Commercialization of Nanotechnology

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by
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Micronomics
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Introduction

Following the Internet boom and the dot-com bubble of the 1990s came the dawn of the new millennium and with it, a world ready for a new class of game-changing technologies. While not new, nanotechnology was just beginning to transition from laboratories to commercial applications. With this transition came a general optimism that “nanoscale phenomena hold the promise for fundamental new applications.” In 2001, the National Nanotechnology Initiative (NNI) was launched as a “long-term research and development (R&D) program [to coordinate between] 25 departments and independent agencies, including the National Science Foundation, the Department of Defense, the Department of Energy, the National Institutes of Health, the National Institute of Standards and Technology, and the National Aeronautical and Space Administration.” By 2005 it was reported “nanotechnology is burgeoning, poised to yield tremendous advances in many fields, from biology to information technology, from chemistry and physics to mechanical engineering and materials science… the nanotech revolution has not quite arrived.” It has been recognized that, “in a relatively short interval for an emerging technology, nanotechnology has made a significant economic impact in numerous sectors including semiconductor manufacturing, catalysts, medicine, agriculture, and energy production.” Indeed “in terms of socio-politico-economics, nanotechnology has a great overall impact and represents a global interest… it offers ways to create more, cheaper, smaller, lighter, faster, sustainable and innovative devices that can use less raw materials and energy.” However, as we approach the fifteenth year of the new millennium many nanotechnology developments “still occur close to the frontiers of research and to the limits of understanding of the properties of materials at the nanoscale.”

This article highlights several fundamental issues identified at a recent panel discussion held during the 2014 LES Annual Meeting in San Francisco where industry
participants shared insights into and experiences with commercializing nanotechnology and considered hurdles that must be overcome by firms in the growing field.

**Background**

Discoveries in nanotechnology have continued to increase as technologies have advanced and commercialization strategies have become better implemented. In 2013, for example, the number of patents issued under the nanotechnology classification, as defined by the U.S. Patent and Trademark Office (USPTO), was 1,130. In fact, the last eight years (2006-2013) have shown steady growth in the number of patents issued, with approximately 4x as many issued in 2013 as in 2006.8

![Figure 1](image_url)

*Figure 1*

**Annual Number of Patents Issued Within USPTO Nanotechnology Classification**

Source: USPTO data for Patent Classification 977

Throughout this growth, the United States has stood in the forefront of technological development. In fact, as can be seen from Figures 2 and 3 below, the
number of patents by the United States, already significantly more than other countries, increased substantially in that most recent decade.

Source:
Data as reported in Chen, Hsinchun, Roco, Mihail C., Son, Jaebong, Jiang, Shan, Larson, Catherine A., Gao, Qiang, “Global nanotechnology development from 1991 to 2012: patents, scientific publications, and effect of NSF funding,” Journal of Nanoparticle Research, August 30, 2013
A variety of industries manufacture products incorporating nanotechnology including biomedical devices, home appliances, batteries, industrial lubricants, computers, cameras, food and beverage, clothing, cosmetics, fashion and manufacturing.

To appropriately measure nanotechnology’s commercial successes it is essential to first define what it is exactly. The National Nanotechnology Institute defines nanotechnology as “the understanding and control of matter at dimensions between approximately 1 and 100 nanometers, where unique phenomena enable novel applications.” The United States Patent and Trademark Office (USPTO) applies a
similar definition of nanotechnology (Patent Classification 977) and further specifies more than 250 subclassifications including nanostructures with biological material component (subclass 702), carbon nanotubes (subclass 742), atomic force probe (subclass 863) and specified use of nanostructures for medical, immunological, body treatment, or diagnosis (subclass 904), gene therapy (subclass 916), dental (subclass 919) and carrying or transporting (subclass 963).

The following table illustrates other structures that exist at the same scale as nanotechnology:

<table>
<thead>
<tr>
<th>Item</th>
<th>Approximate Size in Nanometers</th>
</tr>
</thead>
<tbody>
<tr>
<td>One second of growth of human fingernail</td>
<td>1</td>
</tr>
<tr>
<td>10 hydrogen atoms lined up in a row</td>
<td>1</td>
</tr>
<tr>
<td>Carbon nanotube</td>
<td>1 to 1.5</td>
</tr>
<tr>
<td>DNA</td>
<td>2.5</td>
</tr>
<tr>
<td>Tobacco smoke</td>
<td>10</td>
</tr>
<tr>
<td>Airborne virus particle</td>
<td>50</td>
</tr>
<tr>
<td>Transistor on advanced computer chip</td>
<td>100</td>
</tr>
<tr>
<td>Biggest particle that can pass through a surgical mask</td>
<td>100</td>
</tr>
<tr>
<td>Ebola Virus</td>
<td>100</td>
</tr>
<tr>
<td>HIV Virus</td>
<td>100-120</td>
</tr>
</tbody>
</table>

Under the above definition, size and application are essential determinants as to what constitutes nanotechnology. \(^{10}\) As a result, when trying to determine the effectiveness of commercialization strategies, it is important to be weary of the potential for over inclusion and misspecification so that only true nanotechnologies are considered. This concern recently was highlighted at the International Symposium on Assessing the Economic Impact of Nanotechnology held in Washington DC:

While operational definitions are developed at national or regional levels, e.g. for statistical or regulatory purposes, there are relatively few internationally agreed upon definitions or classifications for nanotechnology or its products and processes. Such definitions are essential for developing a methodology for an economic impact assessment and/or to facilitate data collection.\(^{11}\)
Commercialization Strategies

There are two basic commercialization strategies for nanotechnology - product innovation or process innovation.\textsuperscript{12}

\textit{Product Innovation}

Changes and advances in nanotechnology have resulted in commercial successes in a variety of different industries. In most instances, nanotechnology is used to facilitate a product innovation, often in response to anticipated and/or actual demand for specific product characteristics. For example, “a tennis racket made from a composite material which includes CNTs to improve its mechanical properties is an attempt to create a differentiated and improved product to gain market share”\textsuperscript{13} or a nanofiber that, when used in conjunction with other materials, yields stronger and lighter bicycle frames. In these example, much like real life, nanotechnology is use to augment current technologies to enhance products and/or processes which already exists. Indeed, considered in this light, it often is easier to identify nanotechnology as a process rather than a product.\textsuperscript{14}

Nanotechnology provides the means by which a desired characteristic can be achieved within a product market that already exists. In such cases, the use of nanotechnology becomes almost an incremental decision – one that allows for the achievement of a requisite characteristic already valued by the market.\textsuperscript{15} The numerous other characteristics also included in the technology also are valued and thus the potential for royalty stacking comes into play.

\textit{Process Innovation}

By contrast, process innovations are more embedded, but potentially more radical.\textsuperscript{16} These tend to be much broader, focusing on developing new technologies and thus new markets. For example, consider a hypothetical self-repairing nanomachine in which demand is driven by the entirety of the product.

\textbf{Funding}

Research and development spending and commercialization costs represent significant barriers to entry for firms wanting to enter the nanotechnology market. Development and manufacturing of equipment can be cost prohibitive for firms with limited access to capital. Further, it also is necessary to develop and maintain sufficient levels of human capital.
As with most other industries, access to capital markets for funding is vital to success. For nanotechnology, the single largest share of investment funds comes from corporations. In 2010, worldwide corporate funding amounted to approximately $9 billion while the second largest share of investment funds, federal funding, was just over $1 billion.17

Table 2

Top 20 Assignees of Nanotechnology Patents

<table>
<thead>
<tr>
<th></th>
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<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1) International Business Machines Corporation</td>
<td>190</td>
<td>622</td>
<td>307</td>
<td>1,119</td>
</tr>
<tr>
<td>2) Micron Technology, Inc.</td>
<td>43</td>
<td>555</td>
<td>164</td>
<td>762</td>
</tr>
<tr>
<td>3) Samsung Electronics Co., Ltd.</td>
<td>13</td>
<td>380</td>
<td>288</td>
<td>681</td>
</tr>
<tr>
<td>4) The Regents of the University of California Hewlett-Packard Development Company, L.P.</td>
<td>120</td>
<td>349</td>
<td>120</td>
<td>589</td>
</tr>
<tr>
<td>5) Xerox Corporation</td>
<td>24</td>
<td>429</td>
<td>104</td>
<td>557</td>
</tr>
<tr>
<td>6) Hon Hai Precision Industry Co., Ltd.</td>
<td>138</td>
<td>259</td>
<td>141</td>
<td>538</td>
</tr>
<tr>
<td>7) Intel Corporation</td>
<td>0</td>
<td>250</td>
<td>258</td>
<td>508</td>
</tr>
<tr>
<td>8) General Electric Company</td>
<td>17</td>
<td>395</td>
<td>89</td>
<td>501</td>
</tr>
<tr>
<td>9) 3M Innovative Properties Company</td>
<td>49</td>
<td>297</td>
<td>87</td>
<td>433</td>
</tr>
<tr>
<td>10) Massachusetts Institute of Technology</td>
<td>21</td>
<td>261</td>
<td>94</td>
<td>376</td>
</tr>
<tr>
<td>11) Industrial Technology Research Institute</td>
<td>42</td>
<td>195</td>
<td>76</td>
<td>313</td>
</tr>
<tr>
<td>12) Eastman Kodak Company</td>
<td>15</td>
<td>228</td>
<td>68</td>
<td>311</td>
</tr>
<tr>
<td>13) E.I. du Pont de Nemours and Company</td>
<td>81</td>
<td>190</td>
<td>22</td>
<td>293</td>
</tr>
<tr>
<td>14) Advanced Micro Devices, Inc</td>
<td>39</td>
<td>148</td>
<td>80</td>
<td>267</td>
</tr>
<tr>
<td>15) Kabushiki Kaisha Toshiba</td>
<td>34</td>
<td>204</td>
<td>9</td>
<td>247</td>
</tr>
<tr>
<td>16) Motorola Inc</td>
<td>91</td>
<td>103</td>
<td>0</td>
<td>194</td>
</tr>
<tr>
<td>17) L’Oreal, SA</td>
<td>65</td>
<td>118</td>
<td>5</td>
<td>188</td>
</tr>
<tr>
<td>18) NEC Industries Ohio, Inc.</td>
<td>56</td>
<td>99</td>
<td>23</td>
<td>178</td>
</tr>
<tr>
<td>19) NEC Electronics Corporation</td>
<td>75</td>
<td>84</td>
<td>16</td>
<td>175</td>
</tr>
<tr>
<td>Total</td>
<td>1,150</td>
<td>5,289</td>
<td>2,002</td>
<td>8,441</td>
</tr>
</tbody>
</table>

Source:
Data as reported in Chen, Hsinchun, Roco, Mihail C., Son, Jaebong, Jiang, Shan, Larson, Catherine A., Gao, Qiang. “Global nanotechnology development from 1991 to 2012: patents, scientific publications, and effect of NSF funding,” Journal of Nanoparticle Research, August 30, 2013

Corporate funding can be either in the form of product or process innovation. Product innovations valued within markets such as improved strength, stain resistance,
reduced weight tend to be more immediate and subject to market demands. As such, investors must consider short and long term costs associated with nanotechnology compared to expected value added. Additionally, investors must recognize roles of other technologies used in conjunction with funded nanotechnology requiring additional royalty payments.\textsuperscript{18} Conversely, process innovations typically have longer time frames, higher costs, risk and greater uncertainty with respect to market demand. Indeed, the highly technical nature and uncertainty of process innovations must anticipate and overcome concerns including whether “the basic principles causing an observed behaviour (sic) are sufficiently well understood”\textsuperscript{19} or if “sufficient control over the properties of a material to ensure that desired behavior (sic) can be replicated at larger volumes.”\textsuperscript{20}

The ability of corporations to absorb costs and manage risks over longer time periods allows for funding of process innovations.

Process innovations are more suitable for funding by corporate investment, both because expected payback times can be longer, but also because the value from process innovation can be captured in ways – such as reduced manufacturing costs leading to higher profits – which don’t lend themselves to spectacular revenue growth.\textsuperscript{21}

While the government’s role cannot be overlooked (the cumulative total of federal funding since 2001 is $21 billion),\textsuperscript{22} the majority of these government funds are targeted for research and development and/or process innovation within a variety of different agencies including National Institute of Health, National Science Foundation, Department of Energy, Department of Defense and National Institute of Standards and Technology.\textsuperscript{23}

Results show that dedicated NSF funding used to support nanotechnology R&D was followed by an increased number of relevant patents and scientific publications, a greater diversity of technology topics, and a significant increase of citations.\textsuperscript{24}

With government funding, less emphasis is placed on commercial viability and rates of return compared to commercial funding where investments in commercialization are much larger.\textsuperscript{25}

Funding through venture capital accounts for just 4\% of overall nanotechnology funding.\textsuperscript{26} This is due to significant levels of market uncertainty associated with the
prohibitively long commercialization schedules of newly-developing technologies. Venture capital funds require return over specific time periods, often 24 to 36 months. This often precludes investments in nanotechnology firms in the development and/or early commercialization stages. Additionally, there are few exit strategies acceptable to VCs. It has been noted:

One of the major factors affecting the level of investment is the shortage of cases in which investments have been successfully exited. There have been very few IPOs in nanotechnology – the most important nanotechnology IPO of last five years was the floatation of battery manufacturer A123 Systems, though this failed to inspire other IPOs, and the subsequent poor performance of A123 Systems’ stock is likely to dissuade other firms from going to market.27

Successful Commercialization of nanotechnology

The nanotechnology segment with the largest commercial growth has been carbon nanotubes (CNT) which are seamless graphene cylinders consisting of either a single wall of atoms (SWNT) or multiwalls (MWNT) with diameters of .8 – 2 nm (SWNT) and 5 – 20 nm (MWNT).28 In flawless CNTs, carbon bonds take a hexagonal lattice pattern whereas mass produced CNTs can include bonds that are pentagonal or heptagonal. Factors differentiating CNT include processing methodology, size and diameter, orientation of graphene lattice and thermal conductivity.29

These carbon nanotubes have been described as “one of the most important classes of nanomaterials, having enormous potential to spark off the next industrial revolution.”30 Currently, carbon nanotubes account for a 28% market share of overall nanomaterials demand. In terms of production capacity, Asia Pacific leads, followed by North America and the European Union.31 Yet despite accounting for more than a quarter of all nanotechnology products, the market for CNT is still developing.32 For example, global sales for CNT were estimated to be $650 million in 2010 and were expected to grow to over $1 billion by 2016.33 Similarly, the estimated number of firms manufacturing CNT in 2011, approximately 100 companies worldwide, is expected to double by 2016.34

CNTs are a product innovation, typically used as a manufacturing component in conjunction with other materials or technologies. They provide measurable benefits

(e.g., reduced weight, improved strength, higher conductivity) valued by end user purchasers.\textsuperscript{35}

**Conclusion**

The potential for broader use nanotechnology continues to grow in conjunction with improved technology and better understanding of the sciences. Most commercial successes have involved use of CNT, in conjunction with other materials and/or technologies, to enhance specific characteristics and thereby improve existing products. As such, nanotechnology is often used in response to specific needs understood and defined within recognized product markets.

Conversely, nanotechnology process innovations are inherently more complex and carry substantially more risk and uncertainty. Funding requirements are significantly larger and depend on longer term commitments of cash flows. It follows that successful process innovations likely will dramatically alter existing markets or establish new ones altogether.

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\textsuperscript{1} For example, in 1985 Harold Kroto, Sean O’Brien, Robert Curl, and Richard Smalley discovered the carbon buckyball (Buckminsterfullerene (C60)) which later won the team the “1996 Nobel Prize in Chemistry for their roles in this discovery.” Also in 1985, Louis Brus discovered quantum dots (colloidal semiconductor nanocrystals) for which he later shared the 2008 Kavli Prize in Nanotechnology. (See, Nanotechnology Timeline, the National Nanotechnology Initiative, http://www.nano.gov/timeline.


\textsuperscript{3} Ibid.


As per the National Nanotechnology Initiative (NNI), see for example, Synthesis Report, International Symposium on Assessing the Economic Impact of Nanotechnology, Organisation (sic) for Economic Co-Operation and Development (OECD) and National Nanotechnology Initiative, March 27-28, 2012. This definition is consistent with the USPTO classification for nanotechnology.

Much like classifying software engineering and online commerce under the general term electronics, use of nanotechnology as such an overly broad descriptor can result in unnecessary confusion especially by the uninitiated.


Crawley, Koponen, Tolvas, and Marttila, “Background Paper 2: Finance and Investor Models in Nanotechnology.”

This is very similar to the overly broad concept of the Internet which exists as the means by which specific products such as cloud storage, online advertising, streaming video, etc. are available. The question then becomes whether the differentiation associated with the use of nanotechnology is sufficient to charge a price that justifies costs of using nanotechnology.

Crawley, Koponen, Tolvas, and Marttila, “Background Paper 2: Finance and Investor Models in Nanotechnology.”

This is commonly referred to as royalty stacking and is simply the aggregation of all royalty rates necessary to produce a single finished product.

Crawley, Koponen, Tolvas, and Marttila, “Background Paper 2: Finance and Investor Models in Nanotechnology.”


Crawley, Koponen, Tolvas, and Marttila, “Background Paper 2: Finance and Investor Models in Nanotechnology.”


Author

Nels Pearsall, a Director at Micrometrix, has more than 25 years experience as a testifying expert and economic consultant, including on matters involving valuations of intangible assets such as patents, trademarks, copyrights, and trade secrets. He has been retained in matters involving economic damages based on applications of lost profits, royalty rates, price erosion, and overall changes in IP asset values. He has also analyzed changes in IP values as a result of the introduction and/or existence of substitute products, alternative licensing arrangement, industry royalty rates, and other market factors.
Acknowledgements

Micronomics is an economic research and consulting firm located in Los Angeles, California. Founded in 1988, it specializes in the collection, tabulation, and analysis of various types of economic, financial and statistical data. Areas of expertise include industrial organization, antitrust, intellectual property, the calculation of economic damages, and employment issues. Industries studied include banking and financial services, computer hardware and software, entertainment, healthcare, insurance, medical products and devices, motion pictures, oil and gas, pharmaceuticals, semiconductors, sports, supermarkets, telecommunications and tobacco. Clients include law firms, publicly and privately held businesses and government agencies.

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