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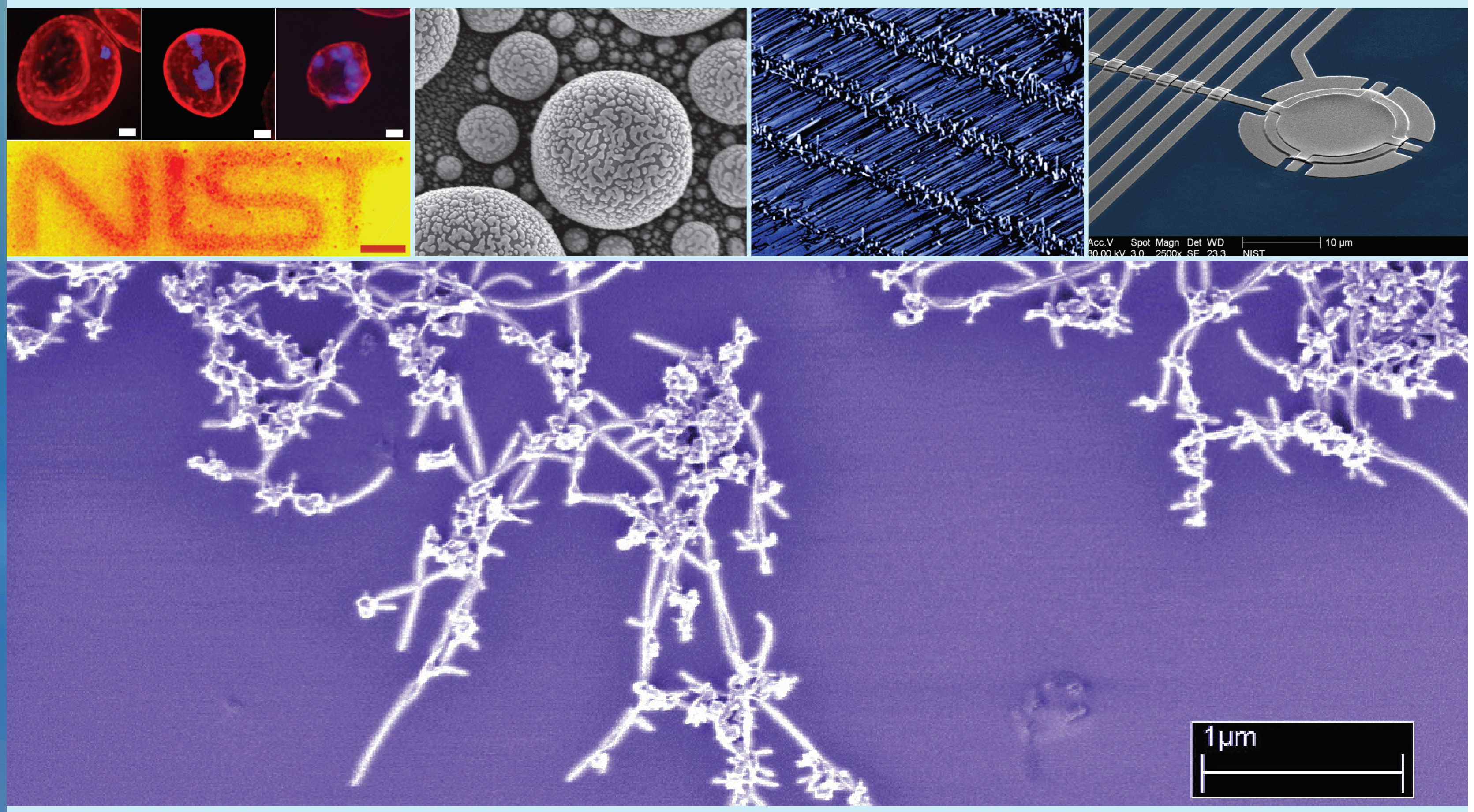
A Case Study of Nanotechnology Documentary Standards



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The Economic Impacts of Early Stage Consensus Standards Development: A Case Study of Nanotechnology Documentary Standards

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ES. Executive Summary

Documentary standards are precisely written agreements that result from a consensus-making process concerning a common recurrent technical issue or set of issues, from terminology to how measurements about quality or perfromance will be made, to product labeling conventions. Typically, such standards ease the frictions inherent in the development and wide application of a new technology application. Documentary standards are part of a national and international innovation system, a public-private technical infrastructure that is critical to the development and diffusion of the new knowledge and know-how that leads to economic growth and development.

One of NIST's core missions is to assist U.S. industry with the standards-related tools and information it needs to compete more effectively in the global marketplace. NIST devotes considerable resources to supporting the consensus standards process. The landscape of NIST's involvement in standards development is very broad and it behooves NIST to justify its support of industry especially when the nature and scale of the benefits of it doing so are not obvious to all. This is especially true of documentary standards: they are not well understood by much of the general public; they are seen as trivial or old fashioned by many economic policy analysts and business strategists; and yet they are critically important to the scientific and engineering community that develops them, increasingly so by those who understand the role of technology as the engine of economic growth.

This economic impact assessment focuses on documentary standards development for nanotechnology. Nanotechnology developments and applications are just emerging; thus, the standards studied in this report are regarded as "early-stage" or "proactive" standards that are promulgated early in the life cycle of the development of nanoscience- and nanotechnology-based products and services. This is both a strength and a weakness. On the positive side, the report provides insights, based on the perspectives of industry participants, not widely available elsewhere. On the negative side, the markets for nanotechnology-based products, and the "industries" that provide them, are inchoate so routine statistics that are often used to assess economic impact are unavailable, certainly at the level of granularity required to assess economic consequences of a specific set of documentary standards.

Unlike most survey-based economic impact evaluations conducted for NIST, in which the impact of NIST's resource investments is evaluated, this case study focuses on the economic significance of nanotechnology standards to industrial firms, both as users of the completed standards and as the standards developers.

The economic importance of NIST efforts in support of consensus standards has been demonstrated in other NIST reports. While standards are recognized by NIST's leadership as fundamentally important to the process of economic growth and development, outside the relatively small community of participants in the standards development process, the benefits and costs of participation are less widely understood.

The significant economic benefits accruing to industry participants in the early stages of the standards development process, as well as non-participating users, are the focus of this assessment. Specifically, the work of the following standards development organization (SDO) technical committees (TCs) and their beneficiaries are analyzed: the ASTM International (ASTM) TC E56, the International Electrotechnical Commission (IEC) TC 113, and the International Standards Organization (ISO) TC 229. The results of the study suggest that there is a major difference of perspective between those in industry who participate in standards development and those who do not. The former appear to be future-focused and committed to developing the means to communicate accurately about the many applications and risks associated with nanotechnology despite the near-term net costs required to do so. It appears that the latter and much larger group of non-SDO participants ("free riders") are satisfied, strategically, to reap considerable near-term net benefits from SDO participants' investments without a commensurable contribution to SDO development; possibly cannot afford to position themselves with respect to important practical matters that are being advanced by the SDOs; or, perhaps, are convinced that active participation in SDOs entails no significant strategic advantage.

The evidence gathered also suggests that an important difference in perspective exists between forward-focused companies that participate in SDOs and many universities (organizations at the forefront of generating knowledge about nanoscale science and technology). While there are notable exceptions, it appears that many university researchers think that documentary standards are irrelevant to their work, yet national technology policy assumes that university research will generate a body of knowledge and know-how that will eventually be utilized by industry. If basic standards were more widely used in the university research community, for example, terminology and nomenclature standards, logic suggests that the resulting knowledge would be less costly for industry to acquire and interpret and be generally more applicable to industry users.

In the United States, industry, government, and a few university representatives have been engaged in the development of nanotechnology standards, formally, since 2005. While it is claimed that that no single technology offers more economic and societal promise than nanotechnology, it is also observed that barriers and potential barriers impede further commercialization that may limit the nation's ability to capture the full potential of nanotechnology, including economic growth, wealth, and job creation, and improvements in our standard of living and quality of life. Among those barriers is the urgent need to develop standards for each phase of the new nanotechnologies: standards for research, production, products, and waste disposal.

The results of this economic impact assessment, shown in Table ES-1, demonstrate that industry-wide investments in early stage development of nanotechnology documentary standards have already started to pay off handsomely. SDO participants as a group have already realized substantial net benefits, and industry-wide net benefits have included very substantial benefits to non-SDO participants, free riders, who reap the near-term benefits of having standards available without the costs of SDO participation. SDO participants, taking a long view, believe that the internal practices they are mastering and social networks they are cultivating as a result of their SDO involvement will yield significant advantages and net economic benefits in the years ahead. The benefit and cost trends reported here show that SDO participants have already realized substantial net benefits. Those net benefits are expected to grow larger in the years ahead.

Table ES-1. Estimate of Economic Impact (constant 2012 dollars)

Performance Metric	Value
Net Present Value in 2005	50,869,841
Cumulative Net Benefits in 2012 (2005-2012)[1]	81,685,848
Industry Rate of Return	270%
Benefit-to-Cost Ratio	13

The benefits of nanotechnology documentary standards are conceptualized as the costs avoided because industry has access to information contained in the standards. On average, nanotechnology-related activities would have cost industry almost 50 percent more in the absence of the standards. The costs incurred in developing and using the standards are the dollar value of hours TC members dedicated to the SDO consensus process plus the cost of pulling the information into their organizations. Beneficiaries who have not participated in SDO processes also incur pull costs.

Because those benefits and costs vary across the respondents from one year to the next, the time value of money and inflation need to be factored into the evaluation. This is accomplished by the financial analysis convention of calculating the net present value (NPV) of the estimated time series of benefits and costs in constant dollars.

The performance metrics shown in Table ES-1 are different ways of representing the return on investment to the resources industry has devoted to developing nanotechnology documentary standards. The net present value (NPV) in 2005 metric says that if, in 2005, TC members could have projected the actual timing and size of the costs avoided they would have valued the project at ~$51 million, net of the costs industry would have incurred. The cumulative net benefits metric looks back at that stream of benefits and costs from the perspective of 2012 and compounds the ~$51 million in NPV by 7 percent per year (the cost of capital used by the federal government when evaluating investment returns). The industry rate of return metric says that the rate of return on industry-wide investment in nanotechnology standards development over the period from 2005 to 2012 has been 270 percent. The benefit-to-cost (B/C) metric says that for every $1 dollar of costs expended by industry (2005-2012), ~$13 dollars in benefits have been returned.

These estimates of industry-wide economic impact can be considered conservative for reasons explained in the report. The results are well within the range of private sector return-on-investment metrics reported in the economics literature and within the range of many other public-private partnerships evaluated by NIST over the last 20 years.

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[1] (Net Present Value in 2005) multiplied by $(1.07)^7$.

As with all economic impact case studies, this assessment has limitations that are discussed in the report that follows. They are limitations necessitated by a tradition of economic analysis, not least at NIST, that attempts to understand the economic implications of very specific technologies and their supporting infrastructure. Without such insights technology managers would be without a compass concerning the benefits and costs of their investments even if the accuracy of the compass is not ideal.

1 Introduction and Background

This introductory chapter presents the rationale for undertaking an economic impact analysis of nanotechnology documentary standards and discusses a range of issues that provide context for the economic analysis of Chapters 3-7.

1.1 Documentary Standards

There are two different types of standards -- *physical measurement* standards and *documentary* standards.

The National Institute of Standards and Technology (NIST) is responsible for developing, maintaining and disseminating national *physical measurement* standards for basic measurement quantities (such as mass, time and frequency), which are traceable to the International System of Units (SI). These standards promote order, efficiency, and fairness in the marketplace, facilitate technological progress, and enhance U.S. competitiveness.

Documentary standards are written agreements among producers and/or users of products and services containing technical specifications or other precise criteria that may contain rules, guidelines, or definitions of characteristics. Documentary standards ensure that materials, products, personnel qualifications, processes, and services are: adequate for their purpose; compatible and/or interchangeable, if necessary; ensure public health and safety; protect the environment; and/or improve economic performance. They can specify product characteristics, establish accepted test methods and procedures, characterize materials, define processes and systems, or specify knowledge, training, and competencies for specific tasks.[2]

Frequently, *documentary* standards act as a bridge connecting national representations of international physical measurement standards to the day-to-day operations of industry in its research and development (R&D) efforts, in the application of this R&D to new technologies and innovations, and in transitioning new products and services into growing markets.

1.2 U.S. Consensus Standards[3]

The U.S. standards system is highly decentralized, primarily voluntary, private sector and marketplace-driven. Unlike other nations, where governments play a more active role and the process is more centralized, the U.S. federal government participates only as one of many stakeholders in the standards development process. By comparison with the

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[2] ISO/IEC Guide 2: 2004, Standardization and related activities -- General vocabulary, provides general terms and definitions concerning standardization and related activities.
[3] This section relies on Maureen A. Breitenberg, *The ABC's of Standards Activities* (NISTIR 7614), August 2009, National Institute of Standards and Technology.

umbrella-type standards organizations that operate in other nations or at the international level, the more specialized U.S. SDOs are often quicker to generate the standards most needed by industry.

Approximately 19 standards developing organizations (SDOs) generate the large majority of standards in the U.S. The American National Standards Institute (ANSI) coordinates the activities of many U.S. SDOs, a role it has played for over 90 years. ANSI is a private, not-for-profit membership organization comprised of government agencies, organizations, companies, academic and international bodies, and individuals. As one of its responsibilities, ANSI accredits U.S. standards developers using criteria based on international requirements for consensus standards.

ANSI, in turn, is the sole U.S. representative and dues-paying member of the two major private sector, consensus-based, international standards developing organizations: the International Organization for Standardizations Organization (ISO) and the International Electrotechnical Commission (IEC). ANSI participates fully in technical programs of both the ISO and the IEC and administers many key committees and subcommittees. As the U.S. member body to the ISO, ANSI accredits U.S. Technical Advisory Groups (U.S. TAGs). The primary purpose of U.S. TAGs is to develop and transmit U.S. positions on ISO and IEC activities.

Many U.S. SDOs produce standards that are used globally. The U.S. representatives of three international SDOs are the focus of this economic impact assessment. Surveyed are U.S. representatives of ASTM International, a standards-developing membership organization that produces the largest number of nongovernmental, voluntary standards in the United States, and the National Electrical Manufacturers Association (NEMA), an industry association whose membership consists of companies that operate in a specific industry sector, and the U.S. technical advisory group (TAG) of ISO's Technical Committee 229.

1.3 Standards and the Technology Infrastructure

1.3.1 Technology Infrastructure

Economists who study innovation recognize that there are many different kinds of institutions—private, public, and mixed—required to maintain the national standard of living and to successfully generate new products and services that fuel economic growth.[4] National and global innovation systems are complex networks of agents, policies, and institutions supporting technical advances.[5] Technology-intensive system and component

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[4] See, Gregory Tassey's, "The Disaggregated Technology Production Function: A New Model of University and Corporate Research," *Research Policy,* Vol. 34, 2005, pp. 287-303; and Albert Link and Donald Siegel, *Technological Change and Economic Performance,* Routledge, 2003.
[5] See Bengt-Ake Lundvall (ed.), *National Systems of Innovation,* PINTER, 1995, pp. 13-15; and Jeffery Furman, et. al., "The Determinants of National Innovative Capacity," *Research Policy,* Vol. 31, 2002, pp.

innovations typically require substantial outlays for research, development, design, engineering, testing, tooling, construction of production facilities, market research, establishment of distribution channels, advertising and promotion, and other support activities. Many functions entail different types and degrees of risk that vary over the life cycle of the innovative product or service, and an institutional "division of labor" exists to mitigate ubiquitous barriers to technology development and innovation. Standards development organizations are important, often overlooked, elements of the private, public, and mixed institutional division of labor that comprises the innovation system.

Economists use a few fundamental concepts to explain the sources and levels of funding for science and technology development. One concept is that of *externalities*, defined as impacts of production and consumption activities that are not directly reflected in market prices. The second and related concept is that of *public goods*, defined as goods and services that benefit all but, because these benefits are difficult to "fence off," too few are supplied by private sector investors.

Private sector firms may produce too much or too little of the goods and services that are affected by externalities and public goods attributes. Negative externalities occur when the actions of one party impose costs on another party, for example because of pollution. In competitive markets, negative externalities lead to too much of the goods and services produced. Positive externalities occur when the action of one party benefits another without requiring compensation for the benefits. In competitive markets, positive externalities lead to too few goods and services being produced by the private sector.[6]

A textbook example of a positive externality is the outcome of a firm's investments in research and development. Often, the inventions that result from private sector research cannot be protected from use by other firms. Know-how is notoriously "leaky." People talk, papers are published, patents are filed, products are "reverse-engineered," and "good ideas," once put into practice, can be imitated. The spillover of know-how acts as a barrier to adequate investment because the investor does not easily capture the benefits of the investment. In addition, some technology implementations, such as measurement technologies, are most effectively utilized if they are widely shared; they have network effects (the value of a product or service increases as more people use it). So it behooves the innovation system to ensure that these technologies are shared as widely as possible. Spillovers and network effects sometimes erect powerful barriers to the development of a robust technology infrastructure and to the innovations it generates.

In the context of this report, the apt example of positive externalities and network effects is a consensus standard. Many benefit from the use of standards but relatively few invest in their development. Standardization affects both innovation and technology diffusion.

899-933. The most complete and most policy-relevant conceptualization of the national innovation system is Tassey, ibid.

[6] Robert Pindyck and Daniel Rubinfeld, *Microeconomics,* Macmillan Publishing Company, 1989, pp. 617-646.

Standards are a form of technology infrastructure that represent the codification of some element of the technology.[7] Consensus standards development typically involves the contributions of public and private organizations. This is evidence of their high "public goods" content.[8]

The economic logic of the technology infrastructure suggests that investments such as consensus standards will be among the most effective for transitioning between current and emerging technology life cycles. Emerging technology, such as nanotechnology, has the potential for superior performance but relative to the current mature technology, the emerging technology is at a performance per dollar disadvantage. As a general matter this may occur because system elements of the new technology platform do not develop at the same rate, the system interfaces may not exist, the technology infrastructure is not fully developed, or initial product offerings are insufficient to predict long run costs.[9]

On the one hand, investments in an emerging general-purpose technology, like nanotechnology, will increase the rate at which the performance per dollar of the emerging technology improves.[10] Investments in technology infrastructure, on the other hand, shift the entire emerging technology diffusion S-curve upward. As hypothesized by Tassey:

> "[T]he collective efficiency gains from multiple [technology infrastructure elements, including standards and their underlying measurement technologies] over a technology's life cycle […] accelerates market penetration of a new technology and more quickly delivers its benefits to society."[11]

1.3.2 Early Stage Documentary Standards

Close observers of the nanotechnology standards development process posit the following distinction between most SDOs and those focused on nanotechnology:

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[7] Gregory Tassey, "Standardization in Technology-Based Markets," *Research Policy*, Vol. 20, 2000, pp. 587-602

[8] For the sake of clarity, the modifier "public" does not refer, in the first instance, to a government role. Rather, it refers to the "publicness" characteristics of the goods or services in question. Broadly speaking, economists identify two characteristics that account for intrinsic publicness: public goods are "non-rival" and "nonexclusive." A good is non-rivalrous if a person can consume the good without reducing its availability to others. The cost of providing for the use of an additional unit is zero. A good is non-excludable if a one can consume the good without paying for it. In such circumstances, a private market will not adequately provide the good. See, Pindyck and Rubinfeld, *op. cit.*

[9] Gregory Tassey, *The Technology Imperative*, Edward Elgar, 2007, pp. 290-295.

[10] General purpose technologies, like nanotechnology, are systems of technology whose benefits spillover and enable new products and services or enhance the productivity of the downstream industries they "feed." They provide a platform from which many markets can evolve. See Robert Atkinson, *The Past and Future of America's Economy: Long Waves of Innovation that Power Cycles of Growth,* Edward Elgar, 2004; and Bresnahan, T., Trajtenberg, M. (1995). "General purpose technologies—Engines of growth?" *Journal of Econometrics* Vol. 65, pp. 83–108.

[11] Tassey, 2007, *op. cit*.

> "Existing standards developing organizations or SDOs, both public and private, organize their work through groups of experts focused on specific application areas. With nanotechnology, however, technical groups spanning the entire technology, or very broad aspects of the technology such as environmental safety and health issues, have been formed to coordinate standard setting activities and to allow for sufficient flexibility to accommodate rapidly evolving knowledge about nanotechnology and its potential risks and benefits."[12]

Nanotechnology development is still in an early stage. Current nanotechnology standards development activities are focused on addressing fundamental issues such as terminology, measurement and property characterization aspects, and material behavior, including toxicological aspects. As interest in nanotechnology has grown, the breadth of consensus standards development has grown.[13]

1.4 Nanoscale Basics

Nanoscience and nanotechnology involve the knowledge of, and know-how for, precisely manipulating the structure of matter at the molecular level. A nanometer is a thousandth of a micron and a micron is a thousandth of a millimeter, so a nanometer is a millionth of a millimeter or 10^{-9} meters. In other words, a nanometer is one billionth of a meter.

As an indication of just how small that is, a single human hair has a diameter between 80,000 and 100,000 nanometers. Many important functions of living organisms take place at the nanoscale. The human body uses natural nanoscale materials such as proteins and other molecules, to control the body's many systems and processes. A typical protein such as hemoglobin, which carries oxygen through the bloodstream, is 5 nm in diameter.[14]

To be classified as a *nanomaterial* (NM), the material must be less than 100 nm in size in at least one direction. A *nano-object* is a material with at least one dimension in the *nanoscale* range of 1 to 100 nm, and a *nanoparticle* is a nano-object with all three external dimensions in the 1 to 100 nm range and showing a property not evident in the bulk material. Hence, a *nanofiber,* 400 nm long and 12 nm in diameter, and a 20 nm

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[12] Vladimir Murashov and John Howard (Editors), *Nanotechnology Standards*, Springer, 2011, p. vi.
[13] A. Jillavenkatesa, Ph.D., H. Evans, Ph.D., and H. Wixon, J.D., "Patents and Intellectual Property Management in Nanotechnology Standardization: A NIST Perspective," National Institute of Standards and Technology, U.S. Dept. of Commerce (Commissioned by the National Academies and Presented to the Symposium on Management of Intellectual Property in Standard-Setting Processes), *Board on Science, Technology, and Economic Policy,* October 3-4, 2012.
[14] Andrew W. Salamon, Patrick Courtney and Ian Shuttler, *Nanotechnology and Engineered Nanomaterials: A Primer*, PerkinElmer, 2010.

diameter *nanoparticle*, are both classified as nanomaterials.[15]

Nanotechnology involves imaging, measuring, modeling, and manipulating matter on the nanometer scale. At this scale, new material properties can emerge (e.g., the color of matter may change due to quantum properties), or entirely new structures may be possible. For example, a C60 fullerene — referred to as a "buckyball" — is a small carbon molecule with a structure similar to a soccer ball that has unique chemical and electronic properties.[16]

1.4.1 Nanoscience and Nanotechnology

Nanoscience involves research into, and discovery of, nanoscale principles and materials. Nanoscience bridges disciplinary boundaries because the same nanoscale principles and tools apply to chemistry, biology, physics, and other fields. Scientists working in this field aim to discover new phenomena, properties, and functions at the nanoscale; develop libraries of components to form building blocks for potential future applications; and advance the tools used in characterizing, monitoring, and controlling matter at the nanoscale. They are also interested in organizing new nanostructures into larger and more complex functional structures and devices.[17]

Nanotechnology is concerned with the control and restructuring of matter at the atomic and molecular levels in the size range of about 1 to 100 nanometers. The aim of nanotechnology is to create materials, devices, and systems with fundamentally new properties and functions by engineering their small structure. Nanotechnologists aim at changing the properties of materials in an affordable fashion, especially for manufacturing and molecular medicine applications.[18]

Advances in nanotechnology promise to enable revolutionary technological advances and introduce new products across a wide spectrum of application areas. For example, nanoscale processors and other electronic components are expected to enable smaller and smaller features that will improve speed and performance. Nanotechnology-based water purification methods are being developed as well as medicines to deliver therapeutic drugs to a targeted cancer cell by means of nanoparticle vehicles. Carbon-based nanocomposites are among a new class of lightweight, strong, fuel-saving material for use in cars, airplanes, and military equipment. High performance paint and other coatings are another area of concentration.[19]

1.4.2 The Future Significance of Nanotechnology

Nanotechnology is recognized as a "general purpose technology" comparable to the development and application of electricity, biotechnology, and digital information.

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[15] Ibid.
[16] Jillavenkatesa, *op. cit.*
[17] Courtland Lewis, *Innovations in Nanotechnology at the NSECS and NNIN: Highlights of Achievements*, prepared for the National Science Foundation, June 2011.
[18] Ibid.
[19] Jillavenkatesa, *op. cit*

Research in nanotechnology is broad-based and multidisciplinary. By capitalizing on the unusual properties of materials at the nanoscale, it is anticipated that the application of nanotechnology will profoundly affect how we live, our health, what we produce, how we interact and communicate with others, how we produce and use new forms of energy, and how we maintain our environment.[20]

The wide range of application areas to which nanotechnology can be applied suggests that the potential market, in terms of products and jobs, is significant. Lux Research, a widely cited source, estimates that in 2009 businesses generated $254 billion in revenue from products incorporating nanotechnology. It estimates that the total market in 2020 could be as high as $3 trillion.[21]

The global landscape for nanotechnology is emerging as a very competitive environment. The United States government advanced the global pace for nanotechnology innovation by launching the National Nanotechnology Initiative in 2000 and by investing almost $18 billion of federal funds since then; however, over the past decade other nations have ramped up their own programs and are significantly investing in and prioritizing nanotechnology over other programs. The realization of the promise of innovations enabled by nanotechnology is closely coupled with the need for environmental, health, and safety (EHS) research. An improved understanding of the EHS effects of nanoscale materials will help foster a regulatory environment that supports the safe development of nanotechnology and that provides certainty for companies as they develop new products incorporating nanotechnology.[22]

1.5 The National Commitment to Nanoscale Science and Technology

1.5.1 The Federal Nanotechnology Infrastructure

According to the President's Council of Advisors on Science and Technology (PCAST):

> "The National Nanotechnology Initiative (NNI) is the U.S. Government's crosscutting program that coordinates Federal research and development (R&D) activities in nanoscale science, engineering, technology, and related efforts among various participating agencies. The Federal Government launched the NNI in 2001 with an initial $500 million budget to accelerate the development of nanotechnology. Over the ensuing […] years [...] the NNI has played a key role in positioning the United States as the world leader in both nanotechnology R&D and commercialization. The NNI has also catalyzed State activities that leverage Federal investments with a focus on economic growth and job creation. Indeed, nanotechnology appears slated to become an

[20] Lewis, *op. cit.*
[21] Jillavenkatesa, *op. cit*
[22] Ibid.

> important contributor to the economic growth of the United States over the coming decade and beyond."[23]

Central to the progress envisioned by the PCAST are two major sources of nanotechnology research and development, both funded by the National Science Foundation: the Nanotechnology Science and Engineering Centers (NSECs) and the National Nanotechnology Infrastructure Network (NNIN). The NSECs and NNIN facilities and the start-ups and other commercial ventures formed as a result of advances made at these centers and facilities have achieved many innovations and also have supported education and outreach efforts.[24]

In addition to the NSECs and the NNIN facilities, federal agencies have underwritten and developed a broad array of capabilities to advance the technology of the nanoscale. For example, the Nanotechnology Characterization Laboratory (NCL), operated under the National Cancer Institute's Cancer Nanotechnology programs, is focused on the pre-clinical characterization of nanomaterials intended for cancer therapeutics and diagnostics developed by researchers from academia, government, and industry. The Federal Drug Administration (FDA) and the National Institute for Occupational Safety and Health (NIOSH) have developed expertise and research facilities for physical and biological nanomaterial characterization over the past few years.

NIST has developed significant capabilities in nanotechnology metrology and measurement. Those capabilities include measurement science and method development for toxicological, environmental, and physical-chemical nanomaterial assessment, including nanoparticle metrology for applications in health and the environment. Additional capabilities include the preparation of gold, titanium dioxide, silver, and carbon nanotube reference materials and other standard reference materials. Also, through its Center for Nanoscale Science and Technology (CNST), NIST maintains the National Shared-Use Nanofabrication facility that provides industry, government, and academia with access to a comprehensive suite of tools, processes, and measurements for nanofabrication.

Federal agencies, such as the Consumer Product Safety Commission (CPSC), the Environmental Protection Agency (EPA), and the NIH's National Institute for Environmental Health Science (NIEHS), have strong interests in nanotechnology research, but tend to fund other agencies or university centers to perform the research.

The Department of Energy's (DOE's) National Laboratories, too, have developed nanotechnology capabilities that are important to their mission areas.

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[23] *Report to the President and Congress on the Third Assessment of the National Nanotechnology Initiative,* Executive Office of the President, President's Council of Advisors on Science and Technology, March 12, 2010.

[24] Lewis, *op. cit.*

The patterns of collaboration within, and among, these organizations and industry are complex. Due to nanotechnology's inherently interdisciplinary nature, groups of researchers are learning to collaborate across organizational lines.[25]

1.6 Nanotechnology and Industry

1.6.1 Market Growth Projections

Since this economic impact assessment is retrospective, future projects are beyond its scope. Not surprisingly, projections tend to outpace actual outcomes. Estimates for the worldwide market for nanotechnology vary, from billions to trillions of dollars over the coming decade.[26]

A 2003 study found that a small number of commercial nanoscale products and applications had emerged, such as nanoscale titanium dioxide, gold, silver and copper additives that improve the performance of plastic, paint, and other bulk materials. It was estimated that more than a dozen companies had established medium-to-large-scale manufacturing facilities.[27] Other products were assessed as close to commercialization, such as nanoscale drug delivery vehicles and carbon nanotubes for field emissive displays. Demand for nanoscale raw materials such as nanotubes was substantial in 2003.

By 2009, a survey by the National Center for Manufacturing Science (NCMS) found that industrial uses of nanotechnology had become routine in companies that had invested in enhancing the awareness and skill levels of scientific and engineering staff.[28] Nano-engineered material properties, near-atomically precise material or thin-film features, and rapid processing methods, they report, are becoming commonplace in a broad range of manufactured components for consumer and durable goods. NCMS found that nearly 25 percent of respondents' organizations are already marketing products and instruments incorporating nanotechnology, and about 85 percent were expected to commercialize products by 2013. According to NCMS survey results, current applications are dominated by:

- Nanomaterials (e.g. nano-structured catalysts, carbon nanotubes, quantum dots, nanowires and dopants);
- Complementary metal-oxide semiconductor (CMOS)-based electronics and manufacturing processes;
- Other silicon-based energy conversion process industries that leverage similar large scale fabrication equipment;
- Thin-film coating processes;

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[25] Vincent Hackley, NIST, personal communication, April 04, 2013.
[26] Mihail C. Roco, et. al., *NanoTechnology Research Directions for Societal Needs in 2020*, WTEC, September 30, 2010, p. v.
[27] Rashba, Edward and Daniel Gamota, "Anticipatory Standards and the Commercialization of Nanotechnology," *Journal of Nanoparticle Research* Vol. 5, No. 3-4, 2003, pp. 401-407.
[28] As discussed in Section 5.1.1 of this report, such companies may be overrepresented in the survey conducted for this impact assessment.

- Closed-environment handling systems;
- Nanotechnology-enabled, miniaturized biomedical and diagnostic devices; and,
- Designer drugs and targeted therapies.[29]

A close industry observer notes that, today, nanoproducts are coming to market too fast for environmental sciences and toxicological sciences to keep up. This is creating gaps in the industry's ability to analyze risk.[30] Closing those gaps is one of the objectives for standards developers.

1.6.2 Nanotechnology Value Chain

The value chain depicted in Figure 1 is a snapshot of the complex process by which many economic actors contribute their "ingredients" to product and service integrators further up the chain. Those contributions "add value" that ultimately provide nanotechnology-based products and services to intermediate producers and end users, such as consumers. Since nanotechnology is expected to affect so many industries it may be more helpful to refer to the "nanotechnology innovation system." In any event, Figure 1 is intended to help the reader picture the basic relationships among the key institutional actors.[31]

Beginning at the top of the figure ("downstream" of the technology's origin), industry representatives distinguish the widest possible ranges of products including foods, beverages, personal care and cosmetics, pharmaceuticals, medical devices, paints and coatings, structural materials, automobile tires, energy, lightweight materials, clothing, sporting goods, and communications. Each of these application areas has its own value chain of intermediate and ultimate consumers but below that level the segments of the value chain will be the same.

Upstream from the application areas are material synthesizers and raw material producers. More than 40 nanomaterials are used in commercial products and in research and development projects. Their applications span a wide range of products.[32]

At the upstream "source" of the value chain is the network of university organizations funded through the NNI, described in Section 1.5.1 of this report.

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[29] *2009 NCMS Study of Nanotechnology in the U.S. Manufacturing Industry*, National Center for Manufacturing Science, August 23, 2010

[30] Andrew W. Salamon, "The Current World of Nanomaterial Characterization: Discussion of Analytical Instruments for Nanomaterial Characterization," *Environmental Engineering Science*, Volume 30, Number 3, 2013.

[31] The value chain concept will be referred to in the discussion of economic impact in Chapters 5 and 6 of this report.

[32] See Salamon, 2013, *op. cit.* and Salamon, et. al., 2010, *op. cit.*

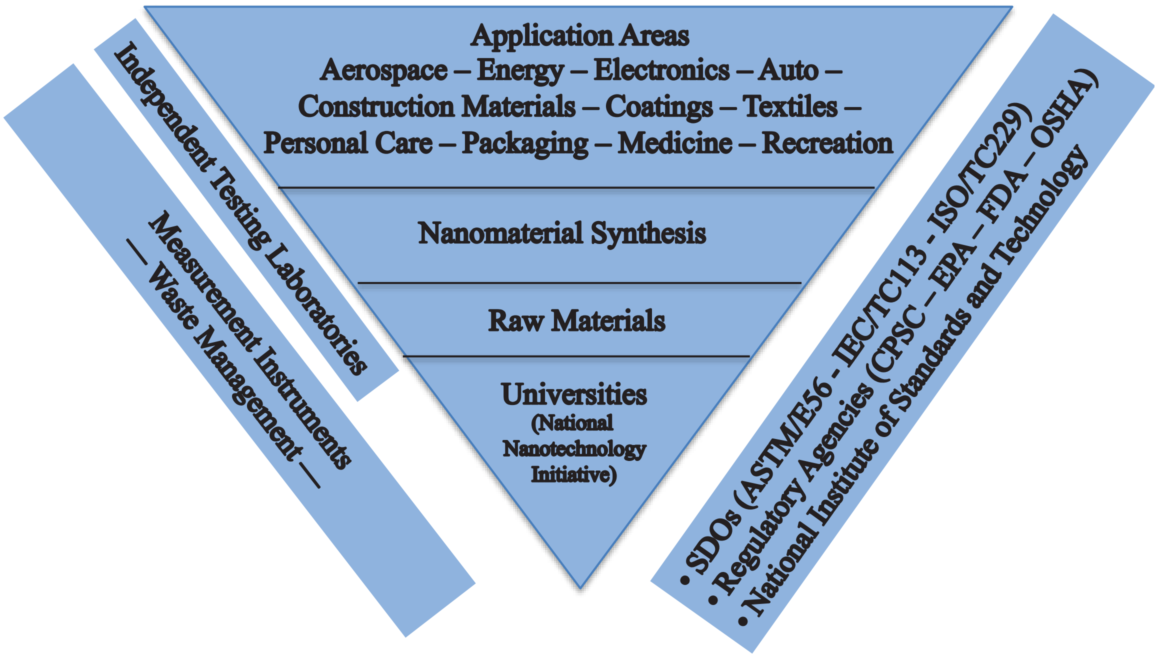

Figure 1. Nanotechnology Application Value Chain

Some elements of the supply chain provide products and services that cut across tiers of the value chain and act as infrastructural elements. The adjacent rectangles on the left represent cross cutting private sector elements. The availability of testing laboratories with proficiency to measure the large number of properties for which values will need to be measured is important to the growth and expansion of nanotechnology applications on the horizon. Independent testing laboratories are participating in nanotechnology standards development and are in the process of "gearing up" to fill their pervasive role.

Instrumentation manufacturers, too, play a crosscutting role. Instrumentation is a key to leading edge university research and is integral with much of NIST's measurement mission. Instrumentation has been a major focus of SDO activities and will play a large role in the implementation of regulation. Instrumentation will also be important across the vast variety of application areas because of the common industry problem of nanomanufacturing waste management and its environmental implications.[33]

The adjacent rectangle on the right of Figure 1 represents both mixed private-public sector value chain element (SDOs) and purely public sector elements (regulatory agencies and NIST). The economic role of the SDOs is discussed in section 1.3.1. The regulatory agencies are in the process of learning how to regulate nanomaterials and products. From an industry perspective their decisions are critical to how the industry will take shape in the years ahead. Some regulators are developing expertise and constructing

[33] Ibid., Salamon, 2013.

research facilities for physical and biological nanomaterial characterization while others are funding existing capabilities to conduct important analyses.

Last, but not least, NIST regularly interacts with upstream and downstream elements of the value chain. NIST routinely works with producers, researchers, and other federal agencies, making significant contributions to all the nanotechnology SDOs. It develops, produces, and distributes nanotechnology-related reference materials and a range of related measurement methods and procedures. In addition, NIST maintains the Center for Nanoscale Science and Technology (CNST), a national user facility equipped with state-of-the-art commercial fabrication tools, next-generation nanoscale measurement instruments, and a multi-disciplinary staff of scientists and engineers.

In this introductory chapter the motivation for this impact assessment has been explained; the basic concept of "nanoscale" has been defined; the national policy interest in nanotechnology has been presented; and the elements of the nanotechnology innovation system have been identified. In the following chapter the central focus of this economic impact assessment, nanotechnology standards development organizations (SDOs), will be identified and many of the issues that motivate the early activities of the SDOs will be highlighted.

2 Nanotechnology-Focused Standards Development Organizations (SDOs)

2.1 SDOs Focused on Nanotechnology[34]

The major nanotechnology standardization efforts of SDOs were initiated in the early to mid-2000s. They include the efforts of ASTM International, the European Committee for Standardization (CEN), the International Electrotechnical Commission (IEC), and the International Organization for Standardization (ISO).

Activities of three of these organizations, ASTM, IEC, and ISO, fell within the scope of this economic impact assessment. Based on communications with the U.S. Technical Advisory Groups (TAGs) of these SDOs, approximately 150 private sector, public sector, and university organizations are involved in the development of nanotechnology documentary standards.

ASTM International, TC E56. Established in 2005, ASTM International's Committee E56 on Nanotechnology focuses on terminology standards, definitive practices, test methods, and interlaboratory studies. ASTM also develops nanotechnology guidance information and requirements specifications. E56 coordinates ASTM committees on aspects of nanotechnology and participates in other nanotechnology standardization organizations. Many of the Committee's standardization efforts focus on measurement or characterization test methods for nanomaterials or their related properties. These test methods provide a common basis for measurement and support the reproducibility of measurement within and between laboratories. Standardized test methods are important for regulators and can reduce regulatory burdens on the regulated community. Subcommittee standardization activities include: informatics and terminology; physical, chemical, and toxicological properties characterization; environment, health and safety; and nano-enabled consumer products.

International Electrotechnical Commission (IEC), TC 113.
IEC TC113 on "Nanotechnology Standardization for electrical and electronic products and systems" began with the establishment of an Advisory Board on Nanotechnologies, 2005. The Advisory Board is charged with reviewing progress, expectations, and impact on electrotechnical standardization in nanotechnology. The scope of this activity includes standards development relevant to electrical and electronic products and systems in the field of nanotechnology.

[34] Unless otherwise indicated, this section relies on A. Jillavenkatesa, Ph.D., H. Evans, Ph.D., and H. Wixon, J.D., "Patents and Intellectual Property Management in Nanotechnology Standardization: A NIST Perspective," National Institute of Standards and Technology, U.S. Dept. of Commerce (Commissioned by the National Academies and Presented to the Symposium on of Intellectual Property in Standard-Setting Processes), *Board on Science, Technology, and Economic Policy,* October 3-4, 2012.

Working group standardization activities include: terminology and nomenclature (jointly with ISO TC229); measurement and characterization (jointly with ISO TC229); and assessment of performance, reliability and durability related to nanotechnology-enabled aspects of electronic components and systems.

International Organization for Standardization (ISO), TC 229. ISO TC229 was established in 2005 with a broad scope, addressing standardization issues related to understanding and controlling matter and processes at the nanoscale, and also to utilizing the unique properties of nanoscale materials to create improved materials, devices, and systems properties.

Working group standardization activities include: terminology and nomenclature (jointly with IEC TC113); measurement and characterization (jointly with IEC TC113); health, safety and environment; and materials specification. Two task groups are also under way to: 1) identify and make recommendations about important issues concerning the consumer and societal dimensions of nanotechnology, i.e., the groups seek to identify important issues in these areas and make recommendations; and 2) review the standardization opportunities for nanotechnologies to address issues in the sustainability arena.

2.2 The SDO's Early Efforts[35]

2.2.1 Proactive Standards Development

The immaturity of the nanotechnology field, the pace of development, and the scope of potential applications have necessitated an important challenge for SDOs that is being met, according to close observers, by a novel approach to standards development:

> "The desire to guide the development of an emerging technology, and to proactively assess and manage any risks arising from that technology at the earliest opportunity, highlights the challenging conditions under which nanotechnology standards are being developed. While the electronics industry has been at the forefront of proactive approach to standards development and IEEE coined the term "anticipatory" standards to describe standards produced well before the products they concern are commercialized, nanotechnology standards development has brought proactive standards development into the main stream and has become a testing ground for this approach. […] The launch of national nanotechnology programs in the first 5 years of the twenty-first century was followed by establishing nanotechnology technical committees and working groups in major standards developing organizations. Unlike the traditional structure of standards development

[35] Unless otherwise indicated, this section relies on, Vladimir Murashov and John Howard (Editors), *Nanotechnology Standards,* Springer, 2011.

> around specific application areas, umbrella committees were formed to cover nanotechnology as a whole, which reflects the nascent nature of nanotechnology and the desire to guide its development."[36]

Nanotechnology standards developers are mindful of the public's initially negative reception of genetically modified organism-based products. Failure by the product developers to consider early the risks that the public would perceive "down the road" contributed to the public's initial attitude. The subsequent slow pace of acceptance significantly hinders the development of what many regard as promising genetically modified organism (GMO) technology.[37]

2.2.2 Early Technical Concerns

The scope of nanotechnology standardization efforts is very broad. Sketched out below are major technical areas of concern: (1) definitions, terminology, nomenclature, and data file formats; (2) reference material standards; (3) metrology and measurement; (4) performance standards; (5) environmental, health, and safety (EHS).

Importantly, observers note that "proactive" standards development faces the unique challenge of reaching consensus under conditions of limited knowledge.[38] A cacophony of definitions, terminology, nomenclature, and data file formats is one manifestation of this knowledge constraint. "The multidisciplinary nature of nanotechnology" writes an SDO participant, "almost invites a similar multiplicity of definitions as each specialty (or scientific discipline) adjusts to the new findings of what is a dynamic research effort." "The same dynamism," it is argued, "leads to ambiguity in meanings and to uncertainty in the overall impact this field will have when products are commercialized."[39]

The properties that various organizations and scientific disciplines associate with nanoscale materials are varied. Standardized definitions, terminology and nomenclature, facilitate the repeatability of experimental data among separate research groups, help support the development and use of standardized reference materials, and serve as a communication tool in grant applications and for the protection of patents. Standardization of file format for the exchange of data on nanomaterials and characterizations is also part of this area of concern.

Reference material standards are an area of interest to nanotechnology SDOs. Reference materials (RMs) have homogeneous and stable properties that have been established for an intended use in a measurement process. They are used in the calibration of a measurement system, assessment of a measurement procedure, assignment of values to other materials, and quality control. They are regarded as essential tools in the quest for comparable and reliable measurement results. Eventually, the production of reference

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[36] Ibid., p. 14.
[37] Ibid., p. 13.
[38] Ibid., p. vi.
[39] Ibid., p. 21.

materials will depend on the availability of laboratories that are proficient in the measurement of the properties for which values need to be measured. As discussed momentarily, concerning metrology and measurement standardization efforts, those properties are many. The awareness of the need for RMs is growing.[40] The availability of reference material standards for nanoparticle size, film thickness, chemical contrast imaging, surface area measurement, powder porosity, and carbon nanotube characterization is important to the work of SDOs that develop test methods.

Metrology and measurement are the bridges from science to technology.[41] They are a major area of concern for nanotechnology SDOs. The predictive models required for nanoscale manufacturing can only be attained on the basis of measurement results that are widely reliable and comparable. Reliability and comparability, in turn, require measurement traceability to international standards; stepping stones to quality products with widest possible acceptance in the global marketplace.[42]

In the words of a nanotechnology SDO participant, “engineers know that if you can't measure it, you can't build it.” That concept applies across the nanotechnology value chain in the source and quality of raw materials, the control of the nanomaterials manufacturing process, and the formulation and integration of end products into systems of products, their use, and their disposal. It is noted that because nanoproducts are coming to market faster than environmental sciences and toxicological sciences are able to keep up, gaps in our ability to measure environmental, health, and safety risks are occurring. These risks are the measurement challenges that are common across the value chain and will be foundations for measurement instrumentation as they develop in response to new commercial uses.[43]

The metrology and measurement challenges are significant. At least twenty-three different physio-chemical material properties are important to characterize as part of the risk assessment process. The nine most common nanomaterial characteristics are the size of the particle, its shape, size distribution, concentration, agglomeration, surface characteristics, presence of surface coatings, presence of impurities, and structure. More than 35 analytical techniques are available to characterize these nine basic nanomaterial characteristics (e.g., scanning electron microscopy (SEM), transmission electron microscopy, atomic force microscopy, and confocal microscopy, dynamic light scattering (DLS), field flow fractionation (FFF), molecular gas adsorption (BET), electrophoresis, ultraviolet/visible spectroscopy (UV/Vis) and fluorescence spectroscopy (FL).[44]

According to instrumentation experts, “there is no single instrument that can do it all …and… multiple instrument manufacturers may provide instrument solutions that exacerbate the need for specific skills to precisely prepare samples, maneuver through

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[40] Ibid., p. 53.
[41] Ibid., p. 81.
[42] Ibid., p. 77.
[43] Salamon, 2013, *op. cit.*
[44] Ibid., p. 103.

different instrument software packages, and finally obtain and interpret the data."[45] As demand for nanotechnology-based products grows, it is expected that demand for new nanomaterial characterization methods and instruments will also grow.[46] Standardization of measurement and characterization for nanotechnology is believed to be critical to the promotion of industrial applications of nanotechnology. It is also thought to be critical to bringing about social acceptance of nanotechnology.[47] Measurement guides and standards have been an important nanotechnology SDO thrust.

Performance standards for nanotechnology-base products are another early area of SDO focus. An SDO participant explains performance standards as follows:

> "[Performance standards] are intended to support the fabrication of new innovative products with extraordinary high performance enabled by the use of nanotechnology. Therefore, they support commercialization of scientific results by providing standardized methods to qualify nanomaterials and control nano-related production processes. Nanotechnology–enabled products are to be developed and produced for a specific purpose. […] [T]he product must be specified in terms of its performance from the perspective of the customer/user, which is a completely different point of view than the view of the engineer or scientist for nanotechnology materials or products."[48]

Illustrating by reference to a nano-enabled battery, the authors continue:

> "The main relevant performance measures from the users' perspective are energy storage capacity, recharging time and the maximum power that can be drawn from the battery. Additionally the user will be interested in the durability… To design and produce such a battery, there has to be a model that relates nanomaterial properties and process parameters in the production process to the superior performance of the battery. […] [T]here is a systematic way to do this. The two tools are called Advance Product Quality Planning (APQP) and Quality Function Deployment (QFD)."[49]
>
> "The central idea is the implementation of the "key control characteristic (KCC)" concept, i.e. the identification of those material and process parameters which are key to ensuring that the technical

[45] Ibid., p. 104.
[46] Salamon, 2013, *op. cit.,* p. 107.
[47] Murashov and Howard, *op. cit.,* p. 91.
[48] Ibid., p. 118.
[49] Ibid., pp. 91-92.

> specifications for the performance parameter of the final product are met."[50]

Material parameters, production process parameters, and product planning tools have been areas of early concentration for nanotechnology SDOs.[51]

Environmental, health and safety (EHS) aspects of nanotechnology are a major public concern and involve standards development aimed at the characterization and minimization of risks; nanotoxicology; and workplace exposure limits, hazard communication instructions, safety procedures and codes of conduct, and industrial hygiene guidance for safe handling of nanomaterials. SDO participants recognize that understanding the risks associated with the manufacturing and use of nanoscale products is an important part of moving from nanoscience to application and also that many of the same issues have been raised in other industrial settings outside the nanotechnology context. It is expected that standards developed for other purposes may need adaptation for application in the nanotechnology context.[52]

Some express enthusiasm for the unusual historical opportunity that early stage nanotechnology standards development offers:

> "For the first time in the history of industrialization, nanotechnology offers the unique opportunity to consider material safety concerns prior to widespread adoption and use by industry. Many scientists around the world have been motivated by this and are working on developing and applying nanotechnology as safely as possible, attempting to avoid the pitfalls of our earlier introductions of new chemicals and chemical processes into commerce."[53]

The anticipated scale of the requirement for nanomaterial testing is significant. One projection puts the timeframe for assessing the toxic potential of all existing nanomaterials in the U.S. between 34 and 53 years at costs ranging from $249 million, for optimistic assumptions, to $1.18 billion.[54]

The nanotechnology SDOs that are the subject of this assessment have been characterized in this section; the unique opportunities afforded by early stage nanotechnology standards development has been highlighted; and some of the main technical concerns of the nanotechnology SDOs have been highlighted. In the following chapter, the framework for estimating the industry impact of SDO participation is described.

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[50] Ibid., p. 114.
[51] Ibid., p. 93.
[52] Ibid., pp. 164-176.
[53] Ibid., p. 179.
[54] Ibid., p. 205.

3 Economic Analysis Framework

3.1 Documentary Standards as a Response to Emerging Market Design Problems

A SDO is a collective activity often involving members from industry, government, academia, and citizen organizations. Previous impact assessments for NIST's Standards Coordination Office have discussed NIST's role in the standards development process from an economic perspective.[55] NIST personnel in standards development organizations typically fulfill two economic roles: that of an "honest broker" due to the absence of a product-specific vested interest thus reducing the cost of coming to consensus; and a that of a "conduit," increasing the likelihood that the underlying measurement principles are traceable to international standards of measurement.

The focus of this economic impact assessment is on private sector participation in SDOs and the associated benefits and costs. Still, from an economic perspective, these collective activities are also responses to emerging market design issues, commonly referred to as "market failures."[56] According to a prominent standards researcher:

> "There is still little awareness about the benefits of standards and standardization among researchers. Due to the broad accessibility to standards […] the connected free-rider ["externalities"] problem has resulted in too few incentives for researchers to become actively engaged in standardization, especially in new fields of research and technology."[57]

The interdependence between research and standardization has been characterized as catalytic; as a technology transfer channel for knowledge integrated within a consensus process. On this account, the selection and prioritization of knowledge and technologies in the SDO consensus process leads to the bundling of resources that helps avoid fragmentation among the many actors in industry, universities, and the public sector. In addition, an exchange of tacit knowledge ("know-how") takes place during the standardization process. Finally, there is also an integration of inputs from heterogeneous sources, especially of knowledge from implementers of technologies and consumers. Because consensus standards are widely accessible, they are more likely to be broadly implemented. Maximum economic efficiency is realized if publicly funded R&D results

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[55] See, *The Economic Impacts of Documentary Standards: A Case Study of the Flat Panel Display Measurement Standard (FPDM),* David Leech and John T. Scott, National Institute of Standards and Technology, December 2011.
[56] For a thorough discussion of "market failures" and their causes, see John Roberts, *The Modern Firm,* Oxford University Press, 2004; Gregory Tassey, *The Economics of R&D Policy,* Quorum Books, 1977; and Oliver Williamson, *The Economic Institutions of Capitalism,* Free Press, 1985.
[57] Kurt Blind, "Standardization as a Catalyst for Innovation," *ERIM Report Series*, 2009 (Reference No. EIA-2009-LIS, SSRN: http://ssrn.com/abstract=1527333).

become public goods via standards. In addition to creating channels for knowledge and know-how transfer within the SDO, as technical infrastructure the standards provide a framework for future research and product development. In early stages of emerging fields, self-regulation via consensus standardization allows flexible framework conditions which can later be transferred into governmental regulations.[58]

As discussed in greater detail below, this depiction of the economic dynamics of early stage standardization accords well with the findings of this report. One of the challenges of the standards development process is convincing potential private sector participants that it is in their interest to share know-how that will provide benefits to all participants. This sentiment is expressed by an industry participant:

> "Nanomaterial-based products have the potential for great monetary gain [therefore creating] a competitive market that is very secretive. Processes, formulations, and product risk mitigation are guarded secrets. Some companies consider their creative and cost–effective environmental health and safety (EHS) solutions as a competitive edge over their competition. In fact, in some cases, the cloak of secrecy covers the manufacturing EHS procedures that keep the workplace safe."[59]

Efforts at private collaboration and public-private collaboration arise in response to barriers to innovation. These barriers, in turn, are driven by two kinds of risk: technical risk and market risk.[60] Economic barriers that are likely to affect industry investment in the early stages of a technology development include:

- **Externalities** that deprive investors of compensation because benefits from their investments in technology "leak out" to other firms. Concerns about such leakage can deprive a burgeoning industry of the momentum needed to "take off." The SDO process can mitigate excessive secrecy by cultivating transparency about the dimensions of what is considered secret and a better appreciation of costs and benefits of excess secrecy.

- **Excessive discount rates** that cause potential benefits to be heavily discounted relative to investment projects with shorter projected recovery times. Qualitatively, this study suggests that the companies that participate in SDOs are focused on building the technical infrastructure for the market long-term.

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[58] Ibid.
[59] Salomon, *op. cit.*
[60] Gregory Tassey, "The Disaggregated Technology Production Function: A New Model of University and Corporate Research," *Research Policy*, Vol. 34, 2005, pp.287-303; *Economics of R&D,* Quorum Books, 1997, pp. 82-100. An extended discussion of barriers to innovation and technology in the context of the role of government and public research institutions is provided in Albert N. Link and John T. Scott, *Public Goods, Public Gains: Calculating the Social Benefits of Public R&D*, Oxford University Press, 2011, pp. 4-19.

- **Information asymmetries and uncertainties** that arise because the complexity of the technology makes agreement about product performance difficult. This is especially relevant to early phases of development when the requirements for conducting R&D and product development demand multidisciplinary teams, unique facilities, or the "fusing" technologies from heretofore separate, non-interacting industries. Market recognition difficulties can also arise because the technical breadth of the potential market is broader than the scope of existing markets and firms fail to recognize potential applications of their technology. The SDO organizations studied in this assessment ranked knowledge acquisition, market intelligence, and business-to-business (B2B) networking among the top beneficial activities associated with participation in their SDOs. (See Section 5.1.3, below.)

- **Network externalities** can affect market participation if a product will not interface with other products in the system and the cost of attaining compatibility or interoperability reduces the expected return on investment to the point that the project is not undertaken. (The mitigation of network externalities may not have been a leading concern of the earliest stage nanotechnology SDO efforts covered by this report; however, product and process interoperability standards are being developed by nanotechnology SDOs going forward.)

Providing an insight into the nature of economic barriers at work, an industry representative enumerated the following important concerns and barrier categories that instrument manufacturers face as they develop their marketing strategies for nanotechnology characterization instruments:

- Nanotechnology is a complex science (information asymmetries and uncertainties);
- Development of engineered nanomaterials requires varied skill sets (information asymmetries and uncertainties);
- The instrument market spans many scientific and engineering disciplines (information asymmetries and network externalities);
- There are a vast number of end-product applications, many unique (network externalities); and
- The industry is draped in secrecy (externalities).[61]

Documentary standards are developed, in large part, to mitigate barriers such as these. The very opportunities afforded by the existence of qualified SDOs like ASTM, IEC, and ISO, and the participation of large and small firms' future-focused business and technology leaders to address common, hard issues in competitively neutral environment, attest to the ubiquitous presence of economic barriers and industry's determination to

[61] Salamon, 2013, *op. cit.*

address them. The study survey instrument was designed to capture the manifestations of the barrier-mitigating effects of early stage documentary standards. Evidence that the standards are reducing barriers is discussed in Chapters 5 and 6.

4 Impact Assessment Approach

4.1 Survey Strategy

The focus of this impact assessment was on industry users and developers of nanotechnology documentary standards. The documentary standards published by three standards development organizations were selected as the study focus: ASTM International's Technical Committee on Nanotechnology (ASTM E56); the International Electrotechnical Commission's (IEC's) Technical Committee (IEC/TC113), Nanotechnology Standardization for Electrical and Electronics Products and Systems; and the International Organization for Standardization's (ISO's) Technical Committee 229 – Nanotechnologies (ISO/TC229). Based on communications with the ASTM and the U.S. Technical Advisory Groups (TAGs) of the IEC and the ISO, approximately 150 private sector, public sector, and university organizations are identified as being involved in the development of nanotechnology documentary standards. These organizations comprise one survey population subset.

In addition, it was hypothesized that many more private sector organizations utilize the published nanotechnology standards to reduce gaps in understanding and increase the efficiency of a wide range of production, testing, and research operations. To represent this facet of the user population, the support of two organizations was enlisted. Approximately 100 members of the broad-based NanoBusiness Commercialization Association (NanoBCA) were targeted. In addition, hundreds of recipients of the National Nanomanufacturing Network Newsletter (a "LISTSERVE") were also targeted to receive surveys.

A third element of the intended survey population included members of a network of university research organizations funded as part of the U.S. National Nanotechnology Initiative (NNI). The National Nanotechnology Infrastructure Network (NNIN) consists of 14 advanced nanotechnology user facilities, located at 14 major universities across the country. The site directors of these user facilities comprised a third survey population subset.

4.2 Survey Execution

The survey instrument was designed following background interviews with selected U.S. technical committee members from industry, universities, and government agencies. On the basis of their descriptions of the substantive benefits and costs of SDO participation, nanotechnology-specific impact activity categories were developed. (See section 5.1.3 below.) The survey instrument was tested and improved with feedback from potential industry survey recipients.

The survey was conducted by email with email or phone follow-up. Preceding the survey execution phase, the project was introduced to the potential survey populations through presentations by the project manager and interviews with U.S technical committee members.

An introductory email message was sent directly to the prospective respondents, some of whom who volunteered to be contacted directly, or, by proxy, though their technical committee chairpersons, a U.S. TAG liaison office, or by the NanoBCA's Executive Director. The email was sent directly to the 14 National Nanotechnology Infrastructure Network (NNIN) site directors. Most potential respondents were contacted multiple times, by the impact assessment project leader, by a U.S. TAG liaison office or technical committee chairperson, by the NanoBCA's Executive Director, and through multiple email appeals by the National Nanomanufacturing Network.

After multiple rounds of direct and indirect communications, 26 survey responses were obtained (in addition to numerous email exchanges). Thirteen (13) of these were industry respondents; 9 were university respondents; and 4 respondents were government agency representatives. The primary focus of the following analysis is the industry response. University and government agency responses are discussed qualitatively.

4.3 Comparison Scenario and Timeline

In general, the benefits of the SDO participation outputs are assessed using a counterfactual technique. In essence, the survey posed the following question to respondents:

> "For the activity area in your organization that benefited most from nanotechnology standards, what would it have cost your organization to perform those activities in the absence of ATM E56, IEC/TC113, and ISO TC229 standards published between 2005 and 2012?"

The counterfactual costs that respondents estimate would have been incurred in the absence of the relevant nanotechnology documentary standards are interpreted as the economic benefits of utilizing the standards. Respondents also estimated the annual costs of participating in the SDO technical committees and "pull costs," one-time labor and materials costs of adopting the standards. These costs are subtracted from the benefits estimates to obtain a measure of the net benefits resulting from the investment in the nanotechnology documentary standards.

The economic impact timeframe is 2005 to 2012. Survey participants provided information about the economic impacts of documentary standards published by ASTM E56, IEC/TC113, and ISO TC229 within that timeframe. (The standards were enumerated in the appendix of the survey instrument. The survey instrument is included in Appendix A of this assessment report.)

5 Survey Findings

5.1 Qualitative Findings

5.1.1 The Composition of Survey Participation

SDO participants were the only members of the industry population to provide survey responses. Despite considerable effort by the leadership of NanoBCA and the National Nanomanufacturing Network to solicit responses, numerous email requests from the impact assessment project leader, and follow-up exchanges, no responses were forthcoming from the potential industry respondents who did not participate in SDO activities.[62]

Too few university-based and government-based respondents provided sufficiently complete responses to estimate the economic impact of documentary standards to their institutions. Regarding government respondents, it was hoped that regulatory agencies would respond since it is believed that their processes have been significantly affected; however, no regulatory agencies responded to the survey.[63]

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[62] It is not unusual for surveys associated with case study economic impact assessments to have a small number of respondents. This has been a feature of narrowly focused microeconomic case studies since the pioneering work of Edwin Mansfield. Echoing the difficuties this study experienced, in his influential paper on social and private returns to innovation Mansfield writes: "As would be expected, a substantial percentage of those who were contacted refused to cooperate because, despite our assurances that the data would be held in the strictest confidence, they felt the data was too sensitive to show to outsiders." (Edwin Mansfield, et. al., "Social and Private Rates of Return from Industrial Innovations," *Quarterly Journal of Economics* Vol. 91, No. 2, 1977, pp. 221–240.) In addition to this general and long-standing sensitivity about sharing information concerning company innovation practices, as discussed in section 3.1 of this report, industry participants use the phrase "cloak of secrecy" to characterize the extraordinary sensitivity of participants in the emerging markets for nanotechnology-based products and services. All things considered, the number of survey responses (26) could be considered relatively good. One might also observe that the survey response *rate* is low. Of course broader participation would have increased confidence in the estimates of economic impact but response rate has rarely been reported in NIST economic impact assessments and usually no attempt is made to treat the survey data from these case studies statistically.

[63] Some potential respondents read the survey instrument as "industry-oriented." While that is true (the survey instrument *was* focused on the economic impact of documentary standards to industry), when they raised that issue in email exchanges they were requested to interpret problematic questions liberally; that the aim of the project was to understand the changes in resource allocations within their organizations, and among their collaborators, that resulted from the development and use of standards. The small number of full responses from some government-based and university-based respondents indicates that a liberal interpretation of "industry-oriented" questions was indeed possible. One government agency respondent suggested that the benefits would be substantial: "Prior to these standards, there was a lot of variation in protocols among laboratories within [our organization]. Work on safe handling procedures for nanomaterials in the workplace [has] been a key contribution ... to global health and safety practices."

One likely reason that potential survey respondents do not respond is that they do not grasp the potential benefits of SDO participation, or of standards more generally. One non-respondent (an industry "start-up") stated baldly: "the questions are really not applicable to the nano business." Yet, it is clear from the results of this economic impact assessment that the survey questions were germane and that the benefits of participation in SDOs are real for companies that understand how standards *are* related to their businesses and to free riders who enjoy the benefits of the SDO's outputs (documentary standards as well as informal industry communications) without contributing to their development.

To some extent, the same interpretation could apply to university-based respondents. A few very complete responses were received but, again, from those few already committed to the standards development process. Several non-responses were accompanied by email exchanges, the crux of which were that many university-based researchers do not appreciate the utility of standards because the academic community, as such, incentivizes scientific innovation rather than standardization. According to one member of the university community, reflecting the sentiments expressed in fewer words by many others:

> "Academic research is based upon peer-reviewed scholarly literature. Information about pre-existing methods is drawn from the "materials and methods" section of published papers. Definitions of terms are based on who coined the phrase, or how the term is widely used, in the literature. Standards documents, whether they agree or disagree, carry little to no weight, and I think that most academic researchers have little awareness of them."

To some extent, too, university researchers are just focused on other issues. According to a university researcher and SDO participant:

> "[A]cademics have a different perspective on standards development since they can investigate libraries of ENMs [engineered nanomaterials] that may not be of immediate interest to industry or suitable for certification as reference materials."[64]

Some university non-respondents are simply unaware of standards or their relevance to their operations. One nanofabrication center manager felt he had no contribution to make:

> "I manage a purely research-oriented university lab, and don't have any knowledge of these standards. My input would not be useful.

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[64] Vincent Hackley, et. al., "Enabling Standards for Nanomaterial Characterization," InfoSim, August, 2009, pp. 24-29.

> I would be very surprised if our grad student researchers were aware of the standards. [...] I can't say how much our site director knows about the standards since I can't recall discussing them with him."

Following-up with the site director, the manager's expectations were confirmed:

> "I am not familiar with the standard development process, and I could only guess as to their utility to industry. I would think that you would be better served by contacting people in industry or in trade groups that serve industry in the nano sector."

In the light of the value chain depicted in Section 1.6.2 of this report, above, and the economic policy assumption that it is desirable for university research to feed industry innovation, the distance from the university focus to an industry focus regarding nanotechnology standards is too great. Adding dimensions to the "value chain distance" issue, another thoughtful non-respondent focused on some of the university's more immediate links to industry:

> "While I can imagine that some of the equipment we use is subject to some of the standards in [the survey] Appendix, it would be the vendors who would relate to them better than our students. …[Y]ou're right from the instrumentation calibration perspective, [but] we rarely do our own. We send them to the vendors.
>
> My thinking is that unless a research topic specifically required us to read/review specific standards they would not be looked at.
>
> Times have certainly changed – I recall as an undergraduate back in the late 70's - it [discussion of standards] was almost a daily staple for some of the classes I was taking. …
>
> Looking at some of the titles under ISO, they would be highly useful. I know as a unit and institution we're becoming more aware of the safety (EHS) aspects of nanotechnologies.
>
> [Regarding] university PI start-ups, good question. I know our tech transfer folks are very interested in licensing IP (university patents) [but] where the standards come into play … I'm not sure – though – certainly if it goes to manufacture [there should be a connection]."

Currently, the links from industry standards to the university community are not obvious. An engineering professor and SDO participant observes:

> "The College and University are developing nanotechnology IP and licensing it, but there are few links between this and the ISO, ASTM, IEC standards developed so far."

Others appear to believe that the impetus for the linkage between standards-related activities and the universities is most likely to come from the outside:

> "The drive to establish this suite of methods is driven by the board ... consisting of representatives from industry, national labs, and other educational institutions."

While survey participation was limited, participants' formal and informal responses and communications provided a wealth of information and insights about early stage development of nanotechnology standards. One of these insights is that there appears to be a lack of effective linkages in the value chain connecting universities, increasingly anxious to transfer their technology, to the industry-wide perspectives represented by SDOs. The SDOs studied here appear to be populated by future-focused industry representatives struggling to lay the technical infrastructure intended to clear some paths to nanotechnology commercialization.

5.1.2 High-Impact Nanotechnology Standards

The survey was not intended to quantitatively discern the economic significance of individual standards or groups of standards; however, the majority of survey respondents identified the nanotechnology standards that were most significant for their organizations in terms of benefits received.

Of the 26 organizations responding, 21 respondents identified the nanotechnology standards that were most significant in terms of benefits created for their organizations. A list of the nanotechnology standards published by the ASTM International, IEC, and ISO technical committees was provided as an appendix to the survey instrument. From 2005 through 2012, there were 10 nanotechnology standards published by ASTM TCE56, 4 by IEC TC113, and 26 by ISO TC229. Each respondent was asked to examine the list of the 40 nanotechnology standards and to identify the five that were the most significant for the respondent's organization. For the standards that were indicated by more than one respondent, Table 1 shows the ranking of the top five (including ties—for example, three standards were top five picks for six of the 13 industry respondents and are tied for third place among the most significant standards for the industry respondents) standards based on a simple count of the number of respondents that chose each standard as one among its most significant five.

Table 1. Standards Among the Top Five (including ties) for Impact on the Organization's Activities

All Respondents (n = 21)	Industry Respondents (n = 13)	Documentary Standard Title
13	8	ISO/TS 80004-1:2010 – Nanotechnologies – Vocabulary – Part 1: Core terms
14	7	ISO/TS 27687:2008 – Nanotechnologies -- Terminology and definitions for nano-objects
10	6	ISO/TR 12885:2008 – Nanotechnologies – Health and safety practices in occupational settings
-	6	ISO/TS 80004-4:2011 – Nanotechnologies – Vocabulary – Part 4: Nanostructured materials
-	6	ISO/TR 13121:2011 – Nanotechnologies -- Nanomaterial risk evaluation
8	5	[ASTM E56] E2535-07 Standard Guide for Handling Unbound Engineered Nanoscale Particles in Occupational Settings
7	5	ISO/TR 11360:2010 – Nanotechnologies – Methodology for the classification and categorization of nanomaterials
7	5	ISO/TR 13014:2012 - Nanotechnologies - Guidance on physicochemical characterization...for toxicologic assessment
-	4	ISO/TS 12805:2011 – Nanotechnologies -- Materials specifications – Guidance on specifying nano-objects
7	-	[ASTM E56] E2456-06 Standard Terminology Relating to Nanotechnology

For the group of all types of respondents—from industry, academia, and government—standards about terminology and vocabulary and about health and safety are of greatest importance for the respondents. To explore further the difference, observed in Section 5.1.1, about the importance of nanotechnology standards for industry as compared with universities, the 13 industry responses were compared with the responses of the five university respondents that provided information about the nanotechnology standards most important for their work. In particular, as observed in Section 2.2.2, standards for materials specification and characterization are critical for industrial applications of nanotechnology, yet even those universities that report that nanotechnologies are significant for their work have a different view than industry about the importance of materials specification and characterization standards.

To explore the difference between the university and industrial respondents in the importance of the various types of nanotechnology standards for their work, the forty standards listed in Appendix A were divided into three categories: (1) vocabulary, terminology, or classification system, (2) health and safety, and (3) materials specification and characterization (not obviously in the health & safety category). With the 40 standards divided into the three broad types, there are nine in the vocabulary, terminology, or classification category,[65] nine in the health and safety category,[66] and 22 in the materials specification and characterization category.[67]

Each of the five university respondents provided a list of the five nanotechnology standards of most importance to the university. Of the five university respondents, four are large, major U.S. universities. For all four, among the five most important nanotechnology standards for the university, none were in the category for materials specification and characterization. The one university respondent from outside the U.S. was an exception. It had three of its five most important standards in the materials specification and characterization category.

[65] Using the numbering of the standards listed in Appendix A, these were standards numbered 1, 15, 17, 18, 19, 22, 26, 27, and 28.
[66] The standards numbered 4, 5, 6, 16, 20, 24, 25, 29, and 38.
[67] The standards numbered 2, 3, 7, 8, 9, 10, 11, 12, 13, 14, 21, 23, 30, 31, 32, 33, 34, 35, 36, 37, 39, and 40.

While 80 percent of the responding universities, and 100% of the responding U.S. universities, showed an absence of the importance for their work of the standards in the specification and characterization category, in contrast only 50 percent of the 12 industrial respondents answering the question reported an absence of important standards in that category.

5.1.3 Industry Activities Most Affected

In background interviews, technical committee members representing industry, universities, and government organizations discussed the ways documentary standards make a difference in their organizations, and from those discussions a list of nanotechnology-related activities emerged. To avoid asking too much of respondents, simply the information about the percentage of benefits in each of the top three categories was collected to indicate the areas of greatest importance. Each survey respondent was asked to determine the three activities in the list that within their organization were most affected by nanotechnology standards. Each respondent was asked to estimate the percentage of all benefits—for the organization from the adoption of nanotechnology standards—associated with each of the three most significant activities. For the 13 industrial respondents, Table 2 identifies and ranks the activity areas by the percent of total benefits accounted for by each activity.

Table 2. Industry Respondents' Activity Areas Most Affected by Documentary Standards*

Nano-Related Activities	Percent of All Benefits (Average of Respondents Reporting Activity Category as in Top Three)	Number of Respondents Reporting the Activity as in Top Three	Range for Percent of All Benefits
Safety & Environmental Monitoring and Risk Management	39	8	10-100
Product Design & Development (Excluding Regulatory Compliance)	38	8	20-50
Pre-Deveopment R&D & Knowledge Acquisition	36	6	20-60
Marketing, Market Intelligence & B2B Networking	30	2	20-40
Contract Negotiations	30	1	30
Quality Assurance & Control	20	2	10-30
Regulatory Compliance, Negotiations, & Monitoring	18	4	10-33
Equipment Adaptation & Acquisition Justification	17	3	10-20
Worker & Student Training	15	2	10-20
Intellectual Property Due Diligence	10	2	10

* Respondents were instructed: "[For the] Nanotechnologies-Related Activities Table ... select the top 3 activities within your organization that you judge have been most affected by nanotechnology standards and estimate the percent of all the benefits from nontechnology standards that each of these 3 activities represent. *(For example, your top 3 activities could each account for 33% of all benefits equally, leaving*

very little benefits accounted for by other activities; or they could account for 50%, 30% and 2%, leaving the unspecified 18% of all benefits spread among the remaining activities.)"

Some respondents briefly described how the existence of nanotechnology standards changed the processes within their organizations that resulted in efficiencies and quality improvements. Their comments reflect the ranking in Table 2, but also the breadth of the ways standards have an economic impact.

Many respondents highlighted the importance to their organizations of planning and implementing EHS procedures. Accordingly, respondents claim that guidance standards related to risk while working with nanomaterials were helpful in establishing internal practices to protect employees from potentially harmful exposure to nanomaterials; facilitating global corporate meetings concerning new risk management procedures or the development of new products; aiding in the work of safety and environmental monitoring of nanomaterials and as guidelines in the safe handling of nanomaterial; training workers in proper protocols and data handling; detailing a prudent approach to workplace safety and product stewardship; and enabling the improved design of laboratory and manufacturing space.

Others stress that terminology standards dramatically improved communications internally and externally. Some claim that consistency in terminology ensures that all participants, regardless of the diversity of their goals and perspectives, know what is meant by defined terms. Others stress that standard terminology supports *correct* communications; that participants know what is being communicated and also that what is being communicated is correct.

Some industry participants also benefit from the role of early nanotechnology standards to set specifications and materials usage in production quality assurance and in developing quality assurance plans.

Respondents stress several facets of the market intelligence value of the standards development process: allowing them to keep a focus on applications that matter to them; knowing the places where nanotechnology is being used; and supporting the product design and development that potential customers require.

Finally some respondents understand current standards as a step on the path to regulation in lieu of, or in conjunction with, slow-moving regulatory legislation.[68]

In summary, SDO members representing industry appear to be focused on gaining a firmer foothold in an ambiguous economic and regulatory environment. They appear to be very much future-focused, perhaps expecting to enjoy early-mover advantages in the marketplace. They are anticipating the market; concerned to reduce the technical and

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[68] Although Table 2 uses the information from the industry respondents only, for comparison, note that university-based respondents focused on EHS, student training, pre-developmental R&D, and quality control.

market risks associated with burgeoning markets; and concerned about the effectiveness and correctness of communications within their sometimes large and diversified organizations but also between their organizations and other stakeholders.

5.2 Quantitative Findings

To gain insight about the benefits and costs of the early stage of development of nanotechnology standards, the perspectives of the 13 industrial respondents, all of which are SDO participants, were examined. The respondents estimated the economic impacts of the nanotechnology documentary standards published by ASTM E56, IEC/TC113, and ISO TC229 within the period from 2005 (when those standardization efforts began) through 2012. As explained earlier, an appendix to the survey instrument provided a list of those standards. Each of the respondents was asked the following counterfactual question:

> For the activity area in your organization that benefitted most from nanotechnology standards, what would it have cost your organization to perform those activities in the absence of ATM E56, IEC/TC113, and ISO TC229 standards published between 2005 and 2012?

For purposes of benefit-cost analysis, the counterfactual costs that in the respondent's estimation would have been incurred in the absence of the relevant nanotechnology documentary standards are interpreted as the economic benefits accruing to the respondent's activity that benefited most from the standards. Each respondent's costs for the documentary standards are the costs of participating in the SDO technical committees plus the additional pull costs to implement the standards.[69] Industry survey respondents provided a range of information from which time series of costs and benefits were constructed. The number of full-time equivalent (FTE) personnel dedicated to the activity most affected by standards (see Table 2 for the activity categories) was estimated.[70] Also estimated was the multiple of these FTEs that would be incurred in 2012 in the absence of the documentary standards.[71] This counterfactual multiple was used to estimate the benefits—the avoidance of additional personnel costs—companies derived from the use of nanotechnology documentary standards in the activity that benefited most from the use of the standards.

Respondents' estimates of the average annual growth rate, over the period from 2005 through 2012, for the activities benefiting most from nanotechnology documentary

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[69] Communications with some respondents indicated that their estimates of pull costs included significant elements of direct operational costs. Adjustments were made to these high estimates based communications with respondents whose estimates, upon further investigation, were found to be a more accurate reflection of "pure" pull costs. Pull costs are indirect costs; the costs of identifying, acquiring, and implementing ("pulling in") information or know-how from external sources. See, Albert Link, *Economic Impact Assessments: Guidelines for Conducting and Interpreting Assessment Studies* (NIST Planning Report 96-1), May 1996.

[70] For the 13 respondents, the average was 3.19 FTE with a range between 0.05-20 FTEs.

[71] The 13 respondents reported multiples as high as 3 times with the average being 1.45 times more.

standards ranged from 0 to 100 percent. The estimated growth rates were used to derive, from the benefit of avoided personnel costs reported for 2012, the benefits in the earlier years of the 2005 to 2012 period. The benefits in terms of hours of personnel time saved were converted to dollar costs using the annual compensation of full-time workers engaged in those activities.[72]

One respondent estimated that there would have been a delay in some sales had important standards been delayed. That additional source of benefits was not factored into the estimated benefits, so there is an unmeasured benefit from avoiding a delay in sales.[73] The cost of SDO technical committee participation was derived from estimates of the average annual time each respondent devoted to technical committee work and each respondent's estimated annual compensation for the employees involved.[74] To this was added each respondent's estimate of "pull costs" to derive the total cost to respondents' organizations of participating in the technical committees' standards development process.[75]

Respondents estimated the scale of their own company's benefits from documentary standards relative to those of their direct competitors. The information about each respondent's share of the benefits was used to estimate benefits for the "industry," that is, the part of the broader emerging nanotechnology industries in which each respondent operates. The 13 respondents operate in different areas of the emerging nanotechnology industries, and each respondent's industry is assumed to include the responding company

[72] For the 13 industrial respondents, that reported annual compensation averaged $137,000 for the fiscal year 2012.

[73] Considering a technical committee's standards as a group, survey respondents estimated that NIST's participation in a technical committee's deliberation process shortened a standard's publication time by an average of 20 weeks. Since this economic impact assessment focuses on industry's costs and benefits, this time saving was not developed into an estimate of the social return on the investment of NIST's time in support of technical committee activities.

[74] The average of the 13 industrial respondents' average annual time for technical committee work was 218 hours per year, ranging from 40 to 500 hours. The average for the 13 respondents' annual compensation was $159,000, ranging from $45,000 to $250,000.

[75] The pull costs ranged from $975 to $66,000 for one-time labor costs and from $1000 to $4100 for one-time material costs. All but one of the 13 respondents were technical committee members during the study period (the one became a member in 2013) and, therefore, participated in the development of the standards. From the perspective of the respondent's sponsoring company, technical committee cost associated with the development of standards could be construed as a type of pull cost. However, for the participants, their technical committee costs were reported and then any separable, additional "pull costs" (apart from the costs of participation in the technical committee) were reported and the two categories of cost are combined into a total cost for each respondent. Companies that benefit from the nanotechnology standards but do not participate in technical committee activities are free riders and do not incur the costs of participating in the committee work to develop the standards, but they do incur pull costs. To estimate these, it was assumed that the temporal distribution of the non-participants' pull costs was identical to the temporal distribution of the separable pull costs reported by SDO-participating respondents (pegged to the earliest standard cited as most significant for the survey respondent's organization). The respondents' pull costs were multiplied by the average multiplier used to estimate benefits and costs of a respondent's close competitors from the benefits and costs of the respondent.

(or division in some cases) and its direct competitors in a particular segment of the nanotechnology supply chain.[76]

[76] While accepting SDO participants assertions regarding non-participants benefits might be questioned, relying on survey respondents to make estimates about their close competitors is a technique that has been used in many of the narrowly focused impact assessments conducted for NIST. See, for example, *Economic Impact Assessment: NIST-EEEL: Laser and Fiberoptic Power and Energy Calibration Services*," NIST Planning Report 00-3; *Economic Analysis of NIST's Low-k Materials Characterization Research*, NIST Planning Report 08-2; *Economic Analysis of NIST's Investments in Superfilling Research*, NIST Planning Report 08-1; and *The Economic Impact of Role-Based Access Control*, NIST Planning Report 02-1, all available at: http://www.nist.gov/director/planning/impact assessment.cfm

Arguably, survey respondent estimates concerning close competitors provides a more reliable picture of competitively meaningful markets (markets defined in terms of competition among providers of close substitutes — the basis of real-world competition) than the best standard, yet highly aggregated, U.S. Department of Commerce industry statistics. (See: http://www.census.gov/econ/survey.html) More detailed market analyses are typically available, at a signifant cost (relative to the typical economic impact assessment budget), from private sector market analysis companies. Unforunately, despite their greater detail (relative to U.S. government industry statistics) experience indicates that additional time and cost is usually required to customize industry data provided by commercial vendors to render them useful for the narrowly focused economic impact assessments conducted for NIST. Moreover, in the case of an emerging, inchoate industry structure, like the nanotechnology-based industry, it may be that information provided by competitors about close competitors is the best source of information available at any cost.

6 Quantitative Analysis

6.1 Industry Benefits

Industry beneficiaries include SDO participants and "free riders." The latter beneficiaries do not participate in the SDO process. To understand the potential for beneficial spillovers from the SDO nanotechnology standards development process, benefits and costs are estimated for each respondent's direct competitors. Some of those direct competitors are also SDO participants. Their benefits from the nanotechnology standards will be similar to those of the respondents. Their cost will include both SDO participation costs and pull costs. However, some competitors will be free riders for whom the costs of using the nanotechnology standards will be their pull costs alone. The survey asked the respondents to report the number of their direct competitors in nanotechnology-related research or in the sale of nanotechnology-related services or products to major customers. Respondents also reported the number of direct competitors were most similar to themselves in terms of the benefits and costs of nanotechnology standards. On average, the 13 industrial respondents reported that the group of direct competitors who were most similar constituted 34% of the total number of direct competitors.

To estimate the spillover of benefits to non-participants in the SDO nanotechnology standards development process (free riders), it is assumed that all of the competitors of each of the 13 respondents enjoy the benefits of nanotechnology standards and that the 34% of the respondents' direct competitors that are most similar to the respondents in terms of the realization of benefits and costs are also participants in the SDO nanotechnology standards development process. The remaining 66% of the competitors are assumed to be free riders.

Table 3 provides a time series of the benefit estimates for the period from 2005 through 2012. Survey respondents estimated benefits for only the activity that benefited the most from the use of nanotechnology standards, yet the respondents each reported that many of their activities benefited from their adoption of nanotechnology standards. Without accounting for the benefits other than the one activity that benefited the most, the total benefits for the respondents' industries would be greatly underestimated. In the survey information used to create Table 2, each respondent reported the proportion of its total benefits received from the use of nanotechnology standards that accrued to the activity benefiting the most. That proportion averaged 0.495 (with a range from 0.30 to 1.0) for the 13 industrial respondents. So, on average across the respondents, the total benefits from using nanotechnology standards averaged twice the benefits received for the activity that benefited the most. Using the benefits reported for the activity that received the most benefits for each respondent, together with each respondent's information about that activity's proportion of the benefits for all of the respondent's activities, Table 3 shows the annual benefits of all activities for the 13 responding SDO participants (designated "Responding SDO Participants"). The respondents also reported the scale of their own benefits and costs relative to that of their direct competitors (both those who participated in the SDOs but did not respond as well as free riders, together designated

"Competitors") and that allows the construction of the benefits and costs series for the competitors shown in Tables 3 and 4.

Table 3. Constant 2012 Dollar Industry Benefits (2005 to 2012)*

Year	Responding SDO Participants' Constant 2012 Dollar Benefits	Competitors' Constant 2012 Dollar Benefits	Total Constant 2012 Dollar Benefits
2005	0	0	0
2006	121,902	524,702	646,604
2007	888,151	1,354,483	2,242,635
2008	1,947,114	9,295,465	11,242,580
2009	2,273,934	10,478,988	12,752,923
2010	2,587,166	11,661,628	14,248,793
2011	3,049,332	13,407,336	16,456,668
2012	3,789,502	16,215,910	20,005,412

* For the sake of survey simplicity, respondents were instructed to estimate benefits and costs in FY2012 dollars. These benefits and costs were spread over time according to the activity growth rate reported by the respondent, beginning with the earliest publication year of the high-impact documentary standards reported by the respondent. Variance in the yearly ratio of competitors' benefits, to participants' benefits, results because of variance in the timing of participants' benefits. The yearly variation in "industry" benefits then reflects the variation in benefits for different mixes of the parts of the emerging nanotechnology industries in different years.

6.2 Industry Costs

Table 4 shows the time series of costs for the 13 respondents and their competitors (SDO participating competitors and free riding competitors). As explained above, in Table 4 it is assumed that 34% of the respondents' direct competitors are SDO participants and have the same costs as the SDO participants with which they compete, while 66% of the competitors would be free riders and would have only the pull costs associated with implementing the standards. If they all had the same costs, each item in the "Responding SDO Participants" cost column would be multiplied by the same ratio used to get the competitors' benefits in Table 3. But, given our assumptions, only 34% will have all of those costs. Therefore, to estimate the costs of the SDO participating competitors the column of costs for the 13 respondents is multiplied by 34% of the multiplier used for each year in Table 3.[77] Then only pull costs for the other 66% of the competitors are added, using 66% of the yearly pull costs that were estimated for all of the competitors.

[77] For 2005, 34% of the Table 3 2006 multiplier is used.

Table 4. Constant 2012 Dollar Industry Costs (2005 to 2012)

Year	Responding SDO Participants' Constant 2012 Dollar Costs	Competitors' Constant 2012 Dollar Costs	Total Constant 2012 Dollar Costs
2005	192,004	284,962	476,966
2006	198,844	296,227	495,071
2007	252,365	141,416	393,781
2008	279,302	460,699	740,001
2009	258,265	431,445	689,710
2010	266,325	560,172	826,497
2011	280,588	469,140	749,728
2012	341,413	751,075	1,092,488

From the benefits shown in Table 3, the costs shown in Table 4 are subtracted to get the net benefits shown in Table 5. Competitors' net benefits are probably overestimated because the pull costs of the free-riding competitors have been estimated with the pull costs of the SDO participants. Actual pull costs for non-participants would be expected to be higher because non-participants in the SDO process would have to gain knowledge that a participant would have absorbed while participating in the SDO TCs.

Table 5. Constant 2012 Dollar Net Benefits to Industry (2005 to 2012)

Year	Responding SDO Participants' Constant 2012 Dollar Net Benefits	Competitors' Constant 2012 Dollar Net Benefits	Total Constant 2012 Dollar Net Benefits
2005	-192,004	-284,962	-476,966
2006	-76,942	228,475	151,533
2007	635,786	1,213,067	1,848,853
2008	1,667,812	8,834,766	10,502,578
2009	2,015,669	10,047,543	12,063,213
2010	2,320,841	11,101,456	13,422,297
2011	2,768,744	12,938,196	15,706,940
2012	3,448,089	15,464,835	18,912,924

Table 6 breaks out the benefits and net benefits for the free riders.

Table 6. Constant 2012 Dollar Net Benefits to the Free Riders (2005 to 2012)

Year	Free Riders' Constant 2012 Dollar Benefits*	Free Riders' Constant 2012 Dollar Net Benefits**
2005	0	-3,972
2006	346,303	341,076
2007	893,959	883,399
2008	6,135,007	6,127,657
2009	6,916,132	6,889,343
2010	7,696,674	7,544,658
2011	8,848,842	8,799,157
2012	10,702,501	10,448,154

*Free riders get 66% of the competitors' benefits shown in Table 3.
**The net benefits for the free riders subtract their pull costs from their benefits. Their pull costs are 66% of the pull costs estimated for the competitors.

6.3 Measures of Economic Impact

Table 5 and Table 6 provide the information needed to estimate the summary economic impact estimates reported in Table 7: net present value (NPV), cumulative net benefits, industry rate of return, and benefit-to-cost ratio (B/C). (For an explanation and discussion of these metrics, see Appendix B.)

Table 7. Estimates of Economic Impact (constant 2012 dollars) for 2005 to 2012

Impact Metrics	Responding SDO Participants	Competitors	Free Riders **	Total
NPV in 2005	8,837,538	42,032,301	29,093,297	50,869,841
Cumulative Net Benefits in 2012*	14,191,155	67,494,690	46,717,477	81,685,848
Industry Rate of Return	177%	321%	8758%	270%
Benefit-to-Cost Ratio	6.5	17	85	13
Present Value of Benefits in 2005	10,450,295	44,602,579	29,437,703	55,052,876
Present Value of Costs in 2005	1,612,756	2,570,279	344,406	4,183,035

*(Net Present Value in 2005) multiplied by $(1.07)^7$
**The exceptionally high return to the free riders is because they did not incur the SDO participants' costs that generated their benefits (see discussion in text).

Despite the very large economic impact found for the early-stage documentary standards, the estimates of economic impact shown in Table 7 are probably conservative because (1) there are unmeasured benefits of avoiding shortfalls in performance (such as a shortfall in sales) even if the firm incurs extra costs to compensate for the lack of nanotechnology standards, and (2) the percentage of competitors that are SDO participants has probably been overestimated.

The benefits of nanotechnology documentary standards are conceptualized as the dollar value of costs avoided because the industry has access to the standards. On average, nanotechnology-related activities would have cost industry respondents almost 50 percent more in the absence of the standards. The costs incurred by developing and using the standards are the dollar value of hours Technical Committee members dedicated to the SDO consensus process plus the cost of pulling the information into their organizations and into the organizations of free riders.

The first impact metric shown in Table 7 (Net Present Value in 2005) uses the year the three nanotechnology SDOs were formally started as the base year and calculates the net present value of the project from the perspective of 2005. The NPV is the inflation-adjusted (real or constant-dollar) value of the net benefits (benefits minus costs) generated by the project over the course of the study period (2005 to 2012). If, in 2005, an SDO's leadership was trying to judge which of two or more projects (new TCs) would yield the highest economic return to the SDO, this is the kind of calculation they would have made. From an economic perspective, the project (TC) with the highest industry-wide NPV would have been chosen.

The second impact metric (Cumulative Net Benefits in 2012 (2005 to 2012)) is intended to interpret the NPV of the net benefits that actually occurred as a result of the SDOs' efforts (NPV in 2005) from the perspective of 2012, rather than from the perspective of 2005. If the net benefits that actually accrued to the effort (NPV in 2005, approximately $51 million) were invested in 2005 and were compounded annually at the rate of the cost of capital used by the U.S. government to evaluate investment projects (seven percent), the value of those benefits today would be approximately $82 million.[78]

The third impact metric (Industry Rate of Return) is similar to an internal rate of return calculation, another corporate finance technique used to judge the performance of an investment project. The modifier "industry" indicates that the value of this performance metric accounts for the benefits and costs that accrue to the industrial firms that have

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[78] The government cost of capital is stipulated as seven percent in Office of Management and Budget (OMB) *Circular no. A-94: Guidelines and Discount Rates for Cost-Benefits Analyses of Federal Programs*, 1992. For a discussion of the rationale of the seven percent discount rate, see, Albert Link and John Scott, *Public Goods, Public Gains,* Oxford University Press, 2011; and (OMB) *Circular no. A-4: Regulatory Analysis*, 2003.

participated in or benefited from the work of the SDOs.[79] The industry's rate of return is the interest rate (also called the "discount rate") that would reduce the NPV in 2005 of the TC's efforts to zero and reduce the benefit-cost ratio to one—the investment would break even at that required rate of return. As a guide to making a decision on an investment project (private or public), if the industry's rate of return is higher than the discount rate, the project is acceptable because the project earns a rate of return greater than its cost of capital.

The benefit-to-cost ratio (B/C) is simply the ratio of the present value (PV) of benefits (2005 to 2012) to the PV of costs (approximately $55 million/$4.0 million). This value indicates that the real value of the benefits of the SDOs' efforts, industry-wide, exceeded the costs by a ratio of approximately 13:1.

These estimates can be considered conservative for reasons just explained. For comparison purposes, it is appropriate to recall a historically important analysis conducted in the mid-1970s. Economist Edwin Mansfield and his coauthors reported on the private rates of return and societal rates of return on private sector innovations. (The private and social rates of return differ because of the "externalities" discussed in Section 1.3.1 of this report). Using a methodology similar to the one used in this assessment, Mansfield reported the median social rate of return (SRR, to which our industry-wide rate of return can be compared) for 17 private sector projects to be 56%, ranging between 13% and 307%.[80] To verify Mansfield's results, the National Science Foundation funded two other similar assessments, each examining an additional 20 private sector innovations.[81] The median SRR for one of these assessments was 70%, ranging between 0 and 371%; the median SRR for the other was 99%, ranging between 0 and 472%. These SRRs can also be compared to the Industry Rate of Return of 270% reported in Table 7.

In that context, the results reported here (in terms of Industry Rate of Return) are close to the middle of the range for rates of return on other innovative activities undertaken by industry; however, observe that the nanotechnology standards development investments examined in this report are very different from the collection of innovative investment projects examined by Mansfield et al. The nanotechnology standards investments are investments in infrastructure technology that, because of their intrinsic "public goods"

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[79] "Industry Rate of Return" is adopted here to indicate the study focus on industry-wide costs and benefits, exclusive of other social costs (for example, NIST's costs of participating in the SDO activities) and benefits. Previous NIST reports have reported a similar metric, the "social rate of return" (SRR), which is an interpretation of the ordinary financial metric, "internal rate of return" (IRR) used routinely by industry to rank private sector investment projects. The "social" in SRR ideally measures the costs and benefits that accrue to all investors and beneficiaries, public and private.

[80] Concerning the historical importance of Edwin Mansfield's work see, "Essays in Honor of Edwin Mansfield," F. M. Scherer and A.N. Link (Guest Editors), *The Journal of Technology Transfer,* Volume 30, Nos. 1/2, January 2005; and Link and Scott, *op. cit.,* 2011, pp. 28-31. The assessment of 17 private sector innovations is reported in Edwin Mansfield, et al., "Social and Private Rates of Return from Industrial Innovations," *The Quarterly Journal of Economics*, vol. 91, no. 2 (May 1977), pp. 221-240.

[81] *A Survey on Net Rates of Return on Innovations,* Foster Associates, Inc., May 1978; and *Net Rates of Return on Innovations,* Robert R. Nathan Associates, Inc., October 1978.

content, are especially likely to have large industry-wide social benefits for the reasons discussed earlier in this report. The evaluation metrics reported here for the nanotechnology standards development investments are also within the range of the evaluation metrics for many other public-private partnerships to develop infrastructure technologies that have been evaluated by NIST over the last 20 years.[82]

Finally, Table 8 reports the economic impact metrics for the nanotechnology industry as a whole, without the distinctions among the various kinds of industry beneficiaries reported in Table 7. As explained in Section 6.1, the exploration of economic spillovers reported in Table 7 required some basis for distinguishing close and more distant competitors within a more broadly defined industry. That distinction is ignored in the following table of industry-wide economic impact estimates.

Table 8. Estimates of the Industry-Wide Economic Impacts (constant 2012 dollars) of Early Stage Nanotechnology Consensus Standards (2005 to 2012)

Impact Metrics	Total
NPV in 2005	50,869,836
Cumulative Net Benefits in 2012	81,685,841
Industry Rate of Return	270%
Benefit-to-Cost Ratio	13
Present Value of Benefits in 2005	55,052,875
Present Value of Costs in 2005	4,183,039

The net present value (NPV) in 2005 metric says that if, in 2005, TC members could have projected the actual timing and size of the costs avoided they would have valued the project at ~$51 million, net of the costs industry would have incurred. The cumulative net benefits metric looks back at that stream of benefits and costs from the perspective of 2012 and compounds the ~$51 million in NPV by 7 percent per year (the cost of capital used by the federal government when evaluating investment returns). The industry rate of return metric says that the rate of return on industry-wide investment in nanotechnology standards development over the period from 2005 to 2012 has been 270 percent. The benefit-to-cost (B/C) metric says that for every $1 dollar of costs expended by industry (2005-2012), ~$13 dollars in benefits have been returned.

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[82] Albert Link and John Scott, *The Theory and Practice of Public-Sector R&D Economic Impact Analysis*, NIST Planning Report #11-1, January 2012, National Institute of Standards and Technology (NIST), U.S. Department of Commerce.

7 Conclusion

NIST devotes considerable resources to the support of industry standards. The Standards Coordination Office (SCO) exists to support industry with the standards-related tools and information to compete more effectively in the global marketplace. Part of that support is to demonstrate the costs and the benefits of documentary standards.

This economic impact assessment is one of many retrospective evaluations conducted by NIST for over 20 years but it is among a few retrospective assessments to concentrate solely on the *industry* benefits and costs and to focus on documentary standards.

Some well-informed participants in the nanotechnology SDO community believed that it was too early to assess the impact of nanotechnology standards. To them, "economic impact" is about selling products and services in well-defined markets, often well downstream of the originating technology application, markets that today have not yet fully emerged. But from an economic perspective, people invest resources today (and from 2005 to 2012) for benefits in the future because they perceive there are good reasons to expect benefits. What “the future” entails will differ for different kinds of companies. This impact assessment shows that the benefits to SDO participants, and the net-benefits industry-wide, have been substantial and the net benefits to SDO participants appear to be increasing substantially in the more recent years of this retrospective assessment.

Additionally, the qualitative assessment presented here indicates that SDO participants are very future-focused and relatively well situated to reap the rewards of the burgeoning growth in nanotechnology-based products and services markets. The large net benefits shown in Table 7 that accrued to the non-participant free-riders are because they did not incur the costs of participating in the SDO nanotechnology standard-setting activities, yet they received the benefits net of only their pull costs. The record of benefits and costs for the free riders exemplifies the positive externality created by the nanotechnology standards setting activities of the SDO participants. Another finding of this report is that the universities that develop knowledge about nanoscience that is transferred to industry in the form of commercialized nanotechnology often do not perceive that the nanotechnology documentary standards are important for their work and largely ignore the standards. Even those universities that do recognize the importance of the nanotechnology documentary standards for their work often do not find the materials specification and characterization standards as significant as do the industry respondents as a group. The asymmetry in the views of universities and industry about the importance and use of nanotechnology documentary standards may inhibit the transfer of nanoscience and nanotechnology into commercialized products and services.

Appendix A. Economic Effects of Nanotechnology Documentary Standards Survey Instrument

Survey
Economic Effects of Nanotechnology Documentary Standards

Introduction

NIST is conducting its first economic assessment of a suite of documentary standards aimed at advancing an emerging technology. NIST has conducted numerous economic assessments over the years. For examples go to < http://www.nist.gov/director/planning/study_info.cfm>.

The survey population was chosen on the basis of their interest in, and familiarity with, nanotechnology documentary standards and their first-hand knowledge of the documentary standard development process.

The focus of the survey is nanotechnology documentary standards published between 2005 and 2012 by the following Standards Development Organizations (SDOs): ASTM International's Technical Committee on Nanotechnology (ASTM E56); the International Electrotechnical Commission's (IEC's) Technical Committee (IEC/TC113), Nanotechnology Standardization for Electrical and Electronics Products and Systems; and the International Standards Organization's (ISO's) Technical Committee (ISO/TC229), Nanotechnology. (See the list of relevant standards in Appendix A of this survey instrument). The choice of this group of standards was pragmatic. They are considered good candidates for understanding the role and economic significance of documentary standards in a field of emerging technologies.

TASC Inc. is an independent analytical services company. We have conducted several such assessments on NIST's behalf ***. All the answers you provide will be held in the strictest confidence. They will not be shared with NIST or the standards development organizations whose standards are the focus of the analysis. All data in the economic effects assessment will be reported in aggregated form, as averages and ranges, so that no individual person, company, or establishment data will be discernable.***

The assessment will be based on data collected for this survey and will employ a present discounted value approach to organizing time series estimates of benefits and costs provided by you, the survey respondents. The data will be used to calculate estimates of the economic effects according to NIST's conventions.

We DO NOT expect your estimates to be based on accounting quality data. We need you to provide your best estimates or estimate ranges to all questions based on your experienced judgment. Where these take you past your comfort zone, consider that there is likely no one in a better position to formulate such a response. If, in addition to your response, you would like to suggest a point of contact within your organization whose estimate we would also benefit from obtaining, please provide us with a name, phone number, and e-mail address. We will contact that person and solicit their estimates as well. We welcome this opportunity.

As a token of appreciation for participating in this survey effort, the final report will be available from NIST in late 2013 and you and your company will be listed in the acknowledgements unless you prefer that they not be. Your full participation in the survey assures that the report will be based on the best information available.

Please return the completed survey to: david.leech@tasc.com
David will discuss the survey questions with you by phone if you desire. Contact him at: 410-346-6338

NOTE: This collection of information contains Paperwork Reduction Act (PRA) requirements approved by the Office of Management and Budget (OMB). Notwithstanding any other provisions of the law, no person is required to respond to, nor shall any person be subject to a penalty for failure to comply with, a collection of information subject to the requirements of the PRA unless that collection of information displays a currently valid OMB control number. Public reporting burden for this collection is estimated to be twenty-five (25) minutes per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed and completing and reviewing the collection of information. Send comments regarding this burden estimate or any aspect of this collection of information, including suggestions for reducing this burden, to the National Institute of Standards and Technology, **Attn: Erik Puskar; Phone: 301-975-8619. OMB Control No. 0693-0033; Expiration Date: 03-31-2016**

Respondent Name:	Click here to enter text.
Contact Information (email address or /phone #):	Click here to enter text.
Organization Name:	Click here to enter text.

If your organization has a broad "product line" of which nanotechnology-related research, services, or products are a part:

Relevant Sub Division Name:	Click here to enter text.
Relevant Sub Division Technical or Product Focus:	Click here to enter text.

Background Information

1. The nanotechnology value chain consists of multiple tiers. Please indicate (X) the industry tiers that best characterize your company's (or relevant division's) role.

Click here to enter text.	Waste management
Click here to enter text.	End product development and application
Click here to enter text.	Nanomaterial synthesis
Click here to enter text.	Raw materials producer
Click here to enter text.	Instrument manufacturer
Click here to enter text.	Internal testing laboratory
Click here to enter text.	Internal R&D laboratory
Click here to enter text.	Independent testing laboratory
Click here to enter text.	Independent R&D laboratory (including universities)
Click here to enter text.	Other (Please specify and offer an explanation of your role.) Click here to enter text.

2. In which of the nanotechnology SDO's identified has your organization participated?

Click here to enter text.	ASTM E56
Click here to enter text.	IEC/TC113
Click here to enter text.	ISO/TC229
Click here to enter text.	We HAVE NOT participated in these nanotechnology SDOs. **[Skip to question #7.]**

3. In what year did your organization first become active in one or more of the SDOs identified above? (If your involvement was instrumental in the formation of one of the above-mentioned organizations indicate the year in which you became involved even if it precedes for formal establishment of the SDO as indicated in the parenthesis.)

ASTM E56 (2005) — Year First Active:	Click here to enter text.
IEC/TC113 (2007) — Year First Active:	Click here to enter text.
ISO/TC229 (2005) — Year First Active :	Click here to enter text.

4. If NIST personnel had not been involved in the SDOs in which your organization participated, estimate the number of weeks that the SDO's publications would have been delayed — on average, across the nanotechnology standard development efforts in which your organization was involved.

Average Weeks of Delay:	Click here to enter text.

<u>Benefits and Costs Estimates</u>

Nanotechnology Working Group Participation

5. Estimate the average annual number of hours your organization's employees or consultants actually dedicated to all the nanotechnology standards working groups in which they were involved (indicated in your response to question #3 above) from their initial involvement through 2012.

ASTM E56, IEC/TC113, ISO/TC229: Average Annual Hours, "Year First Active" through 2012:	Click here to enter text.

6. In 2013 dollars, estimate the value of the fully burdened (i.e., including benefits such as retirement and health) annual compensation for a full-time person with the requisite expertise to participate in the efforts of a nanotechnology working group.

Total annual compensation for one full time person in 2013 dollars $	Click here to enter text.

All data in the economic impact assessment will be reported in aggregated form, as averages and ranges, so that no individual person, company, or establishment estimates will be discernable.

Absent Nanotechnology Standards

Economic effects assessments are often conducted on the basis of a "counterfactual scenario" that posits how things would have been in the absence of the event being assessed. We hypothesize that, prior to the consensuses represented by the 40 nanotechnology standards identified in Appendix A, more time was required of you and your colleagues in the performance of a wide range of activities.

7. From the list of nanotechnology standards listed in Appendix A, identify — by list number — the <u>five</u> (more if need be) that you think are representative of the most significant nanotechnology consensus standards for your organization.

Click here to enter text.	Click here to enter text.	Click here to enter text.
Click here to enter text.	Click here to enter text.	Click here to enter text.
Click here to enter text.	Click here to enter text.	Click here to enter text.

8. In Nanotechnologies-Related Activities Table below, select the top 3 activities within your organization that you judge have been most affected by nanotechnology standards and estimate the percent of all the benefits from nontechnology standards that each of these 3 activities represent. *(For example, your top 3 activities could each account for 33% of all benefits equally, leaving very little benefits accounted for by other activities; or they could account for 50%, 30% and 2%, leaving the unspecified 18% of all benefits spread among the remaining activities.)*

Nanotechnology-Related Activities Table

Pre-Development R&D/ Knowledge Acquisition %	Worker/Student Training %	Investment Justification for Equipment Adoption /Acquisition %	Product Design & Development (excl. regulatory compliance) %	Quality Assurance & Control %	Safety and Environmental Monitoring/Risk Management %
Click here to enter text.	Click here to enter text.	Click here to enter text.	Click here to enter text.	Click here to enter text.	Click here to enter text.
Contract Negotiations %	**Intellectual Property Due Diligence %**	**Regulatory Compliance, Negotiations, & Monitoring %**	**Marketing, Marketing Intelligence, & B2B Networking %**	**Other (Describe) %**	**Other (Describe) %**
Click here to enter text.	Click here to enter text.	Click here to enter text.	Click here to enter text.	Click here to enter text.	Click here to enter text.

9. For the 3 activities selected in the Nanotechnologies-Related Activities Table above, provide a few sentences describing how the existence of nanotechnology standards changed the processes that resulted in benefits to your organization. (A few words are far more helpful than no words.)
Click here to enter text.

10. For the activity with the highest percentage benefits to your organization (from the Activities Table above), estimate one-time labor and material costs — "pull costs" — associated with assimilating the information contained in the standards into your ongoing processes. (DO NOT include cost associated with participating in SDO activities, if any, as these are already been estimated in your response to question #6.)

Material costs $	Click here to enter text.
Year incurred	Click here to enter text.
Number of full-time persons years	Click here to enter text.
Year incurred	Click here to enter text.

All data in the economic impact assessment will be reported in aggregated form, as averages and ranges, so that no individual person, company, or establishment estimates will be discernable.

11a. In column A, of the Activity Benefits Table below, for the activity with the highest percentage benefits to your organization (from the Nano-Related Activities Table above), estimate the number of full-time person-years (FTPs) in 2012 dedicated to nanotechnology-related efforts in that category of activity.

Activity Benefits Table

Column A Full-Time Person-Years (FTPs) Dedicated to this Activity (2012) (E.g., 0.5, 1, 5.5, 10)	Column B Annual Compensation of an FTP w/ Appropriate Expertise ($ FY2013)	Column C Multiple of FTPs Dedicated to this Activity *Absent the Relevant Nanotechnology Standards* (E.g., .5X, 1X, 2.5X, 10X)	Column D Average Annual Rate of Growth in the Level of Nanotechnology-Related Activities 2005-2012 (Percent)
Click here to enter text.	Click here to enter text.	Click here to enter text.	Click here to enter text.

All data in the economic impact assessment will be reported in aggregated form, as averages and ranges, so that no individual person, company, or establishment estimates will be discernable.

11b. In *column B*, of the Nanotechnologies-Related Activities Table, estimate the fully burdened annual compensation (i.e., including benefits such as retirement and health) for a full-time employee with the requisite expertise to engage in the selected activity.

11c. In *column* C of the Nanotechnologies-Related Activities Table, estimate the multiple of FTPs that it would take to perform this function in the absence of consensus nanotechnology standards, holding constant the 2012 level of activity.

11d. In *column D* of the Nanotechnologies-Related Activities Table estimate the average annual rate of growth in the level of this nanotechnology-related activity, 2005-2012.

Skip questions 12a and 12b if your organization has not sold nanotechnology-related products, services, or intellectual property.

12a. If the sale of any products, services, or intellectual property would have been delayed in the absence of nanotechnology standards, what is the average annual revenue from those sales, and how many weeks delay would have been incurred?

Average annual revenue (2005-2012)	Click here to enter text.
Number of weeks delay	Click here to enter text.

All data in the economic impact assessment will be reported in aggregated form, as averages and ranges, so that no individual person, company, or establishment estimates will be discernable.

12b. Please provide a brief description of the products, services, or intellectual property delayed. (A few words are better than no words.)

Click here to enter text.

Scaling the Benefits of Nanotechnology-Related Activities

13a. How many companies/organizations do you collaborate with, or directly compete with, in the conduct of nanotechnology-related research or in the sale of nanotechnology-related services or products to major customers?

Number of direct collaborators or competitors:	Click here to enter text.

13b. How many of your collaborators or direct competitors likely realized benefits and costs comparable to those you estimated in your responses to the question #11 and/or #12 above?

Number of direct competitors/collaborators realizing comparable benefits from nanotechnology standardization	Click here to enter text.

13c. If all the benefits realized by your direct competitors/collaborators summed to 100, what percent is represented by the benefits your organization realized?

Percent of total direct competitor/collaborator benefits?	Click here to enter text.

Thank you for taking the time to provide your best estimates for the answers to the above questions.

We look forward to providing you with the results of our analysis.

Nanotechnology Standards 2005-2012

ASTM (E56) Standards

List Number

1. E2456-06 Standard Terminology Relating to Nanotechnology

2. E2490-09 Standard Guide for Measurement of Particle *Size* Distribution of Nanomaterials in Suspension by Photon Correlation Spectroscopy (PCS)

3. E2524-08 Standard Test Method for Analysis of Hemolytic Properties of Nanoparticles

4. E2525-08 Standard Test Method for Evaluation of the Effect of Nanoparticulate Materials on the Formation of *Mouse* Granulocyte-Macrophage Colonies

5. E2526-08 Standard Test Method for Evaluation of Cytotoxicity of Nanoparticulate Materials in Porcine *Kidney Cells* and Human Hepatocarcinoma Cells

6. E2535-07 Standard Guide for Handling Unbound Engineered Nanoscale Particles in Occupational Settings

7. E2578-07 (2012) Standard Practice for Calculation of Mean *Size*s/Diameters and Standard Deviations of Particle Size Distributions

8. E2842-12 Standard Guide for Measurement of Particle *Size* Distribution of Nanomaterials in Suspension by Nanoparticle Tracking Analysis (NTA)

9. E2859-11 Standard Guide for *Size* Measurement of Nanoparticles Using Atomic Force Microscopy (AFM)

10. E2865-12 Standard Guide for Measurement of Electrophoretic Mobility and Zeta Potential of *Biological* Materials

IEC (TC113) Standards

List Number

11. IEC 62624_Test methods for measurement of electrical properties of carbon nanotubes (2009)

12. IEC/PAS 62565-2-1_Nanomanufacturing - Material specifications - Part 2-1: Single-wall carbon nanotubes - Blank detail specification (2011)

13. IEC/TS 62607-2-1_Nanomanufacturing - Key control characteristics - Part 2-1: Carbon nanotube materials - Film resistance (2012)

14. IEC/TS 62622_Nanotechnologies - Description, measurement and dimensional quality parameters of artificial gratings (2012)

ISO (TC229) Standards

List Number

15. ISO/TS 27687:2008 – Nanotechnologies -- Terminology and definitions for nano-objects -- Nanoparticle, nanofiber and nanoplate

16. ISO/TR 12885:2008 – Nanotechnologies – Health and safety practices in occupational settings relevant to nanotechnologies

17. ISO/TS 80004-3:2010 – Nanotechnologies --Terminology and definitions –Part 3: Carbon nano-objects

18. ISO/TS 80004-1:2010 – Nanotechnologies – Vocabulary – Part 1: Core terms

19. ISO/TR 11360:2010 – Nanotechnologies – Methodology for the classification and categorization of nanomaterials

20. ISO/29701:2010 - Nanotechnologies --Endotoxin test on nanomaterial samples for in vitro systems -- LAL Assay

21. ISO/TS 10867:2010 – Nanotechnologies -- Characterization of single-wall carbon nanotubes using near infrared photoluminescence spectroscopy

22. SO/TR 12802-2010 – Nanotechnologies – Model taxonomic framework for use in developing vocabularies – Core concepts

23. ISO/TS 11251:2010 – Nanotechnologies – Characterization of volatile components in single-wall carbon nanotube samples using evolved gas analysis/gas chromatograph-mass spectrometry

24. ISO 10801:2010 – Nanotechnologies --Generation of metal nanoparticles for inhalation toxicity testing using the evaporation/condensation method

25. ISO 10808:2010 – Nanotechnologies --Characterization of nanoparticles in inhalation exposure chambers for inhalation toxicity testing

26. ISO/TS 80004-4:2011 – Nanotechnologies – Vocabulary – Part 4: Nanostructured materials

27. ISO/TS 80004-5:2011 – Nanotechnologies – Vocabulary – Part 5: Bionano interface

28. ISO/TS 80004-7:2011 – Nanotechnologies -- Vocabulary -- Part 7: Diagnostics and therapeutics for healthcare

29. ISO/TR 13121:2011 – Nanotechnologies -- Nanomaterial risk evaluation

30. ISO/TS 10798:2011 – Nanotechnologies -- Characterization of single-wall carbon nanotubes using scanning electron microscopy and energy dispersive X-ray spectrometry analysis

31. ISO/TS 10868:2011 – Nanotechnologies -- Characterization of single-wall carbon nanotubes using ultraviolet-visible-near infrared (UV-Vis-NIR) absorption spectroscopy

32. ISO/TS 13278 Ed. 1.0:2011 – Nanotechnologies - Determination of metal impurities in carbon nanotubes (CNTs) using inductively coupled plasma - Massspectroscopy (ICP-MS)

33. ISO/TS 13278:2011 – Nanotechnologies – Determination of metal impurities in samples of carbon nanotubes using inductively coupled plasma massspectrometry (ICP-MS)

34. ISO/TS 11308:2011 – Nanotechnologies – Characterization of single-wall carbon nanotubes using thermogravimetric analysis

35. ISO/TS 11888:2011 – Nanotechnologies - Characterization of multiwall carbon nanotubes -- Mesoscopic shape factors

36. ISO/TS 12805:2011 – Nanotechnologies -- Materials specifications – Guidance on specifying nano-objects

37. ISO/TR 10929:2012 - Nanotechnologies -- Characterization of multiwall carbon nanotube (MWCNT) samples

38. ISO/TR 13014:2012 - Nanotechnologies - Guidance on physicochemical characterization of engineered nanoscale materials for toxicologic assessment

39. ISO/TS 10797:2012 – Nanotechnologies -- Characterization of single-wall carbon nanotubes using transmission electron microscopy (TEM)

40. ISO/TR 11811-2012 – Nanotechnologies -- Guidance on methods for nano- and microtribology instruments

Appendix B. Economic Impact Metrics[83]

The economic impact metrics in this report are calculated from a time series of costs and benefits in constant dollars. They represent "real" rates of return. In contrast, "nominal" rates of return would be based on time series of current dollars (the dollars of the year in which the benefits were realized or the costs were incurred).

Industry Rate of Return (IndRR)

The IndRR is the value of the discount rate, i, that equates the net present value (NPV) of a stream of all net benefits associated with an investment project to zero. (This is an adoption for the purposes of this study of what is normally referred to as the Social Rate of Return (SRR) when applied to societal benefits — typical for NIST economic impact studies — or the Internal Rate of Return (IRR) when applied to the investment projects of a company.) The time series runs from the beginning of the project, t = 0, to a milestone terminal point, t = n. Net benefits refer to total benefits (B) less total costs (C) in each time period. Mathematically,

$$(1)\ NPV = [(B_0 - C_0) / (1 + i)^0 + \ldots (B_t - C_t) / (1 + i)^t \ldots + (B_n - C_n) / (1 + i)^n] = 0$$

where $(B_t - C_t)$ represents the net benefits associated with the project in year t, and n represents the number of time periods (years in most cases) being considered in the evaluation.

For unique solutions of i, from equation (1), the IndRR can be compared to a value, r, that represents the opportunity cost of funds invested. Thus, if the opportunity cost of funds is less than the social rate of return, the project was worthwhile from an ex post social perspective.

Benefit-to-Cost Ratio

The ratio of benefits-to-costs is precisely that, the ratio of the present value of all measured benefits to the present value of all costs. Both benefits and costs are referenced to the initial time period, t = 0, as:

$$(2)\ B / C = [\Sigma_{t=0 \text{ to } t=n} B_t / (1 + r)^t] / [\Sigma_{t=0 \text{ to } t=n} C_t / (1 + r)^t]$$

A benefit-to-cost ratio of 1 implies a break-even project. Any project with B / C > 1 is a relatively successful project. Fundamental to implementing the ratio of benefits-to-costs is a value for the discount rate, r.

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[83] The characterization of the three metrics follows A. Link and J. Scott, *Public Accountability: Evaluating Technology-Based Institutions* (Boston: Kluwer Academic Publishers) 1998.

While the discount rate representing the opportunity cost for public funds could differ across a portfolio of public investments, the calculated metrics in this report follow the guidelines set forth by the Office of Management and Budget where it is stated that constant-dollar benefit-cost analyses of proposed investments and regulations should report net present value and other outcomes determined using a real discount rate of 7 percent.[84]

Net Present Value (NPV)

The information developed to determine the benefit-to-cost ratio can be used to determine net present value as:

(3) NPV = B – C.

[84] As noted earlier in the report, the government cost of capital is stipulated as seven percent in Office of Management and Budget (OMB) *Circular no. A-94: Guidelines and Discount Rates for Cost-Benefits Analyses of Federal Programs*, 1992.