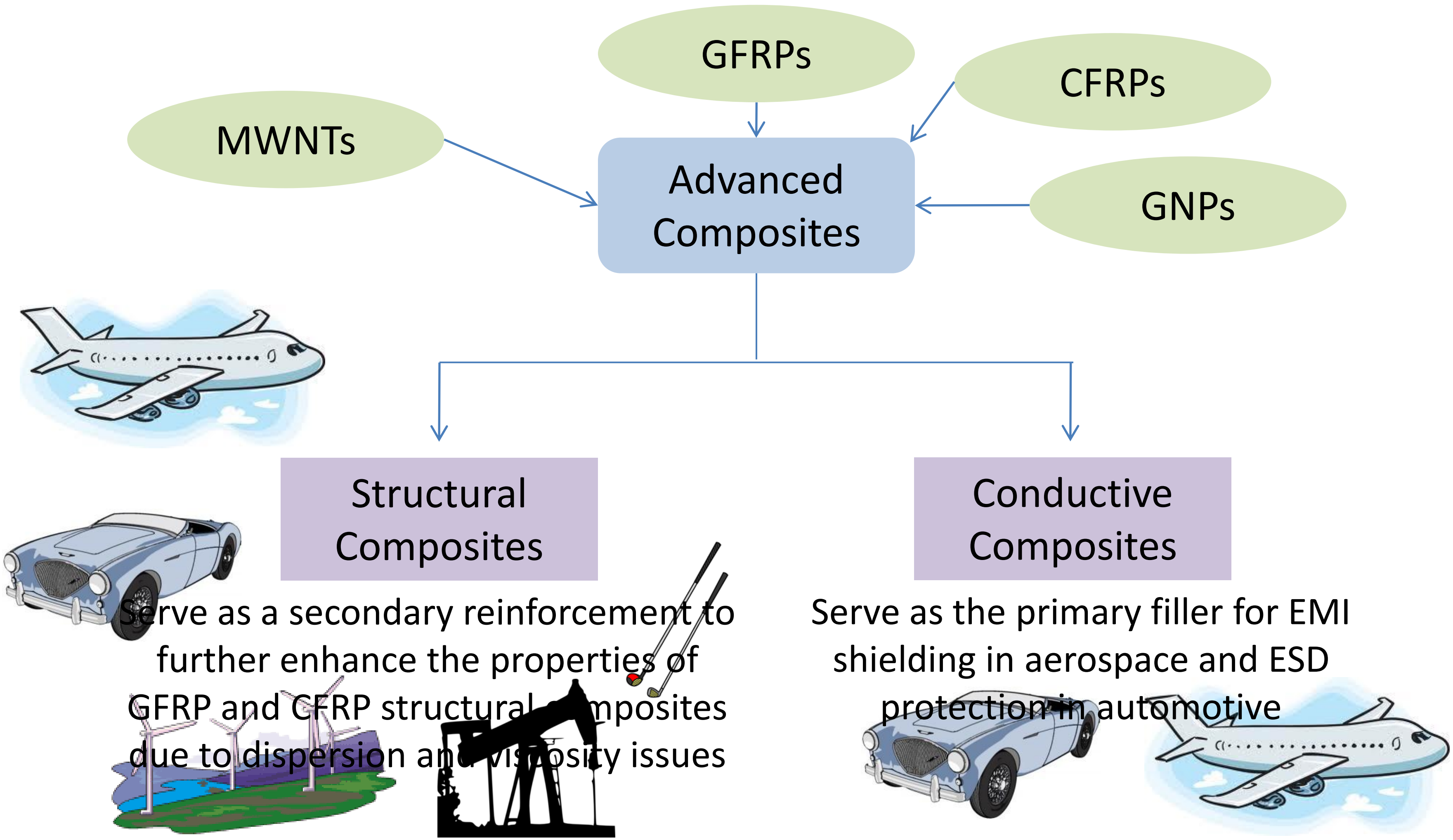
	Graphene nanoplatelets (GNPs)	Graphene films
What it is	Discs of graphene, one to hundreds of layers thick	Uniform, usually monolayer film of graphene across a surface
Applications	Additives to resins/coatings, inks, electrodes for energy storage	Transistor, TCFs
Properties	Strength, conductivity (electrical and thermal), gas barrier	Conducting, semiconducting, transparent
Costs	As low as \$25 to \$100's/kg	\$10's to \$1,000's/m^2
Compares to/ competes with:	Multi-walled carbon nanotubes; nanoclays	Single-walled carbon nanotubes
Commercial status	Pre-revenue; commercial adoption 2-3 years away	Pre-revenue; commercial adoption 5-10 years away

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 \$30/kg	1.8 to 3.0	127 to 232	10^{-3} Ω-cm
MWNT	\$60/kg to \$100/kg	129	714 to 1214	10^{-4} Ω-cm
GNP	\$200/kg to \$500/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 their penetration** to secondary reinforcements in GFRP and CFRP structural materials
- Carbon fiber technology is far more established than MWNT- and GNP-based nanocomposites today, and MWNTs are more mature than GNPs → very different market trajectories in the target industries

Putting MWNT and GNP applications in context



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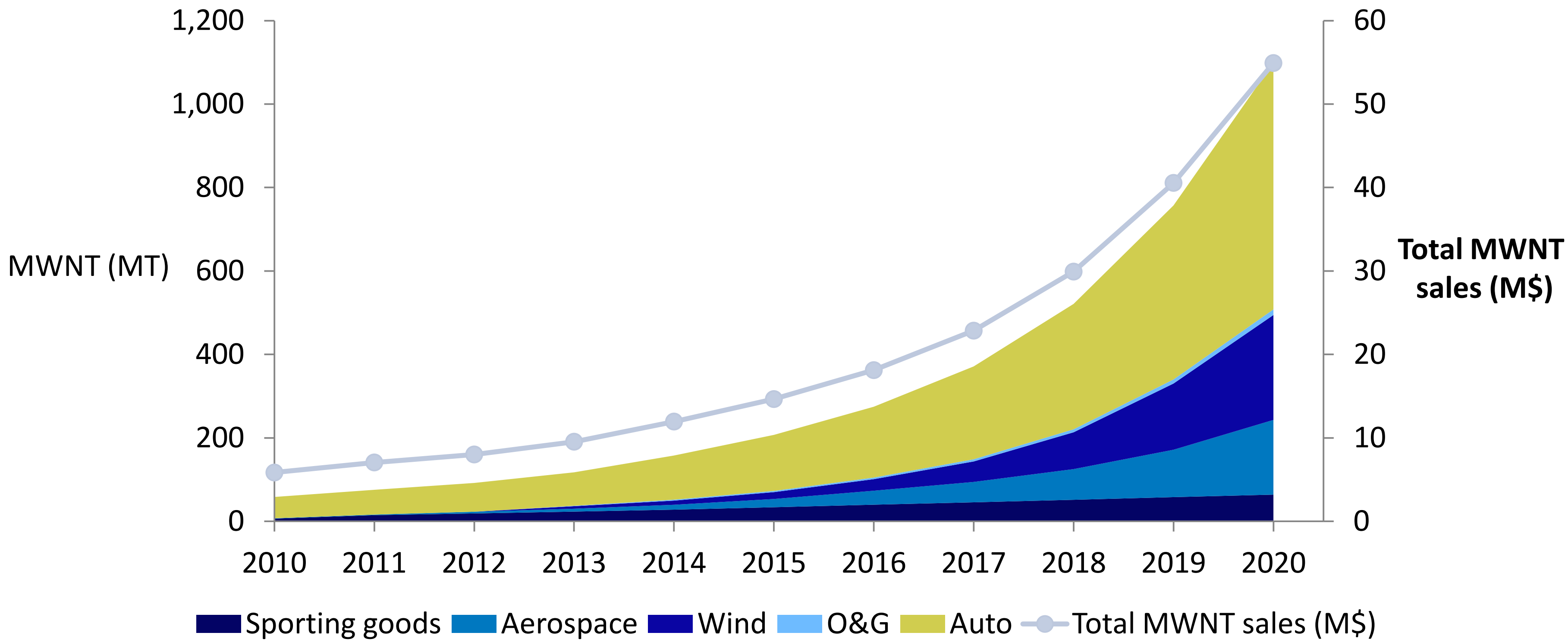
Nanocomposite case study: Zyvex Technologies

- Produces nanocomposites using MWNTs, but looking into SWNTs and GNPs as well
- Targeting niche markets like unmanned vehicles for defense; leaving large wind, automotive, and aerospace markets to its distribution partners
- Extended further downstream into making composite components and parts for target markets

Automotive commands the greatest share of MWNT demand, with 591 MT demand in 2020



	Sporting goods (MT)	Aerospace (MT)	Wind (MT)	O&G (MT)	Auto (MT)	Total MWNT sales ($ MM)
2011	15	1	0	0	59	7.1
2020	64	179	251	13	591	55

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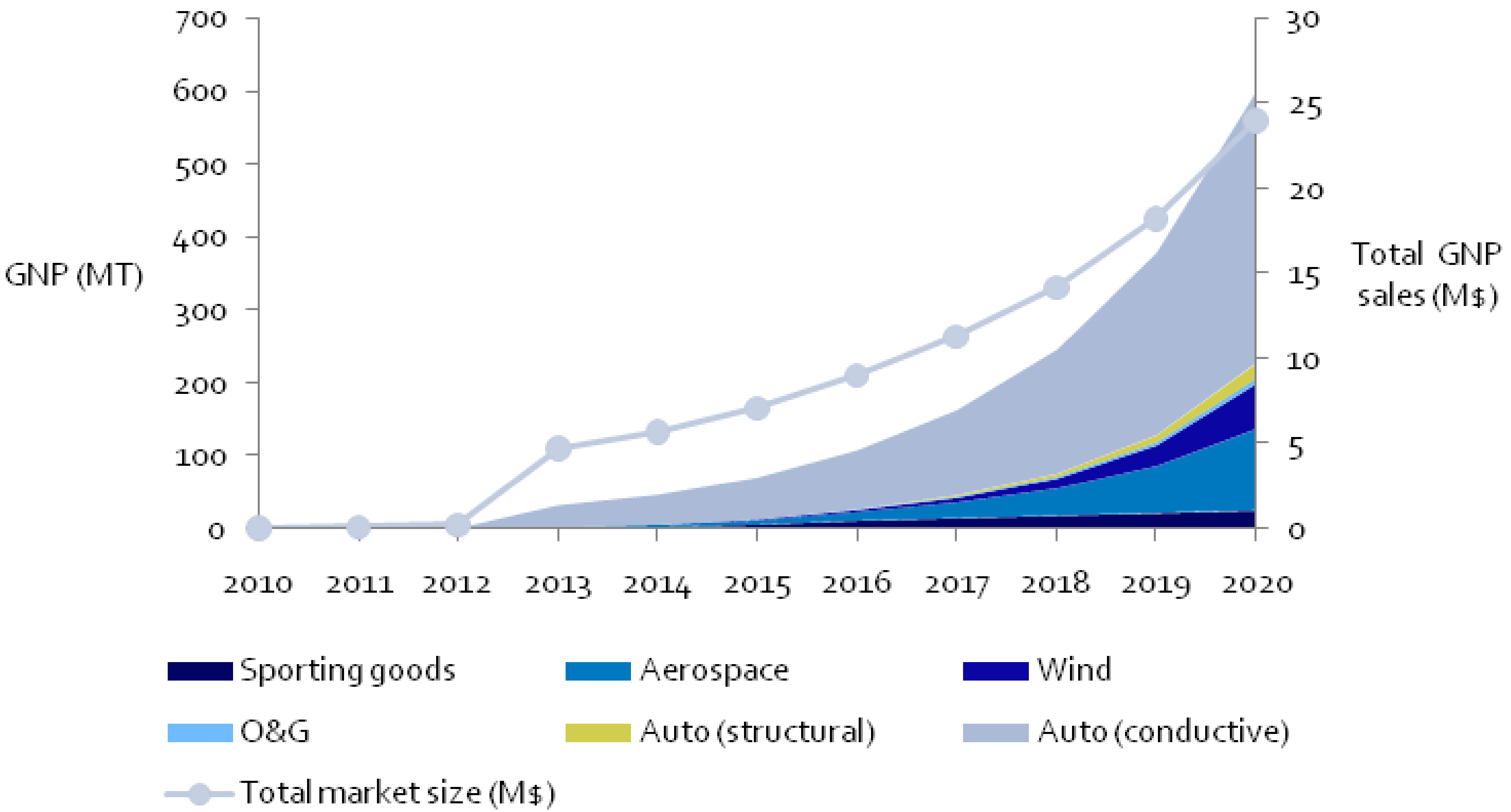
But MWNT suppliers are only entitled to a miniscule fraction of final composite price

- % of final MWNT-enhanced CFRP composite cost from raw MWNT:
  - 0.3% in 2010
  - 0.1 % in 2020
- MWNTs only incorporated at 0.5% loading
- Oversupply situation in MWNT market will persist for at least another 5 yrs
  - MWNT price expected to drop from $100/kg today to $50/kg in 2020
- Composite intermediates including dispersions, wovens, and prepregs command over 2/3 value of final composite
- **Pure-play MWNT suppliers will have a very difficult time succeeding. Nanomaterial suppliers must move down the nanotech value chain to be viable businesses**

Following a slow start, conductive composites electrify GNP composite activity



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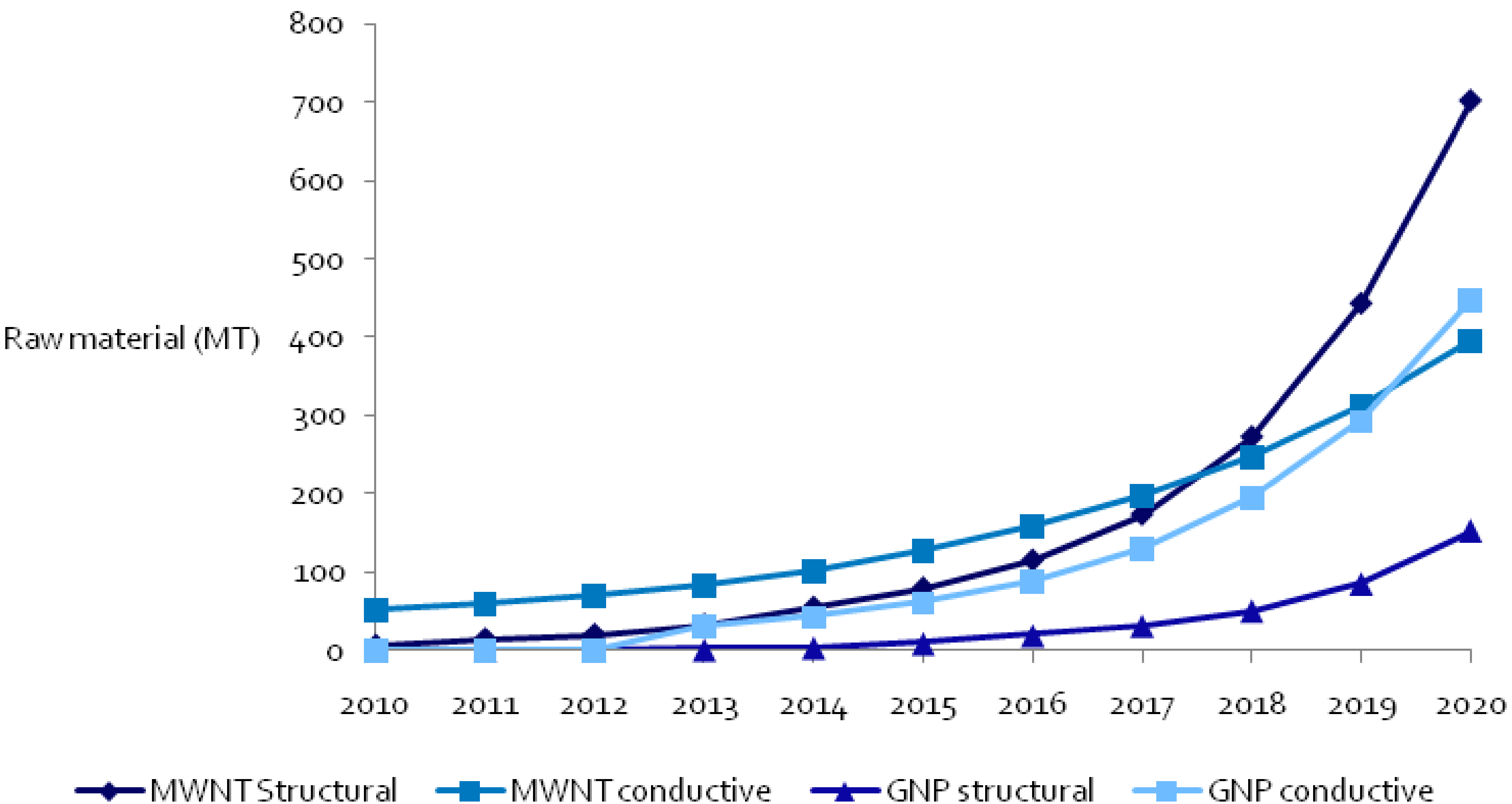
GNPs follow in the footsteps of MWNTs for structural composites, take the lead in conductive



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GNP suppliers fare better, but nanointermediates still grab the lion's share

- A slow start and lower specific strength and modulus will cause GNPs to lag behind in structural applications for the foreseeable future
- GNPs are easier to disperse than MWNTs and have a much lower effect on resin viscosity at any given conductivity level
  - Aggregate demand for GNPs in conductive applications will overtake MWNTs by 2020 and never look back
- % of final GNP conductive composite cost from raw GNPs: 28%
  - GNPs are primary not secondary filler in conductive composites
  - 3%-10% loading in conductive composites vs. 0.5% in structural
- **While GNP material suppliers will fare better than MWNT suppliers, the value of forward-integrating into prepregs and composite parts is still evident**

A solar case study: when nano isn't enough

The promise of nano-based solar cells

- Direct bandgap thin film semiconductors require 1/100th thick active layer as silicon wafer (a-Si, CdTe, CIGS)
- Ink-based nanoparticle semiconductors allow for printable deposition and non-vacuum processing
  - Roll to roll manufacturing
  - Higher materials utilization
- Promise of ultra-low cost opened VC's pockets and spawned many a start-up

Solexant

nanosolar

ISET

International Solar Electric Technology

Alion

Nanosolar

CIGS module production using roll-to-roll deposition process

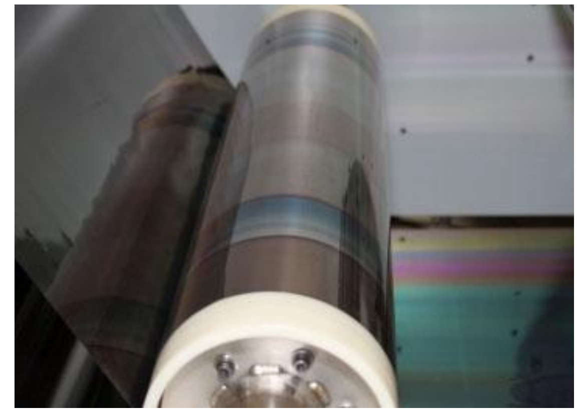
- Roll printing nanoparticle ink-based CIGS solar cells on Al foil
- Selling modules primarily to utilities and project developers, which are employing them in ground-mounted, utility-scale solar plants.
- Lofty promises of becoming the low-cost market leader allowed it to raise $400 million since being found in 2001
- Has kept a very low profile since CEO swap in March 2010

Solexant

Thin-film flexible CdTe module manufacturer using sintered nanoparticle inks

Solexant

- Developing thin-film flex CdTe modules based on metal foil substrates
- Active layer deposition consists of non-vacuum printing process of CdTe nanoparticle inks
- Raised $84 million since 2006
- Abandoned $25 million loan to locate manufacturing facility in Oregon
- CEO swap in June 2011



Why nano is not enough?

- Lab to production transition non-trivial, expensive, and time consuming
- First Solar and low cost c-Si manufacturers are not waiting for others to catch up
  - First Solar funded by Walton family in 1999- had the luxuries of time and money to develop their technology, unlike contemporary PV startups funded by VCs
  - China heavily subsidizes land and loans, has low labor costs, inexpensive construction, and expedited permit approval
- Any PV startup with a new technology trying to become a vertically integrated module maker is going to face a significant uphill challenge

First Solar. SUNTECH YINGLI SOLAR Trinasolar

Even good engineering is not enough

SOLYNDRA®

Developer and manufacturer of CIGS modules

- Cylindrical CIGS PV design specifically targeted commercial flat-rooftop applications
- Received over $1 billion in VC funding and over $500 million from DOE in loan guarantees
- Recently filed for Chapter 11 Bankruptcy
- Could not compete on cost; ended up scaling a technology that wasn't economically scaleable

APPLIED MATERIALS®

Equipment provider for a-Si modules

- Semiconductor equipment giant
- Supplied full turnkey lines for making silicon thin-film modules (SunFab)
- Several key customers cancelled orders
- Discontinued SunFab solar business in July 2010
- Panels from SunFab line cost about 30% more than competing c-Si panels

Innovalight

Silicon nanoparticle ink-based route to silicon solar cells

- Developing nanocrystal silicon ink that can boost the efficiency of silicon wafers by 1-2%
- Originally set out to become a panel manufacturer, but in 2008 modified business model to become a materials supplier and technology licenser
- Licensing model insulates it from solar's brutal price competition – turned competitors into customers
- Acquired by DuPont in July 2011

Lessons from solar case study

- Nanotech companies MUST KNOW THEIR MARKETS – being a good nano or even a good engineering company is not enough
- Nanomaterials perfectly suited to being value-added efficiency enhancers
  - Surface texturizers increase effective surface area and active area light absorption
  - Coatings that reduce reflection and enhance absorption
- Solar manufacturing is extremely capital intensive and becoming increasingly commoditized
- There is a huge and profitable opportunity to incorporate proprietary nanotechnologies into existing manufacturing lines
- Incremental improvements within existing value chain have much greater chance of success than total overhauls

Conclusions

- Nanotech is not its own industry or market but rather an enabling technology that enters and enhances many different industry value chains
- Industry specific dynamics both spur and slow adoption – nanotech developers need to strike the right balance between building brand and driving volumes
- Nanomaterial suppliers must move down the nanotech value chain to be viable businesses
- Nanotech companies must know their markets – being a good nano or even a good engineering company is not enough
- Incremental improvements within existing value chain have much greater chance of success than total overhauls

Thank you

Ross Kozarsky
Analyst
+1 857-284-5687
ross.kozarsky@luxresearchinc.com