Small Things with the Potential for Big Disruption

Advanced Materials and Nanotechnology Outlook Through 2024

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KEY TAKEAWAYS

- *Advanced materials and nanotechnology will drive innovation in industries with high growth potential in the future – robotics, healthcare, electronics, transportation and aerospace.*
- *For Moore's Law to continue, more rapid adoption of nanotechnology based circuits must take place, driving innovation forward.*
- *For all advanced materials to reach their potential, perfecting both scalable and cost-effective manufacturing techniques will have to be developed.*

BACKGROUND

Advanced materials and nanotechnology form a broad and inter-disciplinary area of research and development that can enable new or improved properties in products and engineering processes. Technological advances have allowed the rapid progression in the quality and cost of materials leading to breakthroughs and growth within these industries. We've seen this previously where advances in steel manufacturing allowed it to become stronger, cheaper and more versatile - leading to mass production for use across thousands of products, buildings, and transportation. Today, "advanced materials are solving fundamental problems necessary to make products more efficient, sustainable, less expensive and better performing, key attributes necessary for widespread adoption."[1] This has led to investment from the world's largest businesses, as they require advanced material innovation to improve industrial processes and make their existing products better.

Advanced materials are one of the few industries that can take innovation from across different sectors and apply it to varying products elsewhere in the marketplace. Computing, microfluidics, nanotechnology, genetics, healthcare and the transportation sectors are currently driving innovation of new materials and it is expected these sectors will continue to be on the leading edge in the future.[1]

Preceded by years of offering promises rather than products, advanced materials – and the nanotechnology that drives them – have gained a small albeit growing role in manufacturing, consumer products and medicine. The advanced and nano-material market is dominated by the United States and it is expected to continue to lead the market through 2023.[2]

MARKET SIZE

The promise of advanced and nano-materials drives the wide range of applications these materials could fit into. Although a single material could benefit numerous industries, the applications that have potential to see the most benefit in the near term are the automotive, aerospace and electronics industries where the need for lightweight and durable materials are paramount. North America and Europe are the major regions for the advancement of the materials market due to the large production capacity and sophistication of technology advancement. Other regions vying for market share must continue industrial developments in order to build out capabilities necessary for this type of advanced research and manufacturing.

As of this writing, thirteen governments have major resources dedicated to research including the USA, EU, and BRIC regions. In the United States there are about 40 major research institutions specifically studying nanotechnology; India is close behind with about 30 major institutions driving technological innovation.

[1] http://www.globalcorporateventuring.com/secure_download.php?file=LEIF_Brief_-_Advanced_Materials_Innovation_Final.pdf

2 https://www.mordorintelligence.com/industry-reports/healthcare-nanotechnology-nanomedicine-market

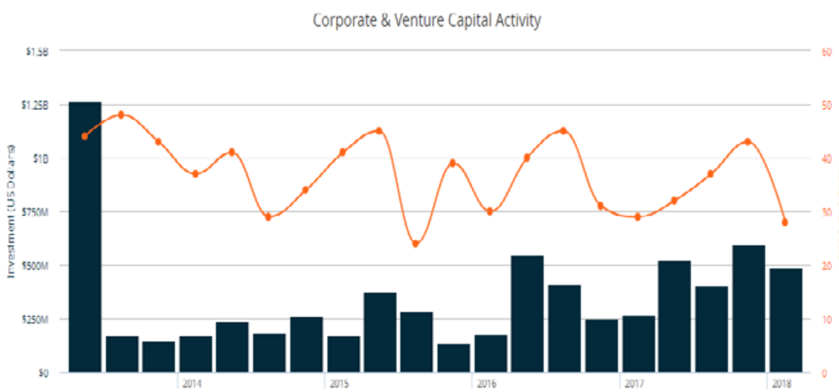
Specifically, Nanowerk.com, a leading nanotechnology news source, lists 890 nanotechnology-based companies currently operating within the United States.[3]

Overall, the advanced materials market was valued at $42.76 billion in 2015 and is anticipated to reach $102.48 billion by 2024 representing a CAGR of 10.4% between 2016 and 2024.[4] Investment in this space reached a record $461 million in Q4 2017 as more mainstream VC investors became active in applied robotics driven by short-term market opportunities, unit economics and recurring revenue.[5]

Similarly, the global nanotechnology market is expected to grow at a CAGR of 17% from 2017 through 2024 bolstered by the health-care and electronic sectors.[6] Specifically, the nanotechnology enabled drug-delivery market is expected to grow to $136 billion by 2021.[7] The drug-delivery sub-section of the market has the seen the most product research, adoption and outside capital from government and private investment thus far.

Both of these industries have seen large investments to-date and as climate change statistics are continuously rising, there is growing pressure from consumers, business, and governments to search for more eco-friendly or efficient materials and manufacturing techniques.

ADVANCED MATERIALS



Source: https://i3connect.com/tags/advanced-materials/677/activity

In laboratories, scientists are perfecting new ways to manipulate matter to inherit complex attributes that can innovate across all industries and areas of society. By definition, advanced materials are novel materials or materials that have undergone modifications to gain superior properties as compared to conventional materials – driving superior performance in one or more characteristic which is critical for the application under consideration. The major products within this category are segmented as follows: ceramics, glass, polymers, composites and metal alloys.

Ceramics are especially notable due to their possible replacement of plastics and metals using high performance ceramic composites. These ceramics and other composites are improved over their current iteration utilizing lighter weight, higher strength and resistance to abrasion ratios. Between 2003 and 2013, the advanced materials market attracted $4.9 billion in investment, $3.5 billion of which came from venture capital investments.[8] Additionally, between 2010 and 2015, the top ten corporate VCs in the sector committed more than $2 billion.[1]

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3 https://www.nanowerk.com/nanotechnology/Nanotechnology_Companies_in_the_USA.php

4 https://www.prnewswire.com/news-releases/advanced-materials-market-estimated-to-reach-us-10248-bn-by-2024-global-industry-analysis-size-share-growth-trends-and-forecast-2016---2024---transparency-market-research-608036376.html

5 https://www.svb.com/uploadedFiles/Content/Trends_and_Insights/Reports/Venture_Monitor_Report/1Q_2018_PitchBook_NVCA_Venture_Monitor.pdf

6 https://www.prnewswire.com/news-releases/global-nanotechnology-market-outlook-2017-2024-with-profiles-of-key-players---altair-nanophase-tech-nanosys-300582991.html

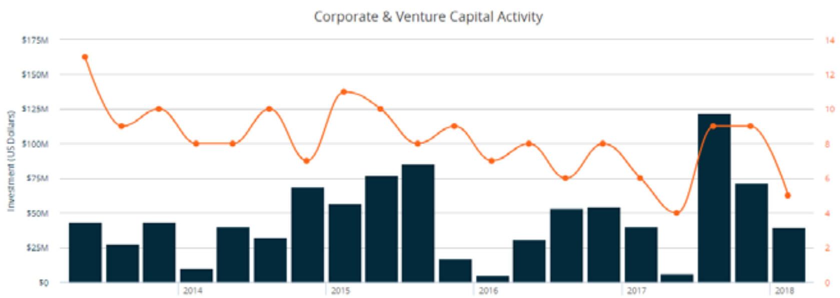
7 https://www.mckinsey.com/~/media/McKinsey/Business%20Functions/McKinsey%20Digital/Our%20Insights/Disruptive%20technologies/MGI_Disruptive_technologies_Full_report_May2013.ashx

8 http://www.phoenix-vp.com/wp-content/uploads/2015/10/Advanced-Materials_Creating-Chemistry_0713.pdf

Advanced materials are the necessary inputs to drive advanced manufacturing forward. These two industries are most notably linked together in the future through robotics, where new manufacturing processes and materials come together. Currently the majority of "robots are still using conventional materials that are manufactured conventionally. Robotics will only really begin to fulfill their potential when advanced materials" are manipulated to form cutting edge products.[1]

NANOTECHNOLOGY

Nanotechnology is a field driving innovation within manufacturing and is considered a specific type of advanced material. Nanotechnology is defined as structures, devices, and systems having novel properties and functions due to the arrangement of their atoms on the 1 to 100 nanometer scale.[9] For reference, the width of a human hair is about 80,000 nanometers wide. The technology takes advantage of different characteristics of materials at the nano-level as opposed to its bulk material counterpart. This occurs because at the nano-scale a much larger percentage, or surface-area, of the atom is exposed to outside forces, making the atom more reactive.



Source: https://i3connect.com/tags/nanomaterials/1458/activity

Today, simple nanoparticles are the most widely used nanomaterial. Invisible to the naked eye, they have found their way into products as varied as coatings, paints, sensors, chemical catalysts, food packaging, pharmaceuticals, sunscreens, bacteria-killing clothing, composite bicycles, golf clubs and tennis racquets.[7] For example, silver nanoparticles have anti-microbial properties and have been added to detergents and woven into performance athletic wear to combat foul smelling bacteria. Clay nanoparticles can make lighter, stronger, and more elastic composites and have been used in car bumpers. They also improve barrier properties and have been utilized in food packaging to increase shelf life.[7] In all, nanoparticles offer unmatched coating, strengthening, durability and other benefits due to manipulation at the molecular level.

Carbon is the most promising nanoparticle because of its versatility. It can bond with many other types of atoms, resulting in the enhancement of a variety of other materials ranging from wood to the cells within your own body. There are a multitude of particles that can be formed with carbon that affect the particles strength, durability and applicability including nanotubes, buckyballs, diamondoids, and one atom thick sheets called graphene. Graphene is one-sixth the weight of steel per unit of volume, but more than 100 times as strong making it the strongest material ever measured. It can be compressed or bent without fracturing and will return to its original shape. Additionally, it has 35 percent less electrical resistance than copper and ten times the conductivity of copper and aluminum making it ideal for use in electrical circuits. With these type of properties it's easy to get caught up in the hype, but carbon nanotubes are currently selling from $50-$700 per gram making it cost prohibitive for mass adoption. Within electronics, a 250 mm^2 single layer graphene square, used to replace silicon wafers, ranges from $264 to $819.[7] For comparison a 300mm^2 silicon wafer will cost anywhere between $50 and $400 per wafer.[10] Finally, graphene nanoplatelets, short stacks of graphene five to eight nanometers thick, are sold for about $220-$230 per kilogram.[7]

Nanotechnology is shaping the electronics industry as the appetite to move to ever smaller, more nimble and faster devices is never satiated. Quantum dots are a major driver of this innovation due to their ability to convert light from one color to another in an efficient manner. Quantum dots are currently fabricated out

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[9] http://www.dummies.com/education/science/nanotechnology/what-is-nanotechnology/

[10] http://www.semi.org/en/node/50856

of cadmium-based materials and are so small that the addition or removal of an electron allows beneficial properties to be observed.[11] This ability has led to a growing demand within quantum computing and device displays because of the ability to provide a full spectrum of pure colors at low energy levels as well as registering and emitting light to facilitate quantum computing. The quantum dot market is expected to grow from $2.57 billion in 2018 to $8.47 billion by 2023 representing a CAGR of 26.97%.[12]

POTENTIAL FOR ACCELERATION

Companies are perpetually looking to innovate and stay ahead of competitors. Nano-materials offer the penultimate in innovation as it represents the smallest scale with which to manipulate matter. Stated another way, it is the last available input that could be changed within manufacturing. This provides a target for companies racing to the limit of innovation to offer consumers arguably the most advanced product, indefinitely. A company could specifically look to leverage the strength-to-weight ratios, increased durability, non-stick, stain and bacteria-resistance properties just to name a few applications. These materials have a broad range of applications across many industries and are touted to have significant impact on almost all industries across all areas of society. Therefore, the potential for adoption increases as the possible opportunities increase.

The nanotechnology market has leveraged funding from both government and private sector entities, partnerships and strategic alliances between countries for research and development. The specialty manufacturing and healthcare sectors are poised for early adoption. Due to high capital intensive costs, advanced nanomaterials are likely to be used in drug-delivery methods evidenced by the “the limited quantities needed and willingness of consumers to pay for potentially life-saving treatments.”[7]

The large surface area and high reactivity of these particles could make them powerful diagnostic tools within the healthcare industry. Recently, there have been breakthroughs in the application of the diagnosis and treatment of chronic diseases like cancer, heart ailments and other tumorous growths. In 2013, there were 80 nano-based drugs in the development pipeline with 7 in Phase III clinical trials. Of the 80 drugs in the pipeline, 43 were for cancer treatments, or 54%.[7] Additionally, quantum dots are expected to assist in biological imaging, cellular labeling, DNA labeling and cancer diagnosis as they act as a light emitting sensor that can attach to specific tissue within the body.[12]

Using 5 to 10 percent of the 20 million new cancer cases expected in 2025 willing to be treated with nano-based therapies, the estimated potential impact of these drug delivery methods would be $150 to $500 billion annually. Based on current research, the future of nano-based therapy could significantly improve outcomes and reduce side effects for many patients. McKinsey estimates the value of improving life expectancy and quality to be around $130,000 to $230,000 per patient.[7]

As Moore’s Law begins to lose relevancy, the electronic industry is looking towards both nanotechnology and quantum dots to keep pace with the theory. Quantum dots have seen increasing demand especially in high-quality display devices, the rise of more energy efficient and less toxic products, and most notably, quantum computing.[12]

Graphene is the nanoparticle closest to mass adoption beyond other nanoparticles already in use. It is being produced today, but in limited quantities and at high cost. Further research is needed to bring down the cost effectiveness and large-scale manufacturing not only of graphene but all nano-materials. Researchers at Unversiti Sains Malaysia have announced significant advances in carbon nanotube production which they claim could reduce the price to $15-$35 per gram.[7] Already, Lockheed Martin has announced that the new F-35 fighter jet has used carbon nanotube reinforced polymer in structural non-load bearing parts based on improved manufacturing processes, which has reportedly reduced the production costs of the material by 90 percent.[7] Lockheed has turned down multiple requests regarding

[11] http://www.abnewswire.com/pressreleases/quantum-dot-market-2018-global-trend-segmentation-and-opportunities-forecast-to-2023_206756.html

[12] https://www.prnewswire.com/news-releases/the-quantum-dots-market-is-expected-to-reach-usd-8-47-billion-by-2023-from-usd-2-57-billion-in-2018--at-a-cagr-of-26-97-300656439.html

manufacturing details of the polymer other than that the process has evolved over the previous four years. Doing so insists it is an invaluable trade secret, laying the groundwork for future manufacturers to withhold, and therefore monetize, the same information. This breakthrough proves a significant technical application that produces an increase in durability and strength over existing carbon fiber reinforced plastic.

Specific signals that this technology is close to rapid adoption will be when manufacturing costs begins to move to a range between 20-30% over current materials. It is reasonable to assume at a certain price point companies will adopt the technology to offer superior products over its competitors. At this price range, it is implied that the increased sale value would offset increased costs based on providing a superior product over its competitors.

Samsung and IBM along with several large research companies have announced research and development of commercial applications of graphene, nanotubes and quantum dots as well demonstrating the potential value of these products.

BARRIERS

Advanced and nano-materials show peak capability and function within a lab setting, but it is important to remember that these materials cannot provide a growth platform unless there is both a clear application and customer base behind that application. The material must be inherently superior to upend the known technological and financial constraints as well as the supply-chain knowledge of the conventional material. The sector is notorious for capital-intensive research and, as such, attracts a high percentage of its overall funding from government grants.

This industry has come a long way since even a decade ago, but standardization and quality are not yet guaranteed in new areas such as additive or advanced manufacturing. For example, a review of 60 graphene products by the Graphene council "revealed that no one single material characteristic was shared by more than 75% of the products."[13] This underscores the importance of standardization that will need to be introduced to effectively market nanoparticles.

Financial constraints may be one of the toughest obstacles to overcome and they are often overlooked. As it relates to graphene, there is already significant global investment in silicon and incumbent entities will look to either improve existing products or ignore new materials before altering or abandoning silicon production assets. Further, manufacturing prices will have to plummet if the material is to ramp up as a substitute.

While many nano-based therapies are more efficient and less-toxic than their conventional counterparts, average cost-per-dose can range from 1-1,000 times higher. For example, the anticancer drug Doxorubicin ranges in price from about $62-162, but the nanoparticle containing competitor Doxil costs about $5,594. Due to the current inability to find a cost-effective method of scaling production, the cost of nano-based therapies is likely to remain high through 2023.[14]

With any new technology, accurate and comprehensive studies must be conducted to identify any environmental and health risks posed by these materials. So far, research suggests that nanomaterials exhibit a wide range of toxicity and environmental damage potential, while many remain untested.[7] As this industry continues to advance, policy makers and citizens will need to collaborate and create regulations guiding nanomaterial's use in medicine and other applications where the material is not encapsulated.

For all other advanced materials to deliver their full potential, perfecting both scalable and cost-effective production techniques will have to be developed which could take more than a decade. This will be essential to developing graphene, carbon nanotubes and quantum dots in high volumes. While many nanoparticles

[13] https://www.cbinsights.com/research/carbon-nanomaterials-industry-growth/

[14] https://www.mordorintelligence.com/industry-reports/healthcare-nanotechnology-nanomedicine-market

and other advanced materials have potentially high-impact applications, it remains far from clear whether most will be capable of driving significant impact by 2025.

OUTLOOK / IMPLICATIONS

Within the next decade, advanced and nano-materials will continue to attract considerable interest and research investment. The London Environmental Investment Forum states that “the world’s largest businesses require advanced material innovations if they are to stay at the top.”1 Particularly, business leaders within healthcare, manufacturing and electronics should consider how advanced materials can be used to create new products or make existing products better.

The manufacturing industry is already showing capabilities to produce carbon-based nanoparticles including nanotubes and graphene. Because of their wide-range of application, these composites will be an initial driver of nanoparticle adoption across different industries. Although the current graphene market is still maturing, it was projected by BBC Research to be around $123 million by 2017 and $987 million by 2022 with the largest demand being capacitors, structural materials and computing. In comparison they also estimated the global market for carbon nanotubes to reach $670 million by 2019. However, these markets have typically lagged behind estimates due to production capabilities.

It is expected that the use of nano-materials within the targeted cancer treatment category alone could generate an economic impact of $150-$500 billion annually by 2025.[6] This market size could create ample opportunities for healthcare technology and pharmaceutical companies. As functionality becomes more standardized within these materials, there is enormous application across a wide range of products.

As we move further into the digital era, quantum dots will see increased application as production capabilities mature and consumer electronics become smaller, faster and more malleable. Further, advanced manufacturing is providing the vehicle for advanced materials to be used in body-adapted wearable devices for self-monitoring, screen-less displays, and better batteries.[15] As robotics, transportation, clean-tech and healthcare come to the forefront, opportunities for the producers of advanced and nano-materials becomes apparent.

Large R&D conglomerates will initially dominate the space due to the upfront capital-intensive costs. It could prove beneficial to track companies that are spun off from research departments in an effort to streamline the manufacturing process of the nano-material. For other businesses looking to take advantage of this technology, the most logical application will be through a purchase or licensing agreement – where a company could build a business to take advantage of the specific nano-material being produced. This would most likely require an infusion of investment capital to begin building inventory and selling the product.

Not to be forgotten, there are large barriers to bringing this technology to everyday products including manufacturing at scale, cost effectiveness and regulatory implications. There are many unknowns within this industry, which has very a high potential to disrupt current business structures. Business leaders who take best advantage of the innovation through either investment or incubation of the technology will be better positioned for acquisition, licensing and partnership opportunities as well as securing the prospect for sustained long-term growth.

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[15] http://www3.weforum.org/docs/IP/2016/CH/WEF_CH_Industry_Vision_report_2016.pdf