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- **Nanomaterials Overview**
- **Nanomaterials Competitiveness**
- **Market Trends and Opportunity**
- **Growth Opportunities in 2011 and Beyond**
- **Conclusions**
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Executive Summary

• Global nanomaterials industry reached $1.7 B in 2010, with an average annual growth rate of 10.4% over last five years
  • Top 10 players are ~80% of global nanomaterials market
  • Nanoclay and carbon nanotubes are dominant materials representing ~90% of market value
• North American nanomaterials industry accelerated by ~25% in 2010 and Europe by ~22%, while Asia and other regions grew by ~32% in 2010, driven by:
  • Active participation of government in nanotechnology R & D funding
  • Advancement in production process
  • Heavy investment in R & D by major players
• Global Nanomaterials market is forecast to become a $6.1 billion in 2016
  • Expected to grow at a CAGR of 23% during 2011-2016
  • Driven by health and personal care, energy and electrical and electronics application
  • Emerging applications include: field lamination display (FED), drug delivery and biofuels
• Healthcare and energy industry expected to surpass E&E in size over coming 2-3 years, driven by nanotechnology advancements in biomedical field and solar energy field
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Nanomaterials: Definition

Nanomaterials are multiphase solid material where one of the phases has one, two or three dimensions of less than 100 nanometers (nm).

In this report, nanomaterials which are 2 or 3 dimensions less than 100 nm are included for study.

<table>
<thead>
<tr>
<th>Dimensions</th>
<th>Nanomaterials</th>
</tr>
</thead>
<tbody>
<tr>
<td>3 dimension</td>
<td>Particles, quantum dots, hollow spheres, etc</td>
</tr>
<tr>
<td>2 dimension</td>
<td>Tubes, wires, platelets, etc</td>
</tr>
<tr>
<td>1 dimension</td>
<td>Films, coatings, multilayer, etc</td>
</tr>
</tbody>
</table>

Nanomaterials are 1000’s time smaller than human hair.
Types of nanomaterials

- Nanoclay
- Quantum Dots
- Fullerene
- Carbon Nanotube
- Metal Nanopowder
- Graphene
- Dendrimers
### Nanomaterials Road Map

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<tbody>
<tr>
<td>Nanoclay</td>
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<tr>
<td>Carbon Nanotube</td>
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<td></td>
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<tr>
<td>Metal Nanopowder</td>
<td></td>
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<tr>
<td>Quantum Dots</td>
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<td></td>
</tr>
<tr>
<td>Fullerenes</td>
<td></td>
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</tr>
<tr>
<td>Dendrimers</td>
<td></td>
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<tr>
<td>Graphenes</td>
<td></td>
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</tbody>
</table>

**Note:**
- **Industrial Demonstrator**
- **Industrialization**
- **Market Entry**

**Creating the Equation for Growth**
Applications of Nanoclay and Carbon Nanotubes

Nanoclay
- Use in bottling of O2 and CO2 sensitive products (beer and cold drink bottles)
- Use in food and packaging industries
- Use in motor compartment of vehicle for casting and connectors
- Use in wire and cable applications
- Timing belt covers in automotive
- Scratch resistant coatings in automotive and aircraft frame & body

Carbon Nanotubes
- EMI/RFI shielding & coatings in electronic devices to control radiation
- CMP slurries in electronic chips and wafers to enhance conductivity
- Diagnostics and imaging in healthcare to enhance clarity in X-ray films
# Current and Potential Applications

<table>
<thead>
<tr>
<th>Transportation</th>
<th>Construction</th>
<th>Packaging</th>
</tr>
</thead>
<tbody>
<tr>
<td>Engine &amp; Fuel Systems</td>
<td>Conductive Flooring</td>
<td>Meat &amp; Food Packaging</td>
</tr>
<tr>
<td>Scratch Resistant Exterior Parts and Coatings</td>
<td>Pipes</td>
<td>Computers &amp; Electronics</td>
</tr>
<tr>
<td>Car Interior</td>
<td>Insulating Materials for Roofs &amp; Thatches</td>
<td>Medicines &amp; Pharmaceuticals</td>
</tr>
<tr>
<td>Aircraft Structure &amp; Framing</td>
<td>House &amp; Building Siding</td>
<td>Beer Bottles</td>
</tr>
<tr>
<td>Wear Resistant Paints &amp; Coatings for Defense Vehicles</td>
<td>Self Cleaning Windows</td>
<td></td>
</tr>
</tbody>
</table>
## Current and Potential Applications

<table>
<thead>
<tr>
<th>Consumer Goods</th>
<th>Electrical &amp; Electronics</th>
<th>Others</th>
</tr>
</thead>
<tbody>
<tr>
<td>Home appliances</td>
<td>Sensors</td>
<td>Anti-foul coatings for marine ships</td>
</tr>
<tr>
<td>Sporting goods &amp; toys</td>
<td>Semiconductors</td>
<td>Industrial equipment to increase strength</td>
</tr>
<tr>
<td>Furniture &amp; others</td>
<td>Hard disk storage in computers</td>
<td>Fire resistant clothes</td>
</tr>
<tr>
<td><strong>Energy</strong></td>
<td></td>
<td></td>
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<tr>
<td>Battery electrodes</td>
<td></td>
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<tr>
<td>Fuel cell membranes</td>
<td></td>
<td></td>
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<tr>
<td>Supercapacitors</td>
<td></td>
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<tr>
<td><strong>Health Care</strong></td>
<td></td>
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<tr>
<td>Body implants</td>
<td></td>
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<tr>
<td>Medical devices</td>
<td></td>
<td></td>
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<tr>
<td>Dental filling materials</td>
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</tr>
</tbody>
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Cost and property analysis of nanomaterials with respect to other materials

<table>
<thead>
<tr>
<th>Materials</th>
<th>Strength</th>
<th>Modulus</th>
<th>Price Competitiveness</th>
<th>Weight</th>
<th>Surface Area</th>
<th>Wear Resistance</th>
<th>Barrier Property</th>
<th>Electrical Conductivity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nanomaterials</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
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<tr>
<td>Ceramic</td>
<td>●</td>
<td>●</td>
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<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>Kevlar (Aramid)</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
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<tr>
<td>Glass Fibers</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>Carbon Fibers</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
</tr>
</tbody>
</table>

Key Insights

- Nanomaterials have highest strength, modulus, wear resistance, barrier properties and electrical conductivity relative to other materials.
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Geographical breakdown for nanomaterials

Global nanomaterials distribution ($ mil) by regions in 2010

- **Asia & Others**: 25%
- **Europe**: 37%
- **North America**: 38%

Key Insights

- North America and Europe were the two largest markets for nanomaterials in 2010.
- European region has significant use of nanomaterials in pharmaceuticals, as many pharmaceutical companies are based in Europe.
- Good growth of nanomaterials was witnessed in Asia region during last 5 years due to:
  - Government support
  - Continued environmental consciousness
  - Expected increase in demand for specialty materials
Nanomaterials Market: Trend and Forecast

Drivers For Nanomaterials Investment

- **Emerging Applications**
  - Expected that nanomaterials to be extensively used in emerging applications: water treatment, drug delivery & nanomedicines

- **Price**
  - Decrease in price of nanomaterials may take place due to expanded production

- **Innovation**
  - Number of patents regarding manufacturing of nanomaterials is increasing year after year

Top 3 Market Segments Regionally

<table>
<thead>
<tr>
<th>North America</th>
<th>Europe</th>
<th>RoW</th>
</tr>
</thead>
<tbody>
<tr>
<td>E&amp;E</td>
<td>Health&amp; Personal Care</td>
<td>E&amp;E</td>
</tr>
<tr>
<td>Health&amp; Personal Care</td>
<td>E&amp;E</td>
<td>Transportation</td>
</tr>
<tr>
<td>Energy Storage Devices</td>
<td>Transportation</td>
<td>Packaging</td>
</tr>
</tbody>
</table>

Trend and forecast in nanomaterials shipment ($ B): 2005-2016

- 2005: 1.0
- 2010: 1.7
- 2016: 6.1

Electrical & Electronics (E&E) market witnessed a robust growth due to large price decrease of carbon nanotubes and increase in mass production of nanomaterials.
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Health care industry is expected to gain market share and overtake E & E segment in size over next five years

Growth opportunities for nanomaterials in various applications

- Health care
- Energy storage
- Electrical & Electronic
- Transportation
- Construction

Market Size (US$ M)

Key Insights

- Nanomaterials have great potential in electrical and electronics applications because of their extraordinary electrical conductivity
- Global recession induced cost/price sensitivity in E & E segment, given its potential to reduce manufacturing costs and increase product competitiveness
- Packaging is another important segment, mainly flourishing in North America and Western Europe
- Energy segment is expected to pick up a nice pace in coming years @ double digit growth rate
Emerging trends in global nanomaterials and nanocomposite industry

Trend A: Growing demand for high strength, durable structural materials

Trend B: New material development and product design

Trend C: New and emerging market applications

Trend D: Falling nanocomposites prices

Trend E: Huge expansion by existing suppliers and new entrants

Trend F: Government support and R&D funding

Emerging Trends in Global Nanomaterials and Nanocomposites Market
Growing demand for high strength, durable materials will create good future opportunities for nanocomposites.

**Properties**

<table>
<thead>
<tr>
<th></th>
<th>Carbon/Aramid / Glass fibers</th>
<th>Carbon nanotubes / nanoplatelets</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strength</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>Weight</td>
<td>●</td>
<td>○</td>
</tr>
<tr>
<td>Impact Resistance</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>Brittleness</td>
<td>●</td>
<td>○</td>
</tr>
</tbody>
</table>

New and exciting uses for nanotubes:

- Aircraft wings and fuselages
- Boat hulls
- Sports cars
- Baseball bats, hockey sticks, and skis
New material development and product design

**Nanoledge Inc. developed prepreg containing nanotubes**
- Nanotubes used to boost mechanical properties
- Developed for experimental use in boat hull

**New Piranha using Zyvex Nanomaterials**
- Reduced weight while greatly increasing payload and cruising range

**Harbor Composites designed nanotube aircraft**
- Impart additional strength and durability to ordinary composites and make them even more appealing

**Velozzi’s Supercar will use nanotube composites - structural parts**
- Objective to improve properties and reduce weight
Technical developments in CNT promise further capacity expansion and price reduction

Key Insights

- CNT prices have fallen substantially, from more than $150 per gram in 2000 to under $50 per gram today (2010)

- Improved manufacturing and large-scale production by CVD process enabled the drop in price

- Current technical developments in carbon nanotube fabrication may encourage further increase in production capacity and reduction in prices
Recent raw material production expansion plans are indicative of strong demand in the sector

Arkema Group

• Fulcrum SP Materials & Arkema to jointly produce improved damage resistant nanocomposites
• Capacity expansion for CNT production in 2011

Showa Denko K.K.

• Developed VGCFTM-X, a new grade of CNT for resin composite design
• Began construction of 400 ton/yr plant in 2009 at Oita

Bayer AG

• Opened a large carbon nanotube (CNT) pilot facility in Leverkusen, boasting annual capacity by 200 tons
• Invested €22 million in the operation located at Chempark in Leverkusen
In past 5 years, a huge amount has been invested in nanotechnology R&D by US and European countries. Japan has shown strong interest in nanotechnology development, spending ~$1 B in nanotechnology R&D in 2010. Global expenditures for nanotechnology R&D expected to grow @ ~23% until 2016.
Growing uses of nanocomposites in transportation industry will create huge demand in future

- Nanostructured polymer composites for transparent Tragholme
- Nano-structured Mg sheet and extrusions for light weight hang-on parts
- Nanoflakes for SMC used in larger structures body molding
- Nanoparticles for wear resistant tires; adherent long running tires
- Scratch resistant paints
- Nanostructure control of multi-material welds
- Nano- enabled LED lights
Creating the Equation for Growth

Potential Applications of Nanocomposites in Aircraft, though market remains nascent due to certification and overall slow adoption

- Special coatings/adhesives with self repair mechanisms
- Carbon nanotubes for improved mechanical, electrical and thermal properties (resin, adhesives)
- Nanofillers for PIEZO-paints, coatings, and fibers
- Micro-particle-reinforced
- Nano-clay CFRP for barrier upgrading
- Metal-Ceramic nanostructured bulk composites
Huge potential of nanomaterials in future power trains

- Nano-fibers and channels for fuel injection
- Corrosion resistant paints & coatings
- Nano-scale material for catalytic converters
- Polymer nanocomposite sensors
- Nanopore fuel & oil filter
- High density & power nanocomposites
- Nano-enabled batteries
- Nanocomposite based hydrogen storage

Creating the Equation for Growth
<table>
<thead>
<tr>
<th>Application</th>
<th>Description</th>
<th>Size of Opportunity</th>
<th>Key Drivers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Field Emission Display (FED)</td>
<td>The CNT is used as light emitter in FED</td>
<td>Large</td>
<td>High luminance, high contrast, high light efficiency, wide view angle</td>
</tr>
<tr>
<td>Body Armors</td>
<td>Can be used for defense and military purpose for protection of body</td>
<td>Medium</td>
<td>Greater safety, light weight and skid resistance</td>
</tr>
<tr>
<td>Water Purification</td>
<td>Used as antimicrobial agent</td>
<td>Medium</td>
<td>Light weight porous materials for water filtration, enhanced performance for purification</td>
</tr>
<tr>
<td>Application</td>
<td>Description</td>
<td>Size of Opportunity</td>
<td>Key Drivers</td>
</tr>
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<td>-----------------------------------------------------------------------------</td>
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<td>-----------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Drug Delivery</td>
<td>Used for improving the treatment of cancer</td>
<td>Medium</td>
<td>Enhanced mechanism for treating the infected cells like cancerous cell</td>
</tr>
<tr>
<td>Bio Fuel Cell</td>
<td>Can be used as electrodes in bio fuel cell</td>
<td>Medium to Large</td>
<td>High enzyme loading, Over comes limitation of small dimensions and large specific surface area</td>
</tr>
<tr>
<td>Wind Turbine Blades</td>
<td>Carbon nanotubes can be used to make larger and lighter rotor blades, thereby sustainably optimizing energy generation.</td>
<td>Medium to Large</td>
<td>Light weight, High strength</td>
</tr>
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</tbody>
</table>
Conclusions

- The nanomaterials market is expected to grow at about 23% annual rate until 2016
- Top 6 players have secured two-thirds of global nanomaterials market shipments; high opportunity for new players to enter this growth market
- Decline in demand in 2009 for nano-enabled products in the automotive industry, such as automotive lubricants, catalytic converters, sensors and filters, among others, drove the heavy downturn in market opportunities for nanomaterials such as multi-wall carbon nanotubes (MWNTs) and ceramic nanoparticles
- Health care and energy markets were two main application areas which helped the global nanomaterial industry recover from downturn experienced in 2009
- Healthcare industry is expected to surpass the electronic and electric industry in size over the coming 2-3 years, driven by nanotechnology advancements in biomedical field
- North America will remain the market leading region for several years as it has significant ongoing R & D activities in nanomaterials
- It is expected that nanomaterials will broaden their markets as they enter into more applications such as drug delivery, armor, defense equipment, weapons, nanomedicines and the like
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About Lucintel

- Lucintel is the leading global management consulting & market research firm for aerospace, marine, energy, construction, consumer goods, transportation, chemical, and composites industries.

- Lucintel creates your equation for growth and is committed to actionable results that deliver significant value and long term growth to our clients.

- Lucintel has been creating measurable value for over 10 years and for more than 1000 clients in 70 + countries worldwide.

### Market Reports

- Aerospace
- Transportation
- Marine
- Construction
- Renewable Energy
- Recreational
- Composite Materials

### Consulting

- **Growth and Strategic Consulting**
- **Benchmarking**
- **Opportunity Screening**
- **Partner Search and Evaluation**
- **Due Diligence and M&A**
- **Market Entry Strategy**
Lucintel has an extensive toolkit to address key strategic questions for increasing your company’s profitability and market presence.

**Key Questions**

- Is market space / opportunity of current product offerings sufficiently robust?
- Markets are focus for many: how can my company profitably differentiate?
- Based on our core skills, where should we focus?
- Should we build or buy? Is build even an option?
- What game changer actions exist and/or is a more incremental approach best?
- What is the order sequence of market entry segments / products?
Clients around the world value our services
Reach Lucintel

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