Abstract

Harris & Harris Group, Inc. believes that the study and development of nanotechnology will improve product capabilities and manufacturing productivity. This process has already begun. In 2007, nanotechnology-enabled product sales amounted to $147 billion and it is estimated that by 2015, that number will increase to $3.1 trillion. Nanotechnology is a set of tools that is applicable to a broad set of industries. Hence, the market opportunity for nanotechnology-enabled solutions is large, diverse and growing. Nanotechnology improves product capabilities and manufacturing productivity because it permits the user to: 1) study and manipulate matter on the nanoscale, 2) harness properties derived from nanoscale phenomena, 3) manufacture products through additive techniques, and 4) design and optimize biological pathways using nanoscale approaches. Currently, Harris & Harris Group has a portfolio of 33 companies that are developing nanotechnology enabled products to address each of these core attributes. This article discusses the basis for Harris & Harris Group's thesis that nanotechnology will improve product capabilities and manufacturing productivity that will result in economic advantages for companies producing and integrating nanotechnology-enabled goods.

Key Words: investment, finance, breakthrough technologies
1. Historical Trends in the Advancement of Technology

The physical properties of products are defined generally by the materials that comprise them and the processes used to make them. Advances in materials and processes can yield improvements in the overall physical properties of a product. In some cases, a better understanding of the principles behind existing properties or the discovery of new properties can yield completely new product capabilities. We refer to these advances as technology revolutions, because they can lead to significant transitions in how consumers use products and in what consumers can accomplish with these new capabilities.

Often, technology revolutions result from the study, understanding and manipulation of materials at an increasingly smaller scale. Five historical examples of the transition to new technologies resulting in technology revolutions are discussed below.

A. Pure Copper to Bronze

In approximately 3000 BC, the transition to using an alloy, bronze, in place of other metals, such as gold, silver, iron and copper, enabled the fabrication of tools, weapons, armor and building materials that were more durable than their predecessors. A basic understanding of alloying metals, the manipulation of the crystal structure of a metal by mixing pure metals with different metals and non-metals, led to a new material. This alloy, bronze, was more durable and harder than the pure metal, copper. This new insight in materials science was the foundation for the Bronze Age.

B. Charcoal to Coke

Heating coal in the absence of oxygen produces coke. The use of coke instead of charcoal as the fuel for smelting, improved the quality of iron and steel converted from iron ore because coke contains less sulfur and produces less smoke than charcoal. The discovery of this fuel was a key element of the large-scale, widespread production of materials that were a part of the foundation for the Industrial Revolution.

C. Wood, Glass and Metals to Plastic

In the early 1900’s, the ability to manipulate the molecular structure of natural polymers (such as rubber) through vulcanization, and the ability to make synthetic polymers (such as nylon) were discovered. These discoveries enabled the rapid proliferation of polymers as a compliment or complete replacement for wood, glass and metals.

D. Classical Biology to Molecular Biology

The discovery of the molecular structure of deoxyribonucleic acid, or DNA, by Watson, Crick, Wilkins and Franklin, in the 1950s, enabled the understanding of how biology’s most important and influential polymer encodes and controls the function of all biological processes. This discovery was the foundation for modern biotechnology.
E. Vacuum Tubes to Semiconductors

The ability to control the flow of electrons in a vacuum enabled the creation of early computers. Increasing the scale of these early computers was difficult because of the size and poor reliability of vacuum tubes. These issues were overcome, in part, by the discovery in 1947, that electrons flowing through a semiconductor material such as silicon or germanium could be manipulated in a similar way to electrons in a vacuum tube albeit on a much smaller scale. The resulting devices were called transistors. Electronic circuits based on transistors use less energy, weigh less, are smaller and are far more reliable than those comprised of vacuum tubes. This materials-based discovery revolutionized modern electronics.

These examples of scientific advances enabled new capabilities and formed the basis for great wealth creation. These advances resulted from the ability to study, understand and manipulate materials at an increasingly smaller scale.

- **Macroscale** – The widespread use of bronze and steel was enabled by macroscale understandings of how to improve the physical properties of copper by alloying it with other metals and non-metals and the use of coke in smelting, respectively.

- **Molecular scale** – Semi-synthetic and synthetic polymers with improved properties were enabled by understanding the molecular scale components of polymers and by controlling how these molecules react with one another.

- **Molecular scale and nanoscale** – Modern biotechnology was enabled by understanding the atomic and molecular organization of DNA.

- **Nanoscale** – Modern electronic devices were enabled by understanding how electrons flow through and can be manipulated within semiconducting materials and by new techniques for nanoscale manufacturing.

2. Nanotechnology: The Next Technology Revolution

Harris & Harris Group believes that many new scientific and technical breakthroughs occur through understanding and manipulating matter at scales smaller than those that drove previous scientific and technical breakthroughs. This trend is the basis for our belief that the next significant transition in product capabilities will stem from understanding and manipulating matter on the nanoscale.

Nanotechnology as a field is not completely new. At the beginning of the 20th century, physicists began to understand the basics of the atomic structure of matter, and they discovered that matter at the atomic level behaved in ways that could not be described by classical Newtonian physics. This realization gave rise to the theory of quantum mechanics, or the concept that matter when studied on an atomic scale has properties of both matter and waves. For example, an electron has a defined mass, but the location of an electron can only be determined as a probability within an orbital path around the nucleus of the atom. This orbital path can be described as a wave function, but not by classical physics. The dominance of quantum mechanics at the nanoscale gives rise to new properties of materials that are enabling a new technology revolution; one that is based on nanotechnology.

We believe there are four important attributes of nanotechnology:
i. The ability to study and manipulate nanoscale phenomena and materials require different tools than those used at the macroscale.

ii. The properties of a material can be significantly different when studied and manipulated on the nanoscale versus the macroscale.

iii. The use of nanoscale materials and chemicals enables methods of additive manufacturing techniques that have important advantages over subtractive techniques.

iv. The ability to study, optimize and design biological pathways using nanoscale approaches enables the use of biology to produce new chemicals and to diagnose and treat disease.

As discussed below, these four attributes of nanotechnology have enabled important advances in product capabilities and manufacturing productivity in a number of industries including instrumentation, electronics and life sciences. Examples from our venture capital portfolio are used to illustrate these advances.

A. The Ability to Study and Manipulate Phenomena and Materials at the Nanoscale

The study and manipulation of nanoscale phenomena requires different tools than those used to study macroscopic phenomena. Traditional optical microscopes use visible light to image a specimen. Wavelengths of light that are visible to the human eye range from approximately 400 to 750 nm. The diffraction limit of light sets the minimum size of features that are able to be resolved by optical microscopy. The diffraction limit for visible wavelengths of light is approximately 200 nm. By comparison, the resolution required to image individual atoms is less than 1 nm. This limit, therefore, prevents optical microscopes from imaging nanoscale features and objects with high-resolution.

In 1981, Gerd Binnig and Heinrich Rohrer, two scientists from IBM Zurich, obtained the first images of individual atoms using the scanning tunneling microscope (STM). The STM allowed for the characterization of surfaces at the nanoscale, which provided more detail than previously possible. Although this Nobel-prize-winning tool was certainly a breakthrough technology, it is not very useful for manufacturing or high-throughput characterization of devices because it scans one atom at a time, which is very slow. Molecular Imprints and Xradia address the need for methods of manufacturing that are not bounded by the limits of diffraction and the need for methods of characterization able to scan large areas rapidly with nanoscale resolution, respectively.

i. Molecular Imprints, Inc.

Optical lithography is the most common technique used to produce patterns of materials and products used in the electronics and telecommunications industries. Each of these industries, particularly electronics, continues to reduce the size of the features that define key components such as the bits for data storage on a hard drive or the transistors in a computer chip. Alternative techniques for patterning are required since optical lithography suffers from the same limitations as optical microscopy (i.e., the limits of diffraction prevent fabrication of nanoscale features with dimensions of less than 20 nm).

Molecular Imprints is addressing this need by commercializing a technology called Step-and-Flash Imprint Lithography (S-FIL) (see Figure 1). S-FIL is conceptually very similar to the transferring of ink to a surface in a desired pattern using a stamp. Using this technique, a rigid plate
that contains the negative image of a desired pattern (e.g., the stamp) is placed into contact with a substrate.

**Figure 1 - Schematic Diagram of the S-FIL Process**

![Schematic Diagram of the S-FIL Process](image)

The resulting voids between the two surfaces are filled with a liquid material that cures under irradiation from ultraviolet light. The stamp is then removed to yield the material with the desired pattern. The minimum feature size attainable is not limited by diffraction because the features are defined by the stamp rather than light. The size of the area that can be patterned in one step is defined only by the size of the stamp, and the overall speed of the process is similar to that of optical lithography.

The hard disk drive market may be the first to adopt the S-FIL technology for high-volume manufacturing because next-generation hard disk drives require patterned magnetic materials with nanoscale dimensions that are not attainable with optical lithography. It is ultimately possible that S-FIL will be used in the manufacturing of CMOS-based electronic devices as that market progresses to feature sizes smaller than 22 nm in width (see Figure 2).
ii. Xradia, Inc.

Products comprised of materials with nanoscale dimensions require special tools to study them. Often, many of these approaches are destructive in nature (i.e., they require removal of layers of material and render the product unusable). X-rays can be used for non-destructive imaging of materials because X-rays can penetrate through many materials. However, X-rays are quite difficult to focus using standard refractive optics (e.g., glass lenses) because standard optics absorb X-rays and/or cannot affect the path of X-rays. Metal structures with nanoscale dimensions and high aspect ratios (height-to-width) (see Figure 3) are able to focus X-rays, but are very difficult to manufacture.14

Xradia has developed proprietary techniques for manufacturing X-ray optics that are the enabling components of a number of novel X-ray imaging tools.15 These tools are used for imaging materials and products at the nanoscale in several markets, including semiconductor, life science, and oil and gas industries. Xradia believes its tools are able to image samples with higher speed and resolution than alternative techniques.
B. The Properties of Materials Are Different at the Nanoscale

Stained glass art was common during the middle ages and artisans used a number of materials to color the glass. Specifically, gold was commonly used to color the glass red. This fact is potentially surprising because bulk gold appears metallic yellow rather than red. This difference in color is attributed to the size of the gold particles that were incorporated. Bulk gold is metallic yellow because the electrons are delocalized amongst all of the atoms in the lattice, thereby, allowing these electrons to absorb light over a broad range of frequencies. Gold nanoparticles contain fewer atoms than bulk gold. The reduction in the number of atoms prevents the electrons from roaming as freely as in bulk gold, and in fact, creates a sort of box in which the electrons are confined. This box defines the wavelengths of light that are absorbed and reflected by the electrons in gold nanoparticles. The red color of gold nanoparticles arises from this property that exists only at the nanoscale. This example also shows that it is possible to impart these nanoscale properties to a bulk material by incorporating nanoscale materials into another material such as a glass or plastic. Cambrios and SiOnyx are developing technologies that exploit these phenomena.

i. Cambrios Technology Corporation

Transparent conductors are used in applications such as solar cells, touch screens and flat-panel displays. The incumbent technology is based on thin films of ceramic materials made of transparent conductive oxides, particularly indium tin oxide (ITO). Although these ceramic materials have attractive properties for these applications, the raw materials are expensive, and the techniques used to deposit the films require large, expensive capital equipment. Any replacement for ITO technology requires similar or better transparency to light and conductivity of electrons. Bulk metals are good conductors, but are not transparent to visible light. Nanowires made of metal also conduct electricity well, but are transparent to visible light because of their diameter (less than 100 nm). Additionally, the incorporation of nanowires, into a bulk material can impart unique properties to the matrix.

Cambrios uses these properties of nanowires to create meshes of metallic nanowires embedded in a polymer film that serves as an alternative to indium tin oxide (ITO)-based transparent conductors. The nanowire-based mesh structure creates a conductive path for electrons through the matrix while allowing light to pass through the thin film. Additionally, these polymer-dispersed meshes can be coated onto flexible and rigid substrates using wet-coating processes rather than vacuum-deposition processes. Wet-coating processes are preferred in the electronics industry because the capital equipment and running costs are substantially less than those associated with vacuum-deposition processes. Cambrios’ approach is advantageous because the materials are less expensive than ITO, the polymer films are less fragile than those of transparent conductive oxides and the films can be manufactured using a wet coating manufacturing tool, including very high throughput roll-to-roll processes.

ii. SiOnyx, Inc.

A number of materials are used to absorb and convert light into electricity for power generation, light detection and imaging applications. The materials used in each application are chosen based on how well they absorb and convert the desired wavelengths of light to electricity. Cell phone cameras, for example, have a layer of silicon that absorbs visible light and converts it into electricity that is then used by a computer chip to create an image of the scene. Silicon is useful for these types of applications because it strongly absorbs visible light and it works in well-lit environments.
Imaging and detection in dark environments, however, is also of interest, particularly for security and surveillance-related applications.

Detection of infrared light is of interest to the telecommunications industry and the security and surveillance industry, which use infrared light for data transmission and night-vision imaging, respectively. Silicon does not work for these applications because it does not absorb infrared light. Instead, most of the devices used to detect infrared light require the use of expensive compound semiconductors such as indium gallium arsenide.20

SiOnyx is using a laser-based process to generate highly doped, nanocrystalline domains of silicon called Black Silicon.21 Black Silicon is a unique form of silicon because it 1) absorbs visible and infrared light (see Figure 4), 2) is able to convert light from each region of the spectrum into electricity at low voltage with higher efficiency than can standard silicon (see Figure 5), and 3) is comparable to expensive alternative materials. These properties are a direct result of the composition and morphology of the nanocrystalline domains created during the process. SiOnyx aims to use these properties to create low-cost, silicon-based photodetectors and image arrays that have the same or better performance as that of detectors and image arrays made of expensive compound semiconductor materials.

Black Silicon may also provide benefits to silicon-based solar cells. The sun emits approximately fifty percent of its energy in infrared light.22 This light is not converted to energy by standard silicon solar cells because silicon does not absorb the infrared light. SiOnyx is exploring the possibility that thin-film, Black Silicon-based solar cells may operate with higher efficiency than that of other thin-film silicon alternatives due to its ability to absorb infrared light.

Figure 4 - Schematic Diagram of Absorption of Light by Silicon and Black Silicon

[Diagram showing absorption of light by Silicon and Black Silicon]

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Figure 5 - Plot of Responsivity Versus Wavelength of Photodetectors

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C. Nanomaterials and Chemicals Enable Methods of Additive Manufacturing

The vast majority of manufacturing processes use subtractive approaches that take a bulk piece of material and remove portions of it to yield the desired product. Standard processes for making electronic devices, for example, start with silicon wafers that are subjected to a number of patterning steps, metal deposition, and etching that removes unwanted silicon and metal. The unwanted material is difficult, if not impossible, to recover, and therefore is disposed of as waste. Additionally, these traditional subtractive approaches 1) use substantial volumes of toxic and hazardous solvents, and 2) use large amounts of energy to power and operate the large and expensive equipment required to deposit, pattern, and etch the materials.

Conversely, additive manufacturing enables active materials to be deposited and patterned in a single step using low-cost printing technologies, such as ink-jet printing or roll-to-roll processing, or using simple molding technologies such as injection molding. The key enablers for additive manufacturing are nanoscale materials and chemicals that are designed at the atomic level to impart the desired properties to the final product. Additive manufacturing techniques are also used to combine one or more molecules into a final product for diverse uses such as industrial chemicals, pharmaceuticals and fuels. Typically these reactions will take place in solution in large drums and will produce not only the desired product, but also a number of by-products. Certain types of reactions are particularly troublesome due to the fact that the molecules that are reacting with one another can do so in a number of different ways. These issues decrease the level of performance of subtractive techniques, such as isolation and purification, which are required to produce meaningful quantities and purities of a desired product. Additive techniques for chemical synthesis
reduce or remove the need for such complex isolation and purification methodologies, and potentially open new opportunities in the synthesis of complex molecules.

Kovio, Ancora Pharmaceuticals and Ensemble Discovery are implementing additive processes to produce a variety of products from electronics to vaccines.

i.  **Kovio, Inc.**

Kovio is using silicon-based nanoinks to create electronic devices using standard printing technologies rather than expensive lithography technology. The company has demonstrated the first all-printed silicon-based transistor (see Figure 6). Kovio is in the process of commercializing radio-frequency identification tags that are made through printing-based, additive processing techniques. Kovio believes this additive approach will enable it to manufacture disposable intelligent devices such as RFID tags, electronic transportation tickets and library cards at significantly lower cost than is currently possible through standard subtractive manufacturing techniques.

![Figure 6 - Image of All-Printed Silicon Thin-Film Transistor](Image of All-Printed Silicon Thin-Film Transistor)

*Reprinted with permission from Kovio, Inc.*

ii.  **Ancora Pharmaceuticals, Inc.**

Carbohydrates are sugar molecules that play a significant role in biology by 1) storing and transporting energy, 2) composing structural components in both animals and plants, and 3) modulating physiological systems such as the immune system. Historically, the use of synthetically produced carbohydrates as therapeutics and vaccines was challenging due to the lengthy and complex syntheses required to make a single structure. These syntheses are complex because of the large number of ways each building block of these molecules can react with each other. These adverse reactions create by-products that are difficult to separate from the carbohydrate of interest.

Ancora is developing an additive synthesis technology that enables the rapid production of a defined complex carbohydrate structure from a limited set of versatile building blocks. The
company also uses a solid-phase technique that controls how the reactive groups interact at the nanoscale and thus this technique substantially reduces the quantities of by-products. In total, the technology enables the synthesis and production of carbohydrate molecules with purities and in quantities that are difficult or impossible to obtain through alternative techniques.

iii. Ensemble Discovery Corporation

Macrocycles are a class of molecules that are comprised of a ring of nine or more atoms. Biologically relevant molecules such as heme (the active site of hemoglobin), chlorophyll, vitamin B12 and vancomycin are all naturally produced macrocycles. Historically, scientists had difficulty making diverse sets of synthetic macrocycles because of the inability to control the ring-closure step in standard solution-phase chemistry. This ring-closure step is where a linear chain of atoms is closed on itself to form the ring. In many cases, the atoms on the chain can react to form rings other than the desired product, which results in a substantial number of by-products and reduces the overall efficiency of the process.

Ensemble Discovery is using DNA to control the additive manufacturing of macrocycles for the discovery of new therapeutic molecules. In DNA-programmed assembly (DPC), a reaction between two molecules occurs only when they are brought within nanoscale distances of one another as two strands of DNA hybridize, or match up, perfectly (see Figure 7). The type and sequence of reactions can be programmed by manipulating the DNA attached to the reacting molecules. Ensemble has used this technology to produce diverse libraries of pure macrocyclic compounds in greater number than is available through solution-phase or biologic techniques, and without the need for sophisticated methods of isolation and purification of the final products.

Figure 7 - Schematic Diagram of DNA-Programmed Chemistry

![Schematic Diagram of DNA-Programmed Chemistry](image)

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D. The Ability to Study, Optimize and Design Biological Pathways using Nanoscale Approaches

Organisms use nanoscale machines called enzymes to catalyze chemical reactions that are key drivers of biological pathways. Enzymes are a sub-set of proteins, and their properties are determined by the order of the amino acid building blocks used for their composition. The order of the amino acid building blocks is defined by the sequence of the portion of DNA that codes for how the protein is assembled. The discovery of the structure of DNA created the foundation for technological advances such as directed evolution, high-throughput screening, genetic engineering, and metabolic engineering. These technologies enabled scientists to design and produce proteins
and create new strains of organisms that have specific functions for a number of uses, ranging from new forms of therapeutics to the production of renewable fuels and industrial chemicals.

i. BioVex, Inc.

Viruses are nanoscale infectious agents that carry DNA or RNA inside of a protein coat.\textsuperscript{30} They are not complete organisms because they cannot replicate outside of a host cell. Viruses can destroy cells by replicating inside of the cell and then destroying either the cell by lysis or by rupturing of the cell membrane. This process releases the replicated virus enabling the infection of neighboring cells and the continuation of the replication cycle.

BioVex is applying this virus replication process to destroy cancer rather than normal cells by using a proprietary, genetically engineered version of the herpes simplex virus (HSV).\textsuperscript{31} The company's technology is built on a version of HSV from which the gene that encodes a particular protein was deleted. This protein is required for the growth of HSV in normal cells, but not for growth in tumor cells. The deletion of this gene makes the virus select only for tumor cells. In addition, the company has engineered the virus to produce a protein that facilitates a strong systemic response against tumor proteins by the human immune system. BioVex has validated this two-pronged approach to the destruction of cancer cells in mid-stage clinical trials where multiple patients have had their disease eradicated. BioVex also hopes the technology will be an effective therapy for other difficult to treat cancers.

3. Why Is Now the Time for Nanotechnology?

Our examples of transitional technologies that served as the foundation for technology revolutions from the Bronze Age to the foundation of modern electronics illustrate that the ability to study, understand and manipulate matter at increasingly smaller scales was a significant element of technological progress. These technology revolutions, however, did not occur overnight. For example, inventions resulting from classical Newtonian physics were part of the factors that enabled the industrial revolution that evolved during a period of nearly 200 years.\textsuperscript{32} Likewise, while we have already witnessed the introduction of new product capabilities and manufacturing productivity enabled by nanotechnology, we expect to witness even greater product capabilities, manufacturing productivity and economic advantage for companies producing nanotechnology enabled goods in the future.

It is possible to trace applications of nanotechnology to the late 1930s, with the invention of the electron microscope.\textsuperscript{33} This microscope was the first tool that enabled the visualization of the components of matter at scales below the limits of the diffraction of light. A number of subsequent advances in nanotechnology were also tools (e.g., STM) that allowed scientists to study nanoscale phenomena.\textsuperscript{34} Scientists then used these tools to study the properties of known nanomaterials such as metallic (e.g., gold, silver, and palladium) and mixed-metal-oxide (e.g., silica, zinc oxide, titanium dioxide and aluminum oxide) nanoparticles.\textsuperscript{35} By using these tools, scientists discovered the structure and composition of new nanomaterials including carbon spheres such as buckminsterfullerenes (1985),\textsuperscript{36} carbon nanotubes (1991),\textsuperscript{37} and graphene (2004).\textsuperscript{38} These nanomaterials proved to have unique properties that resulted from their nanoscale dimensions. The strength of a carbon nanotube, for example, is 1000 times greater than that of steel at one-sixth the weight.\textsuperscript{39} Additionally, carbon nanotubes can be conductive, semiconductive or insulating based on the organization of their carbon atoms.\textsuperscript{40}

The first applications and products that employed nanomaterials exploited only their mechanical and optical properties by incorporating them into a matrix as a filler material. One of the first applications, produced by a former portfolio company of Harris & Harris Group called
Nanophase, was the use of zinc oxide and titanium dioxide nanoparticles in a cream matrix for use as a transparent, colorless sunscreen.\textsuperscript{41} The nanoparticles of these materials absorb ultraviolet light, but do not scatter or absorb visible light due to their size; therefore, the cream appears colorless and transparent rather than the white color of traditional sunscreens.

Carbon nanotubes were also used as fillers in plastic car bumpers to facilitate painting by standard electrostatic painting techniques, and in step stools to give increased strength and rigidity with less weight to the end product.\textsuperscript{42} Early applications of nanotechnology accounted for approximately $147 billion in product sales in 2007.\textsuperscript{43} These early inventions inspired by the ability to see, manipulate and characterize materials on the nanoscale have occurred only over the past 25-30 years. Based on the timeline of previous technical revolutions, it is reasonable to assume that the coming decades will deliver nanotechnology enabled products that are increasingly complex. Lux Research, for example, estimates that the next wave of nanotechnology innovations will result in $3.1 trillion in products incorporating nanotechnology in 2015.\textsuperscript{44}

The commercial emergence of nanotechnology is just beginning and the required foundation (\textit{i.e.}, the tools and materials) is already in place. Companies positioned to lead this commercial emergence have the potential for economic advantage. Sales of nanotechnology enabled products will increase as the emergence of nanotechnology continues. As evidenced by the companies mentioned above, nanotechnology is broadly relevant to many market applications and has the potential to provide a different benefit to each one.

At this time, it is difficult to predict which market applications will be of highest value. Our approach to this uncertainty is to build a portfolio of companies that spans the diverse set of market opportunities for nanotechnology including cleantech, electronics, healthcare, photonics, and component materials. Although our investment portfolio is comprised of a diverse set of market opportunities, there are three attributes that are common among our portfolio companies:

1. \textbf{Experienced management.} While nanotechnology provides a competitive advantage necessary to gain traction for a product in a given market, superior management is paramount to the success of the company.

2. \textbf{Focus on High-Value Intermediates and/or End-Products.} While nanomaterials may impart beneficial properties to a final product, there is no nanotechnology industry in which to sell these materials. Therefore, to capture the value associated with the competitive advantage of nanotechnology, it is important to commercialize high-value intermediates or the end product.

3. \textbf{Intellectual Property.} A smart, well-protected portfolio of intellectual property is required to protect and assert a company’s position in the marketplace.

We believe these three attributes are essential for any company that is established to commercialize or integrate nanotechnology-enabled products.

\textbf{5. Conclusion}

Harris & Harris Group believes that the study and development of nanotechnology will improve product capabilities and manufacturing productivity. This process has already begun, with $147 billion in nanotechnology-enabled products sold in 2007, and an estimate of $3.1 trillion projected to be sold in 2015.\textsuperscript{45} The ability 1) to study and manipulate matter on the nanoscale, 2) to harness
properties derived from nanoscale phenomena, 3) to manufacture products through additive techniques, and 4) design and optimize biological pathways using nanoscale approaches, are core capabilities enabled by nanotechnology that can drive an increase in product capability and manufacturing productivity. The market opportunity for nanotechnology-enabled solutions is large, diverse and growing. Companies established to take advantage of nanotechnology based solutions will still rely on capable management and strong business fundamentals. Companies developing nanotechnology-enabled products and investors in these companies should be well positioned to profit from the emergence of nanotechnology.

ENDNOTES

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1 See Vere Gordon Childe, The Bronze Age (1963).


CMOS stands for complementary metal-oxide-semiconductor and is a class of design and manufacturing processes used to make a large number of electronic devices. See generally R. Jacob Baker, *CMOS: Circuit, Layout, Design & Simulation* (2nd ed.) (2007).


See generally Nassau, supra note 17.


Vancomycin is a macrolide antibiotic. See id.


30 See id.


34 See e.g., Chen, supra note 10.

35 See e.g., Nassau, supra note 17.

36 See e.g., Harold W. Kroto et al., C60: Buckminsterfullerene, 318 Nature 162 (1985).


40 See Iijima supra note 38.


43 See Katz, supra note 1.

44 See id.

45 See Katz, supra note 1.