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NANOMICS: THE ECONOMICS OF NANOTECHNOLOGY AND THE PENNSYLVANIA INITIATIVE FOR NANOTECHNOLOGY*

Thomas O. Armstrong
Pennsylvania Department of Community and Economic Development

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ABSTRACT

The economics of nanotechnology or nanomics considers the manipulation of matter at 1 to 100 nanometers yielding unique physical, chemical and biological properties, and when combined with existing products, additional characteristics occur. Therefore, consumer demand becomes a demand for characteristics within nano-enabled products. Pennsylvania seeks to exploit this potential nano-enabled demand and consequently greater economic development by introducing the Pennsylvania Initiative for Nanotechnology (PIN) in 2005. PIN provides financial resources through university and industry partnerships to increase (1) commercialization of nanotechnology applications and processes through collaboration, (2) technology transfer and enhanced university-based resources and skills, and (3) consortia-driven education and workforce development programs. The total economic impact of PIN upon Pennsylvania ranges from $721.5 million to $868.6 million which may yield up to a return of $10.79 or $13.00 for each state dollar invested. Pennsylvania is projected to produce a range of nanotechnology products from the conservative $1.16 billion in 2010 to $7.7 billion by 2015 or an optimistic $21.03 billion by 2014.

INTRODUCTION

Technology-based economic development (TBED) strategies have become a greater priority among states over the last decade so as to enhance economic development (Douglass, 2006; Geiger and Sa', 2005). Strategies include a range of policy instruments with explicit recognition that institutions of higher education are a key component of any TBED strategy for generating intellectual property to commercialization potential (Armstrong, et al., 2007; CEO Council for Growth, October 2007; Resource Guide, 2006). One area of policy importance is in the nanotechnology development involving government, university and industry partners.

From the 2006 American Society for Testing and Materials internationally recognized definition: "Nanotechnology refers to a wide range of technologies that measure, manipulate, or incorporate materials and/or features with at least one dimension between approximately 1 and 100 nanometers (nm). Such applications exploit the properties, distinct from individual atoms or bulk/macroscopic systems, of nanoscale components."

Nanotechnology's distinguishing feature is the manipulation of atoms and molecules at the nanoscale where unique characteristics occur within chemical and biochemical reactions, electronics, magnetic, thermal and optical behavior, mechanical strength and biological properties

(Pourrezaei, et. al., 2007). These unique characteristics embedded within existing products provide a set of nano-enabled product characteristics demanded by consumers.

These nano-enabled characteristics or hedonics demanded by consumers possess measurable attributes between a given quantity of a product and its technical characteristics where individuals possess preferences for collections of these characteristics (Eastwood, Brooker, and Terry, December 1986). Product preferences are valued because they provide the characteristics sought by consumers.

It is expected that these nano-enabled product characteristics will have a higher demand relative to products without nanotechnology characteristics. As a result greater production is sought with nano-integrated or nano-joint production techniques. Nanotechnology will continue to have an enormous impact in medical and life sciences, computers, industrial process control, energy, environment, electronics, telecommunications, structural materials, defense (Pourrezaei, et. al., 2007). It is expected that sustainable economic development of a region and state is enhanced where university and industry nano-joint research and production occurs to satisfy consumer demand.

The next section of this paper provides a summary of the economics of embedding nano-enabled characteristics within existing product attributes. Consumer choice will determine the value or marginal utility; henceforth, greater demand for the nano-enabled characteristics. The paper then discusses the Pennsylvania Initiative for Nanotechnology (PIN). PIN provides resources for university nanotechnology infrastructures where nanotechnology research can lead to commercialized improved products with a greater likelihood of these nano-enabled products produced in Pennsylvania. Lastly, the conclusion links greater resources through the PIN initiative for nano-enabled characteristic products leading to higher consumer demand resulting in the likelihood of greater economic development.

NANOMICS: THE ECONOMICS OF NANOTECHNOLOGY

The traditional analysis of consumer demand considers at its core a product generating utility. Consumer preference choices occur among a market of goods given their respective prices and a budget constraint. This type of analysis, though, lacks an understanding of the inherent attributes of a product and its impact upon demand. An alternative approach, initially developed by Lancaster (1966 and 1971), considers a product possessing characteristics or attributes generating utility where consumer choices now occur among a bundle of attributes given their respective prices and a budget constraint.

For example a demand for baseball bats is not only a function of prices of bats but the attributes within a bat. An attribute now used in some metallic bats is carbon nanotubes (CNTs). CNTs are at least 100 times stronger than steel, but only one-sixth as heavy. The result is carbon nanotube fibers strengthen just about any material as in nano-enabled bats. Product characteristics including a nano-enabled CNT characteristic may be an important determinant in consumer choice for bats.

Consumer valuation of a product characteristic is analyzed through hedonic demand functions. A hedonic function is a relationship between an implicit hedonic price of a characteristic and the quantities of the characteristics contained:[1]

$$P = h(c) \qquad (1)$$

P is an n-element vector of prices and (c) is a kxn matrix of characteristics. The marginal implicit price paid for a characteristic is the marginal valuation the consumer has for an incremental unit of the characteristic. Nano-enabled characteristics are the application at the nanoscale between 1 and 100 nm. At this scale, properties of many materials display a unique set of characteristics for two main reasons: relative increased surface area and quantum effects. As a particle decreases in size, a greater portion of the atoms are found at the surface compared to those inside. For example, a particle of size 30 nm has 5% of its atoms on the surface while at 3 nm; there are 50% of its atoms on the surface. This can make materials more chemically reactive at the surface relative to the same mass of material consisting of larger particles, and can affect their strength and electrical properties.

In conjunction with the surface area effects, the quantum effects begin to dominate the properties of materials as size is reduced to the nanoscale. This can affect the optical, electrical and magnetic behavior of materials especially as a particle size approaches the smaller end of the nanoscale. Thus with the combined quantum mechanical effects, materials may become more conducting, transfer heat better or other modified mechanical properties relative to properties of individual atoms or bulk materials. When nanoscale materials or characteristics are placed within macroscopic products, nano-enabled products are enhanced.

Nano-enabled consumer products are provided in an on-line inventory by the Woodrow Wilson International Center for Scholars and the PEW Charitable Trusts Nanotechnology Project.[2,3] There are 279 materials referenced in the nanotechnology consumer products listings for October 2, 2007. The Project mentions silver as the most common material or characteristic at 49.8% of all listings. "Carbon, which includes fullerenes, is the second most referenced (15.8%), followed by zinc including zinc oxide (10%) and titanium including titanium dioxide (10%), silica (9.7%), and gold (4.7%)." Some additional nano-enabled product characteristics and applications are the following:[4]

- **Carbon Nanotubes:** CNTs are extended tubes of rolled graphene sheets. In addition to the strengthen characteristics, CNTs can conduct heat better than silicon, and conduct electricity far better than copper. They are already being used in polymers to control or enhance conductivity, and are being incorporated into antistatic packaging.
- **Nanoparticles:** Nanoparticles (generally less than 100nm in diameter) have greater surface-to-volume ratios, increasing the efficiency of surface catalysis. They exist widely in the natural world such as products of petrochemical and volcanic activity, and are created by plants and algae. Nanoparticles can be metallic, mineral, polymer-based or a combination of materials. They have multiple uses including drug delivery mechanisms, dyes, sunscreens, and filters.
- **Nanowires:** Nanowires are extremely narrow threads (less than 50 nm wide) or linear arrays of dots, formed by self-assembly, with unique electrical and optical properties. They can be made from a wide range of materials such as silicon or gallium nitride. They have the potential to be used in nanoscale electrical devices such as electronic chips. In biology, they have the potential to form the heart of extremely sensitive biosensors, identifying molecules associated with disease or the binding of chemicals to a drug target.
- **Cosmetic Applications:** Nano-titanium dioxide and zinc oxide can absorb and reflect UV light in tandem to being transparent to visible light that are currently used in sunscreens. New products are under development, such as cosmetics that slowly release vitamins.
- **Energy Applications:** Some of the most advanced nanotechnology projects related to energy are: storage, conversion, energy saving by better thermal insulation and enhanced renewable energy sources. Nanotechnology could further increase the efficiency of light conversion by using nanostructures with continuum bandgaps for use of solar cells. These high efficiency fuel cells could include hydrogen storage in nanotubes.
- **Computer Applications:** Smaller computers that are more powerful, in part due to nanoscale transistors becoming smaller will provide, for example, advancing security,

breaking current encryptions, better simulations to predict natural disasters, and identifying based on personal features or biometrics.

- **Environmental Applications:** There are environmental concerns about nanoparticles, but nanoparticles could also play an important role in protecting the environment. A typical application would be based on a column containing nanoparticles that bond to a particular containment. As water passes through the column, the contaminant, such as chlorinated hydrocarbons, would be absorbed into the nanoparticles. The nanoparticles then could be retrieved and the contaminant washed out.
- **Defense Applications:** Nanotechnology can significantly improve many materials, products and systems for the military. The improvements include new protective soldier uniforms, stronger and lighter weight airframe structures, enhanced munitions, improved armor protection vehicles, and enhanced corrosion protection for ships.
- **Medical Applications:** Nanotechnology will help the development of tissue-engineered body parts, prolong life, improve its quality and extend human physical capabilities. For example, nanocrystalline zirconium oxide is a hard, wear resistant, bio-corrosion resistant and bio-compatible that presents and alternative material for medical implants made of titanium and stainless steel alloys. Currently on the market are wound dressings that exploit the antimicrobial properties of nanocrystalline silver. Nanoparticles could be used as vehicles for gene and drug delivery, such as a cancer delivery treatment to destroy diseased cells only. Nanoscale polymers are used in biocompatible tissue-engineering and implant market.
- **Manufacturing Applications:** Materials with high performance, unique properties and functions will be produced that traditional chemistry cannot create. Some of the benefits that nanostructuring can bring include: lighter, stronger, and programmable materials; reductions in life-cycle costs through lower failure rates; innovative devices based on new principles and architectures; and use of molecular/cluster manufacturing, which takes advantage of assembly at the nanoscale level for a given purpose.

The characteristic demand analysis considers the price of a good, such as in a liquid sunscreen protection product, equals the total expenditure on the sunscreen characteristics and the nano-enabled characteristics when the sunscreen is bought. Total expenditure on characteristics equals the summation of characteristic prices times characteristics quantities, if the characteristic function is linear; and a more complex function otherwise.[5] For example, the implicit price of reflecting harmful UV light is associated with the amount of nano-zinc oxide in a measurable liquid volume of sunscreen. Now hedonic prices are prices and quantities of characteristics where the price of a good is the aggregation equaling total expenditure on characteristics.

The consumer's utility function, Q, can be written:

$$Q = Q(c,M) \qquad (2)$$

where one heterogeneous good (written for simplicity) with characteristics c, and M is a vector of other homogenous goods.[6] Consumer's utility or level of satisfaction is a function of input characteristics and quantities of goods.

The consumer decides how much to spend on an nano-enabled product, such a sunscreen, meaning how much budgetary income should be allocated to expenditures on sunscreen or other nano-enabled products relative to how much should be spent on other products including sunscreen that is not nano-enabled.

The result is a set of consumer demands dependent upon characteristic prices and characteristics of products including income.

$$X = X(P(h(c)), M, I) \quad (3)$$

where I is budgetary income. Of importance in equation (3) is that the purchase of product can vary if a firm can vary or add at least one characteristic including a nano-enabled characteristic.[7]

Now a firm's purchase of inputs is similar to a consumer purchasing consumption goods. Thus, equation (2) can be interpreted as a production function for output, Q, which has heterogeneous inputs with characteristics (c), and other homogenous inputs, M.

Attributing equation (2) to nanotechnologies contribution to production, nano-enabled characteristics of a product can be considered as investment or capital goods as an input into the production process. Advances in nanotools involve analysis instrumentation, characterization and lithography. These advances enabled nanofabrication producing quality and scalable nanomaterials including nanotubes, nanoparticles and nanowires, while in the early stage, are contributing into a value-added stage of production or joint production to a final nano-enabled product (Kennedy, March 2007; Mid-Atlantic Nanotechnology Alliance, October 2006).

A critical investment into the production process is investment in human capital. Equation (1) can be considered a hedonic wage equation with wage rates on the left side and human capital characteristics from equation (1) appear in equation (2). A skilled workforce with nano-enabled skills such as clean-room technicians with the ability to use nanofabrication facilities would be a complementarily worker characteristic into a production process.

Now outputs with nano-enabled characteristics are produced from an initial start-up firm or from an existing firm with licensed nano-technology. Discovery of emerging nano-technology applications tend to begin at the research universities with proto-type to commercialization stages developed with industry partners or university/industry spin-outs.

Now, the production of an output is the joint production of a bundle of characteristics:

$$t(c,K,L,MA) = 0 \quad (4)$$

The production transformation function for equation (4) states that the output of a nano-enabled product is measured by the quantities of the characteristics produced, c, with standard inputs of capital, K, labor, L, and materials, MA.

A price taking firm or producer selects the optimal varieties to sell given equations (1) and (3). The result is firms will select the optimal combination of characteristics where relative marginal costs of characteristics equal incremental revenue from them. Thus different firms will produce different products with different characteristics including nano-enabled characteristics.

Products with nano-enabled characteristics that increase satisfaction or utility for consumers will provide sustainable economic development for a region through value-added production to meet the consumer demand. The critical economic problem around technology-based economic development, concerns the critical role of industry research and development, R&D (Geiger and Sa', 2005). Firms tend to under-invest in R&D due to uncertainty of long-run returns on investment for basic research and results may be difficult to appropriate for any one firm.

In addition, there are specific problems with firms engaging in nanotechnology production and commercialization as follows (Booker and Boysen, 2005; Maynard, July 2006; Mid-Atlantic Nanotechnology Alliance, October 2006; Murdock, et. al., 2005):

- Cost of nanotechnology equipment is too expensive where an individual, small business or an academic institution cannot justify the costs relative to expected limited usage

- Cost and quality of nanomaterials may not have reached industry standards for replicability
- Lack of early stage private investment due to uncertainty of returns of nano-enabled products by nanotechnology start-up companies
- The availability of specialized support services
- Regulatory guideline uncertainties increases costs
- Intellectual property issues where overlapping intellectual property patents raises litigation uncertainty
- Need for analytical tools to evaluate both product quality and environmental, health and safety issues
- Lack of nano-trained workforce including institutions of higher education course development and articulation agreements to meet the workforce needs[8]
- General lack of understanding of nanotechnology's potential

The problems listed above provide for an economic rationale for government subsidies of nanotechnology economic development so as to lower research costs, increase industry participation, stimulate technology transfer, and assist firms who want commercialize nanotechnology discoveries (see Armstrong, et. al., 2007 for university economic development rationale).

Pennsylvania recognized the possible sub-optimal investment in the state's nanotechnology. If so, the consequences to the state is relatively less nano-enabled products brought to market. Consumers can not optimally increase their satisfaction or utility for greater nano-enabled products. Consequently, nanotechnology economic development is less than its potential. Nanotechnology investments by the Commonwealth during the late 1990's and early 2000's culminating in the Pennsylvania Initiative for Nanotechnology in 2005 continues to provide strategic direction and resources for the goal of greater economic development.

PENNSYLVAINA INITIATIVE FOR NANOTECHNOLOGY

Pennsylvania launched the Pennsylvania Initiative for Nanotechnology (PIN) after the release of the Department of Community and Economic Development's (DCED) whitepaper on the *Pennsylvania Initiative for Nanotechnology* (2005) based on the ANGLE Report (2004). The ANGLE Report and the PIN whitepaper identified areas of concern within Pennsylvania's nanotechnology TBED life cycle and provided primarily a two-fold direction.[9] First is to increase equipment and applied research resources so as to enhance nanotechnology transfer and commercialization discoveries. Second direction is to enhance nanotechnology workforce development skill sets for nano-human capital labor input into the commercialization production.[10] The over arching goal is to apply financial resources in the critical stages of nanotechnology discovery to prototype where revenue flow is negative, and there is a strong likelihood of a lack of commercialization success (see **New Company/New Product Life Cycle** graph below). This area is termed the "Valley of Death" that refers to the critical stage of new company formation and/or new product development which is most risky and where most companies/products fail.

Zucker and Darby (March 2005) report in the initial generation of a technology, there has been a rapid growth in nano science and technology (S&T) publications primarily from universities. Nano S&T publications now exceed 2.5 percent of all science and engineering articles in 2003. In addition, 0.7 percent of all science and technology patents are nanotechnology patents in 2004. Nanotechnology scientific technology which includes published research and patents are increasing in the areas of Technology to Product Idea as shown in the **Life Cycle** graph.

To take advantage of these scientific breakthroughs including nanotechnology breakthroughs, Zucker and Darby (March 2005) report that access to knowledge primarily retained by discovering scientists or excludable knowledge is needed. Top scientists become the human capital resource where new firms are built or existing firms transformed. In addition as scientists increase their collaboration with industry researchers, this has a strong positive effect on a company's success. PIN funding provides Pennsylvania research universities to focus and foster commercialization of nano-enabled products.

The PIN whitepaper provided strategic direction for primarily university partners or non-profit entities seeking financial resources from the Ben Franklin Technology Development Authority as follows: [11]

- Increase technology transfer and enhance university-based resources and skills. A mixture of state and university investments along with leveraged Federal research funds and partnering business investments will advance university-based nano-resources. PIN will continue to build the nanotechnology research base including leveraging federal opportunities as a foundation for economic development.
- Increase commercialization of nanotechnology applications and processes through collaboration. Murdock, et. al. (2005) report that future corporate spending is projected to outpace government spending as increasing number of businesses provide nano-enabled characteristics within existing products or in new products. PIN will leverage other academic research and industries including bioscience and electronics to bring forth nano-enabled products and services.
- Develop consortia-driven, educational and workforce development programs. PIN will continue to commit resources for nanotechnology skilled workforce along with partnering with other workforce development programs. A trained workforce is a requirement for technology advancement. In addition, companies consider the presence of a trained workforce as a significant decision choice for location investment (Murdock, et. al., 2005).

The six currently funded PIN initiatives are presented in the order of initial historical funding as approved by DCED or the Ben Franklin Technology Development Authority (BFTDA).[12] From 1999 to 2007, DCED and BFTDA funding was $66.8 million. BFTDA provides a vehicle, upon their approval, for investing in economic, community and university-based innovation (University Research Program Guidelines, January 2008).

(1) Pennsylvania Nanotechnology Manufacturing Technology (NMT) Partnership. The Pennsylvania NMT Partnership is recognized as a national model for nanotechnology education and workforce development. The Partnership enables two-year and four-year degrees at institutions across Pennsylvania using the resource-sharing concept to enhance science, technology, engineering, and math (STEM) education in the Commonwealth by "teaching the teachers" the concepts of nanotechnology. This is done in hands-on nanotechnology workshops held for the Commonwealth's secondary-school educators who can then meaningfully expose their students to the new possibilities and opportunities of nano-science and technology. In addition to enabling 2- and 4-year nanotechnology-based degrees and educator workshops, the NMT offers professional development workshops in nanotechnology fabrication and characterization for incumbent industry personnel as well as *Nanotech Academies* for middle and high school students.

The NMT Partnership is a statewide collaboration between Penn State University, Pennsylvania's community colleges, the Pennsylvania campuses of Allegany College of Maryland, the Pennsylvania College of Technology, the Pennsylvania State System of Higher Education, and industry partners. The Partnership's funding began with a $2 million allocation in 1998 to address the needs of Pennsylvania industry for skilled nanotechnology workers by creating a clean-room technical education program (Hallacher, Fenwick and Fonash, 2002). State funding provided the leveraging to establish at Pennsylvania's community colleges the nation's first associate degrees in nanotechnology. In 2001, the NMT Partnership was designated as a National Science Foundation (NSF) Advanced Technology Education Center for Nanofabrication Manufacturing Education, receiving a four year $2.8 million award and renewed for 2005 to 2008 as well as other federal grant awards. The NMT Partnership, encouraged by the NSF, proposed the creation of a national Center in 2008 (NSF response is expected by October 2008).

(2) Lehigh University's Pennsylvania Materials Research Science and Engineering Center, PA MRSEC. Lehigh University, in partnership with Carnegie Mellon University, is developing innovative and advanced materials and applications through research, including emphasis on nanoscale characteristics and behavior which can provide significant commercially relevant advances. A current area of importance is the developing of the research base in advanced materials synthesis, nanocharacterization, interfacial kinetic engineering, and mesoscale interface mapping. PA MRSEC facilitates joint research and business development activities including advanced regional economic and workforce development efforts in nanotechnology.

Initial funding by DCED began in 1999 with a funding from FY 1999-2001 of $900,000. Under this program Lehigh and Carnegie Mellon University have developed a strong infrastructure in nanocharacterization, with major enhancements to programs and facilities that support interdisciplinary research and interactions with large and small companies across Pennsylvania. These improvements have provided unique, accessible equipment and expertise to address technical challenges, and opportunities for student research that is critical to growing Pennsylvania industry.

(3) The Nanotechnology Institute, NTI. The NTI, a partnership between the University of Pennsylvania, Drexel University and the Ben Franklin Technology Partner of Southeast Pennsylvania, along with 12 affiliate higher education or academic medical institutions, contributes to the regional and state economy by developing an infrastructure to reduce barriers through the commercialization of nanotechnology inventions. This includes the NTI as a "single point of contact" by licensing to established companies and by providing the basis for forming start-up companies through uniform confidentiality, intellectual property management, and sponsored research agreements among the university partners.

NTI was initially approved for annual funding at $3.5 million in 2001. This effort to form the NTI was led by the University of Pennsylvania, Drexel University and the Ben Franklin Technology Partner of Southeast Pennsylvania. Their focus is on research and commercialization in Southeastern Pennsylvania especially in industry concentrated areas of biotechnology and pharmaceutical application of nanotechnologies.

(4) Penn State University's Advanced Materials and Nanotechnology Research and Commercialization Program. The Advanced Materials and Nanotechnology Research and Commercialization Program supports a range of activities including federal National Science Foundation nanotechnology research grants, assisting with acquisition of instrumentation, expanding of nanotechnology research user facilities, providing research seed grants that leverage federal and industry funding, and bolstering technology commercialization efforts.

In 2002, Penn State received an award of $3.5 million to support nanotechnology research and commercialization with annual funding through 2004, while in 2006, $2.5 million was awarded to the Program. The funds have been used to further Penn State's research and development strengths including materials research. The Program's commercialization effort is to assist existing industry and launch new companies to commercialize Penn State's advanced materials technology and nanotechnology.

(5) PA NanoMaterials Commercialization Center. The Center, founded in 2005, is a partnership with industry founding partners, Alcoa, Bayer Material Science, PPG Industries, and United States Steel; and university partners, Carnegie Mellon University, University of Pittsburgh, Pennsylvania State University, and Lehigh University. The Center promotes and commercializes nanotechnology research and development acting as an intermediary to leverage other public and private investments for Pennsylvania entrepreneurs applying nanotechnologies as well as enhancing the impact for resident companies working in these application areas.

The NanoMaterials Commercialization Center was first funded in 2006 for $1 million. An important aspect of its operation is the creation of relationships between university research and entrepreneurial firms. This relationship is intended to compliment current industry laboratories. The Center's unique commercialization model comprises three key elements: (1) driving focused nanotechnology research and development based on industry defined market needs, (2) facilitating the formation of collaborations between university researchers, small and large companies to successfully commercialize promising nanotechnology research, and (3) providing seed capital and support to bridge the "Valley of Death" between technology proof-of-concept and early prototype development.

(6) Lehigh University's Nanophotonics Technologies. Lehigh University's Nanophotonics Technologies initiative continues to develop commercialization pathways for nanophotonics specific projects within regional Pennsylvania and Keystone Innovation Zone nanotechnology entrepreneurs and enterprises, leveraged federal research funding, growth in regional nanotechnology expertise and recognition, and growth in students and interactions with other Pennsylvania institutions of higher education (see Armstrong and Yazdi, 2004, for discussion of Keystone Innovation Zones).

The Nanophotonics Technologies initiative was first funded in 2006 as an outgrowth of a DCED supported program--Lehigh University's Center of Optical Technologies. Nanophotonics is the study of behavior of light on the nanometer scale. Lehigh has identified three initiatives involving nanotechnology: (1) nanophotonics for green energy, (2) nanophotonics for biomedical diagnostics and sensing, and (3) silicon nanophotonics. These and other initiatives will enable both research and joint industry programs for intellectual property generation and commercialization.

Table 1 shows the six PIN funded initiatives and their alignment with the three PIN strategies of increasing technology transfer and university-based resources, commercialization of nanotechnology applications and consortia-driven educational and workforce development programs.

From the **New Company/New Product Life Cycle** graph, accountability measures are required so that the PIN initiatives are tracking positive technology-based economic outcomes (Measuring Up, 2007). From the technology idea to prototype to production via licensing to an existing company or new university/industry spinout, metrics are generated to determine impact of the PIN initiatives. **Table 2** summarizes the impact of the PIN initiatives since 1999 including more detailed breakout impact data since July 1, 2007.

Table 2 shows evidence that the six PIN projects are an integral component for regional and state technology-based economic development. Overall since 1999, PIN technology-based economic development activities were awarded $66.8 million of in-state funding that resulted in $470.3 million in total leverage funding (the PIN figure does not include the $8.1 million in PIN funded activities awarded for FY 2008). The total leverage funding includes venture capital, private equity, debt financing, federal, local, foundation funding, or other funding sources and excludes Pennsylvania state sources. The result of state PIN funding is a 7.0 to 1 leverage ratio.

Comparing the **New Company/New Product Life Cycle** graph with the metrics on the bottom section of **Table 2**, the impact of PIN is provided, where the figures are the result of PIN funding and PIN leverage funding only (Measuring Up, 2007). Notice for the last six months of 2007, greater detailed break-out data was provided resulting from the enhanced metrics reporting requirements from Measuring Up (2007). There was $12.7 million devoted to nanotechnology research, development, testing and evaluation where 365 articles and other publications were published (1,648 since 1999) along with 11 new technologies developed.

Continuing along the **Life Cycle** graph with the metrics reporting in **Table 2**, 42 patents were filed and 4 awarded for the last six months of 2007. Eight licenses were granted during the same time period. Since 1999, 200 patents and licenses have been awarded. The result of patenting intellectual property is the starting up of new companies or the licensing to existing companies. For those six months, six newly created startups occurred where three were institutions of higher education spin-outs and three were industry spin-outs.[13] The amount of licensing revenue earned for the last six months of 2007 was $200,000. In addition, 11 new nano-enabled products were developed.

The human capital impact upon Pennsylvania due to PIN funded projects has been significantly positive. Since 1999, there have been 35 combined graduate and undergraduate internships, where 12 internships occurred since July 1, 2007. From July to December 2007, 8 percent (5 of 64) of undergraduate students that graduated took a job in Pennsylvania as the result of PIN funding. Even more impressive in the same time period and as a result of PIN funding, 40 percent (8 of 20) of graduate students that graduated took a job in Pennsylvania.

Now, total spending or direct spending impact is the sum of DCED, BFTDA and leverage funding equaling $537.1 million ($66.8 million and $470.3 million) from 1999-2007. Type I (1.3432) and II (1.6171) Pennsylvania economic impact nanomultipliers, provided in **Table 3**, were calculated from Penn State's Workforce Education and Development Initiative IMPLAN (Impact Analysis for Planning) model considering current nanotechnology impacted NAICS industry sectors.[14]

The nanomultipliers summarize the total expected impact from an increase in nanotechnology spending activity. The Type I multiplier shows the additional impact of indirect effects of the industry. Indirect effects are the added total economic output generated by purchases made by the Pennsylvania nanotechnology industry from other industries in the Pennsylvania economy. These purchases made by nanotechnology establishments stimulate output from these supplying industries. For every dollar of output from the nanotechnology industry, $1.34 of total economic output are produced--i.e., an additional $.34 of output added by supplying industries.

The Type II multiplier shows the additional impact of indirect *plus* the induced effects of the industry. Induced effects are the added total economic output created due to income spent by the workers in the Pennsylvania nanotechnology industry as well as income spent by workers whose jobs are generated in other Pennsylvania industries as a result of Pennsylvania nanotechnology activity. For every dollar of output from the nanotechnology industry, $1.62 of total economic output are produced--i.e., an additional $.62 of output added by supplying industries *plus* output induced by the spending of disposable personal income. According to Misner and Culp (2005), regional multipliers produced from packages such as IMPLAN allow for accuracy and validity in conclusions drawn from a research study.

Table 3 calculates the direct PIN impact of $537.1 million multiplied by the Type I and II PA nanomultipliers producing the total economic impact of PIN upon the Commonwealth of $721.5 million or $868.6 million. The difference between the total and direct PIN impact is the additional indirect effect of $184.3 million or the additional indirect and induced effects of $331.5 million.

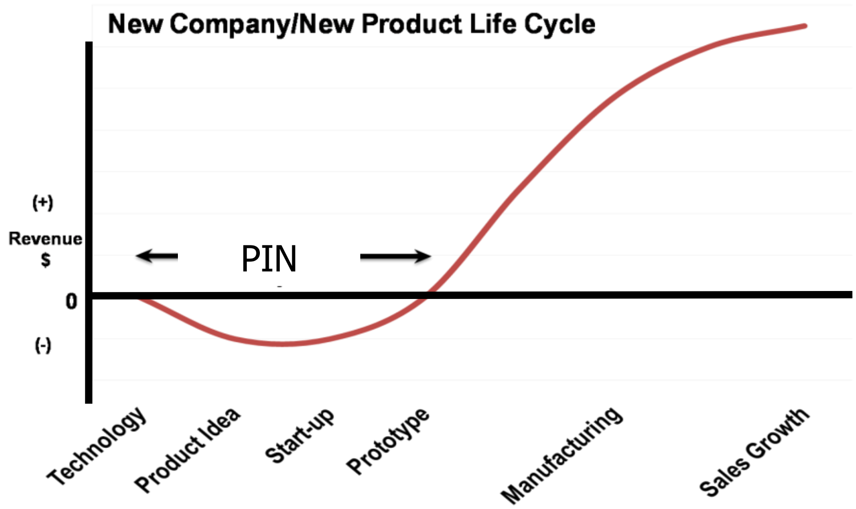
Now, it should be recognized that there is not a one-to-one correspondence between each dollar invested in PIN and each dollar of output in nanotechnology where the economic impact figures may be overstated. PIN investments are meant to stimulate innovation and, as a consequence, economic activity in the nanotechnology industry as defined in this paper. The Pennsylvania nanotechnology industry is a significant source of economic activity as evidence by the Type I and II multipliers. At this point, no one knows the relationship between PIN investment and nanotechnology economic output. However, the stakes for PIN investment are high, because for each dollar of Pennsylvania nanotechnology output, as much as $1.62 in Pennsylvania total economic output is created.

Of interest is the return on taxpayer dollars due to DCED and BFTDA. From 1999 to 2007, the DCED and BFTDA spending was $66.8 million. **Table 4** shows that for each dollar invested by the Commonwealth for the six PIN projects yielded a return of $10.79 or $13.00 in total PIN economic impact to Pennsylvania.

As PIN continues to advance nano-enabled commercialized products, it is expected through the Commonwealth's investments in public and private partnerships that more of these products will be produced within the Commonwealth. **Table 5** provides market forecasts for nanotechnology projects from a conservative Mitsubishi (2002) figure of $150 billion in 2010 to the well published National Science Foundation 2001 (2004) figure of $1 trillion in 2015 to the optimistic scenario of $2.6 trillion in 2014 by Lux Research (2004).[15] Using Pennsylvania's percentage of worldwide trade, Pennsylvania is projected to produce a conservative $1.16 billion in 2010 to $7.7 billion by 2015 or an optimistic $21.03 billion of nanotechnology products by 2014.

CONCLUSIONS

Pennsylvania's Initiative for Nanotechnology is not one initiative but many initiatives through its PIN partners. PIN continues to evolve as nanotechnology continues to be realized. Nanotechnology development continues from first-generation materials to second generation components and third generation device and drug nano-enabled products. The challenges facing PIN is to provide appropriate strategies to reduce the likelihood of commercialization failure from idea generation to prototype scaling of nano-enabled products and operations. With this in mind, the Commonwealth is in the process of updating PIN with its public and private partners. As the Commonwealth continues to advance nanotechnology as a technology-based economic development initiative partnering with higher education institutions and industry, PIN will provide a key component for sustainable economic development.



Source: Alan Brown and Pauline Yankes, 2008.

Table 1: Alignment of PIN Initiatives to PIN Strategies

	Technology Transfer & University-Based Resources	**Commercializaton of Nanotechnology Applications**	**Consortia-Driven, Educational & Workforce Programs***	
(2) PA MRSEC	X	X	X	(6) NANOPHOTONICS
(3) NTI and (4) ADVANCED MATERIALS, COMMERCIALIZATION PROGRAM	X	X		(5) PA NANOMATERIALS CENTER
(1) NMT	**	**	X	

*NTI and PA Nanomaterials Center previously were involved in educational and workforce development programs.

** NMT Partnership transfers knowledge and expertise to other educational institutions in PA and other states through the NSF Center, and also supports commercialization through industry outreach including incumbent worker training and referring companies to technology commercialization resources.

Source: BFTDA Project Summaries

Table 2: PIN Initiative Metrics

Pennsylvania Initiative for Nanotechnology Impacts: 1999-2007			
Dollars Leveraged*	$470,275,424	Undergraduate and Graduate Internships	35
Patents and Licenses	200	Participating Undergraduates Enrolled	1,157
Citizens Impacted	5,006	Participating Graduates Enrolled	800
Businesses Assisted	611	Journal Articles, Scholarly Papers, or other Publications***	1,648
Pennsylvania Initiative for Nanotechnology Impacts: 7/1/2007 to 12/31/2007**			
Dollars Leveraged*	$22,312,320	Undergraduate and Graduate Internships	12
Licenses Granted	8	Participating Undergraduates Enrolled	284
Licensing Revenue Earned	$200,000	Participating Graduates Enrolled	326
Patents Filed	42	Enrolled Undergraduate Students that Graduated	64
Patents Awarded	4	Enrolled Graduate Students that Graduated	20
Businesses Assisted	175	Enrolled Undergraduate Students that Graduated and took a Job in Pennsylvania	5
Newly Created Startups	6	Enrolled Graduate Students that Graduated and took a Job in Pennsylvania	8
Industry Spin-Outs	3	Journal Articles, Scholarly Papers, or other Publications***	365
Institutions of Higher Education Spin-Outs	3	Research, Development, Testing, and Evaluation****	$12,680,067
Development of New Products	2	New Technologies Developed	11

*Leveraged dollars is the sum of venture capital, private equity, grants, and debt financing dollars.

**Collection of additional data began 12/31/2007 as the result of reporting requirements from Measuring Up (2007). 22 jobs created and 19 jobs retained are relatively minor given the early stage of nanotechnology commercialization; break-out figures were not provided before this reporting period.

***Faculty scholarly activities associated with the University Research Grant funding.

****Research, Development, Testing, and Evaluation (RDT&E) expenditures include monies spent on labor, services, materials and equipment used to conduct research, development, testing and evaluation as recognized by your company or institution of higher education, regardless of where the RDT&E was physically undertaken. RDT&E excludes in-kind contributions provided by your institution of higher education, company and/or third-parties.

Source: Semi-annual report submissions. Category definitions reported in Measuring Up (2007).

Table 3: PIN's Economic Impact on the Commonwealth: 1999-2007

Total PIN Spending	$537,113,424	$537,113,424	Total PIN Spending
Type I PA Impact NanoMultiplier*	1.3432	1.6171	Type II PA Impact NanoMultiplier*
Total PIN State Economic Impact	$721,461,885	$868,566,612	Total PIN State Economic Impact
Total Indirect Impact	$184,348,461	$331,453,188	Total Indirect+Induced Impact

*Direct, Indirect and Induced effects are in 2006 dollars used to calculate the Pennsylvania impact nanomultipliers.
Source: Semi-annual progress report submissions by PIN partners and from Penn State's Workforce Education and Development Initiative IMPLAN model.

Table 4: Return on DCED and BFTDA Investment

Return on Taxpayer Dollars	1999-2007 DCED and BFTDA Six PIN Projects*	Reported Total State Economic Impact of PIN	Ratio
PIN Funding (Type I NanoMultiplier)	$66,838,000	$721,461,885	10.79
PIN Funding (Type II NanoMultiplier)	$66,838,000	$868,566,612	13.00

Source: DCED and BFTDA approved funding of PIN projects.

Table 5: Worldwide, United States and Pennsylvania Nanotechnology Projections

Country and State	GDP (PPP)* 2006 $m	Percentage of World	2010 Nanotechnology Products $m (Mitsubishi Institute, 2002)	2014 Nanotechnology Products $m (Lux Research, 2004)	2015 Nanotechnology Products $m (National Science Foundation, 2001)
World	$66,228,669		$150,000	$2,600,000	$1,000,000
United States	$13,020,861	19.66%	$29,490	$511,172	$196,605
Pennsylvania**	$510,293	0.77%	$1,155	$20,033	$7,705

*The Gross domestic product (GDP) dollar estimates are derived from Purchasing Power Parity (PPP) calculations.
**Total Gross Domestic Product by State, Bureau of Economic Analysis

ENDNOTES

[1] Information is this section primarily is from Triplett (2004), NewPA (http://www.newpa.com/default.aspx?id=56), and NanoWerk(http://www.nanowerk.com/). From Eastwood, Brooker and Terry (December 1986), the characteristic model assumes that all products possess measurable attributes, and individuals differ in their valuations of different characteristics not levels of attributes. Also it should be noted that the relationship between a given quantity of a product and its characteristics is essentially a technical relationship.

[2] The current use of nanotechnology is not necessarily new. Chemists have been making polymers using nanoscale subunits for many decades while humans have been unknowingly using nanotechnology for centuries. Now, the continued miniaturization of features on computer chips continues to be one of the demand drivers for nanotechnology research applications. In addition, advances in nanotechnology research tools over the last 25 years including scanning tunneling microscope, atomic force microscope and the various scanning probe microscopes along with advances in computer software permit advances in characterization and manipulation at the nanoscale. Furthermore fabrication tools which can control and repeat items in the nanoscale range along with the characterization tools to measure and see at this range have contributed substantially to nanotechnology advancements. Fabrication at the nanoscale involves two approaches: top-down and bottom-up. The top-down approach produces small nanoscale structure from larger pieces of material, such as by etching to create circuits on the surface of a silicon chip. The bottom-up or self-assembly approach, where under specific conditions, atoms or molecules arrange themselves into a structure due to their natural properties, such as crystals grown for the semiconductor industry. One other bottom-up or positional assembly approach, atoms or molecules are moved individually using appropriate tools. Note that this approach, currently, is costly and not suitable for mass industrial applications.

[3] The Nanotechnology Project provides a current listing of nanoproducts and nano-enabled characteristics (http://www.nanotechproject.org/inventories/consumer/). Upon discussions with the Project, there may be an under representation of nanoproducts and nano-enabled characteristics listed, but it is currently the only public list within the focus of the Project that is available. From the October 2, 2007, 650 listing of nano-enabled consumer products and percentage of total listings are the following categories: Health and Fitness (54.8%), Home and Garden (10.3%), Food and Beverage (10.2%), Electronics and Computers (7.1%), Cross Cuttings or Coatings (6.8%), Automotive (5.1%), Appliances (3.2%), and Goods for Children (2.6%). Each category has sub-categories. As an example within the Health and Fitness are the following sub-categories: Clothing (24.7%), Cosmetics (23.9%), Personal Care (22.8%), Sporting Goods (15.9%), Sunscreen (7.3%), and Filtration (5.4%). Products just produced within Pennsylvania are not listed.

[4] From Rocco (2005), nano-enabled products are expected to include research in the following areas: (a) self-assembly design molecules, (b) energy conversion with controlled interaction between light and matter, (c) exploiting quantum control within the mechanical-chemical molecular processed, (d) nanosystem biology for healthcare and agricultural systems, (e) human-machine interface at the tissue and nervous system level, and (f) convergence of nanotechnology, biotechnology, information technology and cognitive sciences.

[5] No consensus on appropriate functional form has been reached (Eastwood, Brooker, and Terry, December 1986).

[6] The utility function has the usual curvature properties, such as continuous, quasi-concave with positive first order derivates.

[7] Consumer and, later on, producer maximization problem with first and second order conditions and resulting marginal rates of substitution and transformation are not provided and can be found in Triplett (2004).

[8] Murdock, et. al. (2005) report that the number of nanotechnology technicians needed in the United States over the next decade may be over 800,000.

[9] Sa', Geiger and Hallacher (2008) argue that the evolution of Pennsylvania nanotechnology policy was accidental. While in the beginning, Pennsylvania may not have had an overarching policy direction; nevertheless through its university partners, policy was provided to increase nanotechnology workforce, research, and commercialization through accepted PIN projects by Pennsylvania's DCED or Ben Franklin Technology Development Board Authority (BFTDA). As a result, greater economic development was achieved relative to a condition where university partners, in cooperation with DCED or BFTDA, did not pursue these policies.

[10] The nanotechnology strategies follow the recently enacted Ben Franklin Technology Development Authority University Research Grant Program Guideline (January 2008) strategies:

- Developing and increasing new technologies, escalating technology transfer, and enhancing university-based resources and skills
- Increasing commercialization of applications and processes through university, industry and government collaboration
- Forming new spin-off companies that are deriving a significant portion of its commercial activities from the use of technology and/or know-how developed at a Pennsylvania higher education institution or another company collaborating with a Pennsylvania higher education institution
- Leveraging of funding by the federal, state and local government; philanthropic foundations; strategic investors; and industry sponsored research
- Creating consortia-driven, educational and workforce development programs
- Developing strategies for financial sustainability

[11] The strategies for PIN align appropriately with those of the Federal Government's National Nanotechnology Initiative (NNI) Strategic Plan four goals (December 2004, December 2007) to: (1) develop and sustain educational resources, a skilled workforce, and the supporting infrastructure and tools to advance nanotechnology; (2) foster the transfer of new technologies for commercial and public benefit including economic growth and jobs; (3) advance a world-class research and development programs aimed to realizing the full potential of nanotechnology; and (4) support responsible development of nanotechnology grouped into two categories of (a) environmental, health and safety implications and (b) societal dimensions of nanotechnology. The NNI is now in its eighth year.

[12] Sa', Geiger and Hallacher (2008) provide historical information on the six PIN projects.

[13] *Small Times* reported for March 2005, there were 1,455 U.S. nanotechnology companies with about half being small businesses.

[14] Current nanotechnology impacts upon NIACS coded industries is complex due to early stage on-going research. Thus, the degree of nanotechnology impacts upon various NAICS coded industries has not been fully determined. Upon discussion with Lux Research, the descriptions and NAICS codes used to calculate the nanomultipliers are as follows: power generation and supply (2211); fiber, yarn, and thread mills (3131); other hosiery and sock mills (315119); petroleum refineries (32411); petroleum lubricating oil and grease manufacturing (324191); all other petroleum and coal products manufacturing (324199); petrochemical manufacturing (32511); industrial gas manufacturing (32512); other basic organic chemical manufacturing (32519); cellulosic organic fiber manufacturing (325221); noncellulosic organic fiber manufacturing (325222); pharmaceutical and medicine manufacturing (32541); rolled steel shape manufacturing (331221); fabricated structural metal manufacturing (332312); semiconductor machinery manufacturing (333295); optical instrument and lens manufacturing (333314); photographic and photocopying equipment manufacturing (333315); heating equipment, except warm air furnaces (333414); electronic computer manufacturing (334111); computer storage device manufacturing (334112); computer terminal manufacturing (334113); other computer peripheral equipment manufacturing (334119); telephone apparatus manufacturing (33421); broadcast and wireless communications equipment (33422); other communications equipment manufacturing (33429); electron tube manufacturing (334411); semiconductors and related device manufacturing (334413); all other electronic component manufacturing (334412, 334414, 334415, 334416, 334417, 334418, 334419); electromedical apparatus manufacturing (334510); search, detection, and navigation instruments (334511); automatic environmental control manufacturing (334512); industrial process variable instruments (334513); analytical laboratory instrument manufacturing (334516); storage battery manufacturing (335911); primary battery manufacturing (335912); motor vehicle body manufacturing (336211); aircraft manufacturing (336411); aircraft engine and engine parts manufacturing (336412); architectural and engineering services (5413); scientific research and development services (5417).

[15] The Lux Research figure suggest that the market for nano-based technology products will be larger than forecasts information and communication technology market and exceed the biotechnology market by ten times (Hullman, November 2006).

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