Symposium on Assessing the Economic Impact of Nanotechnology

SYNTHESIS REPORT

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UNITED STATES NATIONAL NANOTECHNOLOGY INITIATIVE

The National Nanotechnology Initiative (NNI), established in 2001, is a United States Government research and development (R&D) initiative involving 27 department and agency units working together toward the shared and challenging vision of "a future in which the ability to understand and control matter at the nanoscale leads to a revolution in technology and industry that benefits society." The combined, coordinated efforts of these department and agency units have accelerated discovery, development, and deployment of nanotechnology to benefit agency missions in service of the broader national interest.

The NNI is managed within the framework of the National Science and Technology Council (NSTC), the Cabinet-level council by which the President of the United States coordinates science and technology policy across the Federal Government. The Nanoscale Science, Engineering, and Technology (NSET) Subcommittee of the NSTC's Committee on Technology coordinates planning, budgeting, program implementation, and review of progress for the initiative. The NSET Subcommittee is composed of representatives from participating agencies and the Executive Office of the President. The National Nanotechnology Coordination Office (NNCO) acts as the primary point of contact for information on the NNI; provides technical and administrative support to the NSET Subcommittee, including the preparation of multiagency planning, budget, and assessment documents; develops, updates, and maintains the NNI website http://nano.gov; and provides public outreach on behalf of the NNI.

This report of the Washington Symposium is dedicated to the memory of Dr. Jung Il Lee, who died suddenly and unexpectedly in March 2012 on the way to the symposium. Dr. Jung Il Lee was the Director of the Heritage Science and Technology Centre at the Korean Institute of Science and Technology (KIST), and led the Korean delegation to the OECD Working Party on Nanotechnology. His invaluable contribution, energy, enthusiasm, generosity and sense of humour, are sorely missed. His deep involvement in issues related to business environments and green growth, in particular on issues related to the impact assessment of nanotechnology, greatly contributed to the success of the symposium and the broader progress made by the Working Party on Nanotechnology. Dr. Jung Il Lee was very active in nanotechnology activities worldwide. His loss is very much felt, both in Korea and in the wider international community.

이 워싱턴 심포지엄 보고서를, 2012년 3월 심포지엄 참석 도중 파리에서 불의의 사고로 돌아가신 고 이정일 박사님께 바칩니다. 고인은 한국과학기술연구원(KIST)의 전통과학기술사업단장으로 재직하시면서, 오랫 동안 OECD 나노기술작업반의 한국대표로 활동해 오셨습니다. 고인의 소중한 기여, 에너지, 열정, 관대함, 그리고 유머까지도 그리울 것입니다. 기업환경과 녹색성장, 특히 나노기술의 영향분석과 관련된 이슈들에 대한 고인의 적극적인 참여는 심포지엄의 성공적인 개최와 나노기술작업반의 광범위한 진전에 크게 기여하였습니다. 고인은 전세계적인 나노기술 관련 활동들에도 매우 적극적이셨습니다. 고인을 잃은 슬픔은 한국뿐 아니라 국제 사회에서도 이루 말할 수 없이 큽니다.

FOREWORD

The Organisation for Economic Co-operation and Development (OECD) and the United States National Nanotechnology Initiative (NNI) held an international symposium, *Assessing the Economic Impact of Nanotechnology*, in March 2012. Hosted by the American Association for the Advancement of Science (AAAS) in Washington DC, it brought together participants from the public and private sectors with expertise all along the nanotechnology value chain – scientists, engineers, policy analysts, private investors, technology leaders, and the general public – from both OECD and emerging economies.

The symposium was organised around expert talks and discussions on issues, such as the role of research funding portfolios; intellectual property frameworks; private-sector and industry investments; patents and publications; venture capital; public-private partnerships; state and local initiatives; international co-operation; and development metrics for nanotechnology. In addition to plenary talks, sector-specific breakout sessions were organised in transport and aerospace, nanomedicine, electronics, energy, materials, and food and food packaging.

This synthesis report aims to summarise the discussions and key messages from the symposium. It also draws on four background reports that were developed for the symposium:

- Challenges for Governments in Evaluating Return on Investment from Nanotechnology and its Broader Economic Impact, by Eleanor O'Rourke and Mark Morrison, Institute of Nanotechnology, United Kingdom

- Finance and Investor Models in Nanotechnology", by Tom Crawley, Pekka Koponen, Lauri Tolvas and Terhi Marttila, Spinverse, Finland

- The Economic Contributions of Nanotechnology to Green and Sustainable Growth, by Philip Shapira[*#+] and Jan Youtie[#+]; [*] University of Manchester, UK; [#]Arizona State University, USA; and [+] Georgia Institute of Technology, USA

- Models, Tools and Metrics Available to Assess the Economic Impact of Nanotechnology,by Katherine Bojczcuk and Ben Walsh, Oakdene Hollins, United Kingdom

The report was developed by Marie-Ange Baucher and Richard Scott from the OECD and Chris Cannizzaro, Stacey Standridge, Elizabeth Nesbitt, and Tarek Fadel from the NNI. The OECD and NNI are grateful to those who gave their time to review this report.

The report does not necessarily represent the views of the NNI, the OECD, the AAAS; a consensus among participants; or the views of the sponsoring organisation, the National Science Foundation.

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Executive Summary

Governments have a fiscal and social responsibility to ensure that limited research and development resources are used wisely and cost-effectively in support of social, economic, and scientific aspirations. As a result of significant public and private investments in nanotechnology during the past decade and an expanding array of commercial applications, the field of nanotechnology has matured to the point of showing significant potential to help societies achieve the shared goal of improving efficiencies and accelerating progress in a range of economic sectors, including medicine, manufacturing, and energy. Countries that wish to promote the continued responsible development of nanotechnology will, however, need quantitative data on the economic impact of nanotechnology to guide further investment and policy decisions. Few widely accepted economic impact assessments have been conducted, however, and there are many questions regarding the best methodologies to be used.

In view of this, the OECD and the United States National Nanotechnology Initiative (NNI) held an international symposium, *Assessing the Economic Impact of Nanotechnology*, in March 2012. Hosted by the American Association for the Advancement of Science (AAAS), it brought together participants from the public and private sectors with expertise all along the nanotechnology value chain – scientists, engineers, policy analysts, private investors, technology leaders, and the general public – from both OECD and emerging economies. The conclusion was that the technology is sufficiently mature to justify the collecting of data to support the performance of economic impact assessments. This report provides some of the reasoning behind this conclusion and identifies some of the potential challenges involved.

Investment in nanotechnology

In addition to identifying factors that drive investment in nanotechnology, the symposium recognised the need to understand the economic rationale for government intervention and to learn where systematic underinvestment may be occurring. There are many reasons for public investment in nanotechnology, and these may vary depending on a country's scientific and economic specialisation, competitiveness goals, and social objectives. Among the reasons are: to address societal issues such as public health or environmental concerns; to support industrial competitiveness and economic growth; to gain fundamental knowledge through basic research; and, more recently, to accelerate commercialisation of novel technologies and products.

Challenges for assessing the economic impact of nanotechnology

The symposium participants recognised challenges for assessing the impact of nanotechnology, some of which are common to emerging and enabling technologies in general. Others are more specific to nanotechnology, an enabling technology with applications across broad economic sectors and with impacts along the entire value chain from development to commercialisation. The setting for analysis is therefore complex, especially in view of an evolving science and technology policy environment.

The attendees also considered the question of a definition for nanotechnology. While operational definitions are developed at national or regional levels, e.g. for statistical or regulatory purposes, there are relatively few internationally agreed upon definitions or classifications for nanotechnology or its products and processes. Such definitions are essential for developing a methodology for an economic impact assessment and/or to facilitate data collection. Participants mentioned that definitions should be flexible so that they facilitate the development and valuation of the technology; they also noted that definitions might vary in different contexts or sectors.

Additional issues were raised:

- Its multipurpose, enabling nature makes measuring the impact of nanotechnology difficult. It can be fundamental to a product's key functionality (e.g. battery charge time or capacity) but ancillary to the value chain (e.g. represent a small portion of the final product or process). Nanotechnology is also likely to have a range of incremental impacts on goods and services as well as existing manufacturing techniques. This requires understanding the value added at different stages of the production chain.
- Nanotechnology's impact is often intermingled with that of many other interventions and technologies so that determining its precise role can be difficult.
- The large and varied amount of data linked to nanotechnology development may lead to difficulties in cleaning and manipulating the data meaningfully.
- Confidential business information and the proprietary nature of products and services may make it difficult to obtain information from industry. Moreover, it is not clear how a nanotechnology company or a company using nanotechnology is defined or defines itself or to what extent companies, universities and associate institutions are involved in exploiting and developing nanotechnology.
- For now, data are mainly collected through surveys. It is important to weigh the benefits against the additional workload that surveys place on administrations, research institutes and industries. Information should be obtained efficiently, focusing on the data of greatest interest for assessing the value of the technology.
- The nanotechnology policy landscape is evolving. It is important to consider non-specific, rather than nanotechnology-specific, funding strategies and policies when assessing economic impacts such as return on investment.

While certain issues may be resolved through improvements and over time, some restrict the ability to conduct valid nanotechnology impact assessments, such as the complex relationship between science, innovation and the economy; the interaction between public and private actors; the role of other factors in technology development and innovation; and the time lag between investments and their returns.

Valuing nanotechnology

Some steps have been taken towards assessing the impact of nanotechnology. Examples mentioned during the symposium include the U.S. STAR METRICS database, which uses an input/output approach to determine the outputs of federal funding of science and technology, and Brazil's Lattes system, in which researchers, students and institutions share information about their interests and backgrounds to facilitate information sharing and collaboration. The Lattes system is also intended to aid in the design of science, technology and innovation policies and to help understand the social and economic impacts of previous investments. DEFRA (Department for Environment, Food and Rural Affairs, United Kingdom) values a given nanotechnology product in monetary terms against an incumbent and thus calculates additional value added over current technology.

Other valuation methods mentioned included the "traditional" cost/benefit analysis (often accompanied by scenario development for immature technologies such as nanotechnology) and life cycle assessment (LCA). LCA addresses the impact of nanotechnology along the entire product value chain. It is important to conduct LCAs as early as possible in product development to define the full value of a product using nanotechnology. Value chain assessments can also help address the challenge of determining the role of nanotechnology in a final product, where economic value is most commonly assessed.

Participants recognised the difficulty of developing a "one size fits all" methodology. The data collected and the indicators and the methodologies chosen need to fit the situation. Precisely defining the objectives of the impact assessment is critical: "What do we want to measure?" (e.g. the impact of a specific nanotechnology investment or the impact of a nano-enabled replacement product on environmental performance). "What outcomes do we want from the analysis?" (e.g. monetary value and GDP growth or qualitative measures of environmental and social benefits).

Input indicators (e.g. R&D investment, infrastructure) are the easiest to collect; they provide information on the development of a technology in a given region, country or globally. Output indicators, such as patents and publications, provide information on the trajectories of a technology and on key areas of innovation. The most useful for policy makers are indicators of impact, but high-quality data, especially quantitative data, are difficult to collect. Indicators of impact provide a basis for assessing direct (market share, growth of companies, new products, wealth creation) and indirect impacts (welfare gains, consumer surplus). The economic and social impact of nanotechnology goes beyond what can be measured with existing statistics and traditional surveys. A pilot survey by the Russian Federation plans to examine nanotechnology issues that are not necessarily covered by traditional statistical surveys, such as technology transfer and linkages between different segments of the national innovation system. The OECD Working Party of National Experts on Science and Technology Indicators is also working on the development of a statistical framework for the measurement of emerging, enabling and general purpose technologies, which includes the notion of impact.

While quantitative measures may be preferable, impact assessments based on qualitative indicators using methods such as technology assessment scenarios and mapping of value chains can also provide valuable information.

Conclusions

Participants reported on national and international initiatives for assessing the impact of nanotechnology and other technological fields. There was a consensus among participants that more pilot initiatives and trials are needed, however, to gain experience and knowledge and to aid in the development of good practices or guidelines for impact assessment. Also, the data obtained would facilitate efforts to develop robust international documentary standards, which are critical to the broad commercialisation and adoption of nanotechnology.

The role of the public was emphasised throughout the symposium. Open assessments of the impacts of nanotechnology were viewed as essential for public trust and acceptance of the technology as well as for accurate determinations of what investments are justified and under what circumstances the technology offers clear benefits to society and the economy. Without the public's acceptance of nanotechnology, even high value / low risk applications could potentially fail commercially.

Impact analysis can take different forms and measure various aspects of a technology's impact on either a quantitative or qualitative basis. The data must be of high quality and rely on objective information. The main source is surveys of public institutions or industries. Symposium participants drew attention to the need to gather information about impact without greatly increasing the burden on respondents. Rationalisation of the need for information was outlined as an important step: what really needs to be measured so that the field of nanotechnology can efficiently move forward and that information gathered can help support policy decisions and public awareness?

The symposium emphasised the importance of measuring the full range of the technology's impacts, addressing risks, costs and benefits. Impact analyses need to be on a sound footing in order to be undertaken on a global scale and comparable. Internationally agreed upon definitions of nanotechnology are needed, taking into account the different purposes of analysis.

Introduction to the Symposium

The Organisation for Economic Co-operation and Development (OECD) and the United States Nanotechnology Initiative (NNI) organised an international symposium, “Assessing the Economic Impact of Nanotechnology”, on 27-28 March 2012. The American Association for the Advancement of Science (AAAS) hosted the symposium at their headquarters in Washington, DC. The objective of the symposium was to:

> “systematically explore the need for and development of a methodology to assess the economic impact of nanotechnology across whole economies, factoring in many sectors and types of impact, including new and replacement products and materials, markets for raw materials, intermediate and final goods, and employment and other economic impacts”.

Participants came from a broad spectrum of backgrounds and expertise: scientists, engineers, policy analysts, industry, government, business, private investors, technology leaders, key decision makers, and the general public.

The symposium was organised around expert talks and discussions on issues, such as: the role of research funding portfolios, intellectual property frameworks, private-sector and industry investments, patents and publications, venture capital, public-private partnerships, state and local initiatives, international co-operation, and development metrics for nanotechnology. Economic metrics for other technological assessments were discussed and their appropriateness for nanotechnology materials and products were considered. One of the aims of the symposium was to identify issues and areas for future study and help generate policy-level discussions on impact assessment for nanotechnology.

In addition to plenary talks, sector-specific breakout sessions were organised in transport and aerospace, nanomedicine, electronics, energy, materials, and food and food packaging.

The symposium agenda can be found in Annex I, the participant list in Annex II. Presentation slides and audio recordings are available at nano.gov/symposium. Four papers provided to symposium participants as background material can also be found at nano.gov/symposium.

This report, prepared by the OECD and the NNI, aims to summarise the discussions and key messages from the symposium. It does not necessarily represent the views of the NNI, the OECD, the AAAS; a consensus among participants; or the views of the sponsoring organisation, the National Science Foundation. The OECD and the NNI are grateful to those who gave their time to review this report. Affiliations of speakers, chairs and co-chairs in the report are as of March 2012.

Opening words

Alan Leshner (Chief Executive Officer, AAAS, United States) opened the symposium. He began by noting that for many years the scientific community has used data to make a case for science and technology’s effect on the economy. He further noted that most studies have been based on discoveries that proved economically profitable. Mr. Leshner argued that nanotechnology is new enough and moving quickly enough to be used, if sufficiently well organised, as a case study of science and technology’s role in innovation and its subsequent economic impact. Mr. Leshner emphasised the complex relationship between science and technology and the economy; it is affected by a range of variables including federal funding policies, intellectual property rules, private investment strategies, and workforce issues. However, these issues are not unique to nanotechnology. Mr. Leshner challenged attendees to seek a model for better understanding nanotechnology’s impact on the economy and for demonstrating its returns and improving its accountability.

The National Nanotechnology Initiative

Tom Kalil (Deputy Director for Policy, Office of Science and Technology Policy, Executive Office of the President, United States) provided some background on the United States' National Nanotechnology Initiative. The annual budget for nanoscale science and engineering at U.S. federal agencies increased from USD 270 million in 2000 to USD 495 million in fiscal year 2001. The annual budget has since reached USD 1.8 billion. The NNI was accompanied by major initiatives in universities, and other countries have also developed versions of the NNI. Mr. Kalil suggested that now is an appropriate time to start looking at the economic returns from these investments; after 12 years, we are beginning to see fundamental advances in nanoscale science and engineering and the incorporation of nanoscale materials and devices into products.

The justification for the NNI in the late 1990s was the hope that nanotechnology would be a general-purpose technology with a pervasive effect across sectors. It was clear that nanotechnology required government intervention because the necessary advances in science and engineering were beyond the time horizons of most industrial firms. Nanotechnology also provided a way of rebalancing federal funding towards physics, chemistry, and material sciences following a period of large increases in biomedical research funding. A dedicated funding programme, with support from the research community, sought to overcome some of the interdisciplinary challenges raised by nanotechnology. It also raised the initiative's profile. In addition, a multi-agency effort was required because there were roles for different government agencies involved in basic science, metrology, national user facilities, and mission-specific research in areas such as national defence and aerospace.

Mr. Kalil then mentioned some of the methodological challenges associated with measuring economic returns from the investments made under the NNI and more generally in science and technology. The general-purpose nature of nanotechnology means that there is no strong link with a specific industry. To the extent that nanotechnology affects existing products, part, but not all, of the value associated with these products is attributable to the impact of nanotechnology. There are various means of evaluating the impact of R&D. One is to identify and estimate the benefits of potential technological breakthroughs, such as reducing cancer mortality by using economic valuations of life years. Another is to examine citations of industrial patents to see the role of research funded by government or non-profit organisations. Yet another is to trace back important innovations to their roots in publicly funded science, although this is clouded by the interplay of private and public actions.

Using this approach, the National Academy of Sciences has found that university-based research played an important role in the development of major information technology (IT) innovations that underpin markets now valued in excess of USD 1 trillion. Government-supported, university-based research played an important role in the development of technologies such as the Internet, timesharing and gigabit networking, advanced microprocessors, and human-computer interaction in wireless technologies. In still other approaches, econometric studies have investigated the rate of return to R&D, with many suggesting that social returns outweigh private returns. This provides a rationale for government funding of R&D or for R&D tax credits; by itself, the private sector would under-invest in R&D relative to the socially optimal level.

Mr. Kalil stressed that many of the approaches to assessing the impacts of science and technology rely on data and that improving the statistical infrastructure for R&D investment can facilitate future analysis. Agencies in the United States have collaborated on STAR METRICS, which collects information on the government-funded scientific workforce, and have been developing new methodologies in this area. However, quantitative methodologies are complemented by expert review, a practice also maintained by the NNI. There is a growing need to use these and other techniques to determine if the level of investment in R&D is justified at a time when governments face strong fiscal constraints.

The OECD Working Party on Nanotechnology

Françoise Roure (French Ministry of Economics, Finance and Industry and Chair of the OECD Working Party on Nanotechnology, WPN) presented the work of the WPN, which was created in 2007 and is a working party of the OECD Committee on Science and Technology Policy (CSTP). The WPN advises governments on emerging policy issues related to the responsible development of nanotechnology and promotes international co-operation to facilitate research, development and responsible commercialisation of nanotechnology. The WPN is primarily concerned with nanotechnology but is increasingly turning towards the convergence of nanotechnology and biotechnology, in collaboration with the OECD's Working Party on Biotechnology. It is also collaborating with the OECD National Experts on Science and Technology Indicators (NESTI), who are responsible for science and technology indicators related to defining and measuring emerging technologies and convergence, and the OECD Working Party on Manufactured Nanomaterials (WPMN), which aims to ensure that the approaches taken to hazard, exposure and risk assessment for manufactured nanomaterials are of a high quality, science-based and internationally harmonised.

The WPN's strategic priorities for 2011-14 are: to monitor and analyse policies for nanotechnology, including scientific and technological policies; to consider policies for gaining economic returns from investments in nanotechnology; to facilitate an enabling environment for nanotechnology; to monitor the social impact of nanotechnology; to consider the policy implications of technology convergence; and to engage with other organisations and groups focused on nanotechnology development.

The current work programme of the WPN has five themes: social dimensions of nanotechnology and responsible development; regulatory frameworks for nanotechnology in food and medical products; convergence of nanotechnology with other technologies; nanotechnology for green innovation and sustainable growth; and assessing the economic impact of nanotechnology.

The WPN has worked on assessing the economic impact of nanotechnology since 2008. At that time very few economists were active in the field; it was assumed that economists would contribute more once there were more market applications of nanotechnology. The WPN has also sought to facilitate discussions among various communities interested in the impacts of nanotechnology. Ms. Roure stated that a lack of terminology and descriptions of nanomaterials, limited data on nanotechnology activity and issues related to defining product improvements have hindered efforts to establish means of assessing the economic impacts of nanotechnology. Because nanomaterials can provide incremental improvements to existing products, the challenge is to define value added and possible improvements in quality created by the application of nanotechnology.

Over 2012-13 the WPN, together with the WPMN, is undertaking a case study on nanotechnology for the sustainable development of tyres. It is considering the economic and social impact of the use of nanotechnology in tyres, as well as environmental impacts and health and safety risks. It is also examining the transfer of knowledge in this sector. Nanotechnology has been used in the tyre industry to improve the safety and longevity of products.

Ken Guy (Head of Science and Technology Policy Division, OECD) recalled that various methodologies had come and gone in the field of assessing the impact of science and technology, often covering the same issues. The aim should be to achieve a better appreciation of the tools and instruments available for impact assessments and evaluations, and, rather than re-invent them, to improve them to address new technologies. The complexity of assessing impact is well known; policy makers are seeking means of dealing with that complexity.

Setting the scene

Important investments have been made over the years to develop and advance the field of nanotechnology. However, it is still difficult for policy makers to assess the return on these investments, such as the impact of nanotechnology on social and economic objectives, and the extent to which those investments have been sufficient and well-targeted. Assessing the impact of nanotechnology is difficult because it operates in a complex landscape in an evolving policy environment and with increasingly close interactions with other technologies. Richard Johnson (Senior Counsel and Senior Partner, retired, Arnold & Porter LLP; Chairman or Vice-Chairman, OECD/BIAC Nanotechnology, Biotechnology, and Technology Committees) pointed out that it is very important for policy makers to have a rationale and a sound basis for allocating scarce resources at a time of fiscal constraint and when their countries also need new sources of growth and new jobs and skills. Charles Wessner (Director of the Technology and Entrepreneurship Programme, The National Academies, United States) emphasised that governments around the world at all stages of economic development are focused on many of the same issues: getting a higher return in terms of product development, addressing social and global challenges, and creating jobs.

The next two sections look at why it is difficult to measure the economic impact of this technology and what can currently be measured.

Economic rationale and strategies for an advanced manufacturing sector

Gregory Tassey (Chief Economist, National Institute of Standards and Technology, United States) started by emphasising the complexity of recent technological advances. He stated that the global technology-based economy has grown rapidly but that, at the same time, technology lifecycles are being compressed. This gives government a more complex and varied role and will require agencies to design an increasingly varied set of support functions more efficiently.

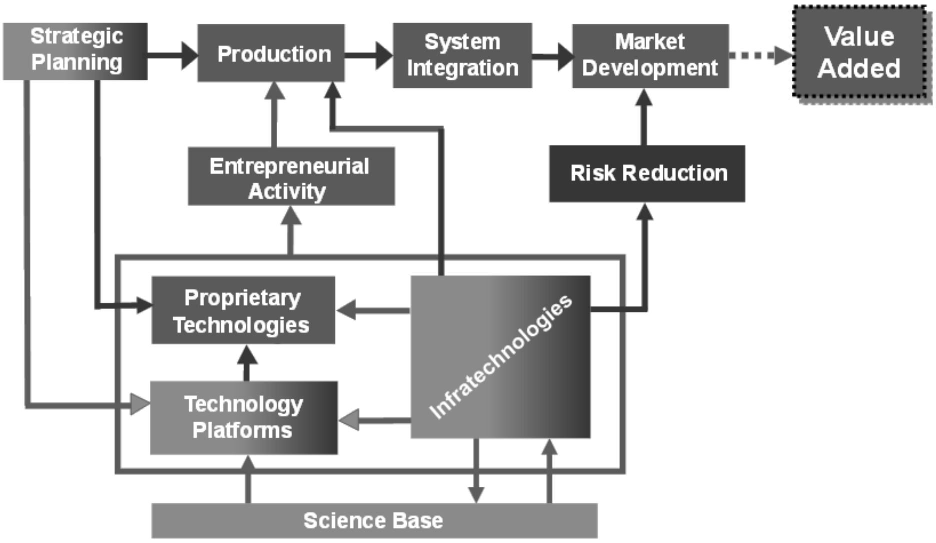
On the topic of the economic rationale for government intervention, the question was raised of whether an advanced economy needs a manufacturing sector. Mainstream economics and the dominant model of economic growth typically leave this question to the market and suggest it is possible for economies to specialise instead in other areas. Mr. Tassey, however, argued that manufacturing is essential to an advanced economy because of its dominant role in an advanced economy's technology development infrastructure and the high-paying jobs provided by the R&D-intensive portion of this sector. The key to managing a technology-based manufacturing sector is to understand the economic rationale for intervention, particularly by identifying where systematic underinvestment is occurring. The targets of government response can be identified through cost/benefit, rate-of-return, and investment gap analyses. Specific metrics can be developed to help evaluate particular policy mechanisms once they are selected. It is particularly important to select accurate long-term economic impact metrics, such as the difference between labour productivity and multifactor productivity. Using the wrong metric can lead to identifying the wrong problem or choosing the wrong policy response.

The compression of global technology life cycles has changed the role of governments. It requires more investment in R&D, greater attention to the type of R&D conducted and, especially, more efficient R&D (optimal organisation of public and private inputs). Excessive risk leads to underinvestment and is one of the primary rationales for government intervention in rapidly evolving technologies. However, risk occurs in different forms over the technology lifecycle. The "valley of death," a term popularised by the U.S. Congressional Science and Technology Committee[1] as the "gap between federally funded basic research and industry-funded applied research and development", is responsible for systematic underinvestment in the early part of the R&D cycle. Spillovers – technology benefits that accrue to more than sellers and buyers – can also lead to underinvestment. However, spillovers are hard to measure and occur at different rates and at different points in the technology lifecycle. Policy instruments have to be adjusted to the circumstances. Shorter technology lifecycles can also act to reduce investment as companies apply higher discount rates to prospective investments to account for the increased probability of inadequate rates of return.

Traditional "black-box" models of technology still drive a lot of thinking in policy circles, yet do not accurately reflect the modern technology-based economy. Whereas basic science is considered a public good, technology is often labelled as a private good, leading to the assertion that price signals in the marketplace are all that is needed to induce companies to invest in technology. Casual observation suggests that this is not the case and is becoming less so as time goes on.

Mr. Tassey suggested a "technology-element" model as an alternative means of driving policy and managing the R&D cycle. As Figure 1 shows, technology can be broken down into three elements: proprietary technology (the black box), technology platforms and "infratechnologies". Proprietary technology is the applied R&D that firms invest in with the hope of getting an adequate rate of return. Therefore, policy focuses on the other two elements. Technology platform development refers to the proof of concept research that is necessary to induce industry to invest in subsequent applied R&D that produces the proprietary technologies. Infratechnologies are a set of tools and methods that high-technology industry uses throughout R&D, production, and even market transactions, often in the form of standards. Industries would not be able to function without them (the semiconductor industry, for example, uses about 1600 standards). These last two elements of the typical industrial technology are funded in part by industry and in part by government. Mr. Tassey presented a preliminary taxonomy for separating nanotechnology into the three categories of mixed technologies.

Figure 1: Technology-element growth model



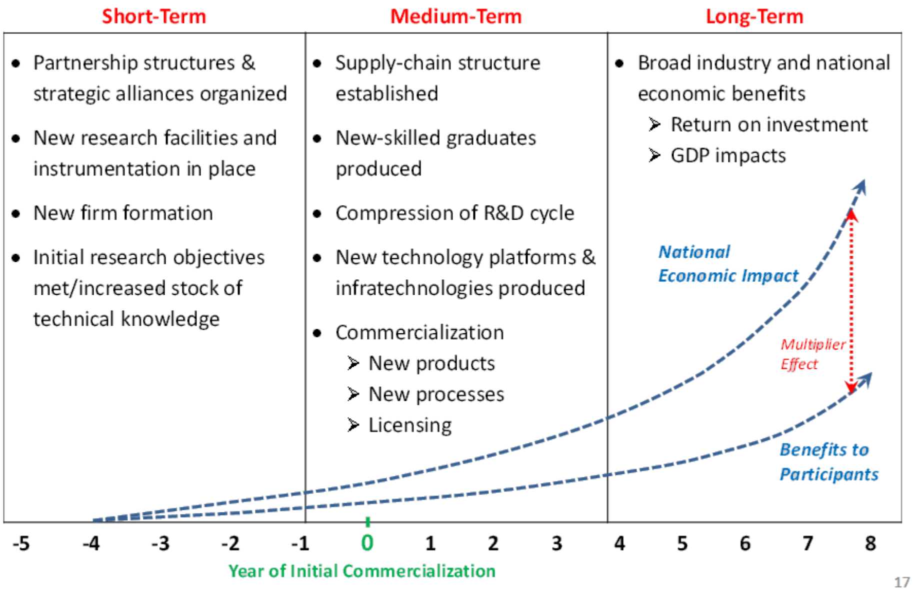
Source: Tassey, G. *The Knowledge Imperative*, 2007; and "The Disaggregated Technology Production Function: A New Model of Corporate and University Research, *Research Policy*, 2005.

Mr. Tassey then looked at characterising and choosing metrics to assist policy making for different aspects of technology, using technology platforms as an example. Early-stage R&D faces two types of risk: technical risk (it may not lead to a technology that meets market needs); and market risk (demand may disappear or an alternative technology may appear). The U.S. Industrial Research Institute's index of planned spending distinguishes between the projected amount of short-term R&D aimed at improving an existing technology on an existing platforms and the much smaller amount allocated to long-term disruptive R&D.

For infratechnologies, Mr. Tassey presented the results of a study of the expected benefits in reduced cost and time for the development of new drugs if the availability of infratechnologies were improved. It found substantial percentage declines were possible in the cost of new drug development and in development time (from discovery through to FDA approval).

In conclusion, Mr. Tassey emphasised the importance of technology lifecycles. He suggested that the United States had tended to focus on R&D to the detriment of the adoption and market penetration of nascent technologies. He contrasted this strategy with that of Germany, which regularly has a manufacturing trade surplus despite a similar R&D intensity and higher manufacturing labour costs. In terms of metrics (Figure 2), short- and medium-term metrics are important for programme management and for intermediate accountability, even if the eventual economic impacts appear much later.

Figure 2: Impact metrics for a nanotechnology innovation cluster model



Source: OECD/NNI Symposium on Assessing the Economic Impact of Nanotechnology, 27-28 March 2012, Presentation by Gregory Tassey (Chief Economist, National Institutes of Standards and Technology, United States).

Challenges for evaluating return on investment in nanotechnology and its broader economic impact

Mark Morrison (Chief Executive Officer, Institute for Nanotechnology, United Kingdom) discussed challenges governments face for assessing the impact of nanotechnology and the return on their investments in this field (see Box 1). Among the main challenges are:

- Nanotechnology is only one of many areas of government intervention and is increasingly interconnected with other enabling technologies. Extracting the precise role of nanotechnology may be difficult.
- The nanotechnology policy landscape is evolving as countries adopt more challenge-focused and manufacturing-focused policies and strategies.
- There are no accepted definitions of nanotechnology products, processes or companies, yet they are essential for collecting data and comparing countries.
- Survey collection should be improved to facilitate sharing of information by companies.
- Nanotechnology can play a role throughout the value chain; it is important to look not only at the final product but also at its potential contribution along the product value chain. This will give a better sense of its full impact.

Box 1. Overview of symposium background paper - Challenges for governments in evaluating return on investment from nanotechnology and its broader economic impact

Assessing the economic impact of any investment made by governments is a challenge. A combination of factors makes assessing investments in nanosciences and nanotechnology particularly difficult. This paper considers challenges faced by governments in this area. It provides an overview of the nanotechnology policy landscape in a number of OECD and non-OECD countries and summarises and evaluates the economic indicators currently in use for nanotechnology economic impact assessment. Finally, it attempts to define the economic impact and how it can be measured most successfully.

Nanotechnology is developing in a complex policy environment; however, it is a critical component of public investment aimed at addressing the grand challenges facing all countries and ensuring an innovation-led, manufacturing-based economic recovery. As countries have adopted different funding policies and strategies, it is difficult to make comparisons. Many countries are moving towards more challenge-driven, manufacturing-focused research and innovation funding policies. Nanotechnology becomes one among various approaches and technologies for addressing specific socioeconomic objectives. Identifying the impact of nanotechnology is complicated by factors such as regulation. It may be that the development and improvement of nanotechnology-specific indicators may not be required in the longer term. However, in the short term countries such as the United States, India and Germany have nano-specific funding programmes that require improved economic indicators of the impact of nanotechnology.

The fact that nanotechnology can have an impact all along the value chain highlights the need for those collecting economic data to understand fully the impact of nanotechnology at each stage of the value chain and across the multidisciplinary/multi-application value chains that can arise from the enabling nature of nanotechnology and its *potential to contribute to solutions for many global challenges.*

Source: OECD/NNI Symposium on Assessing the Economic Impact of Nanotechnology, Background paper: Challenges for Governments in Evaluating Return on Investment from Nanotechnology and its Broader Economic Impact, Eleanor O'Rourke and Mark Morrison, Institute of Nanotechnology, United Kingdom.

Mr. Morrison noted that many OECD and emerging economies have funding for nanotechnology. Some of these funds still go to basic research, but there is now more attention to improving the link between innovation and value chains. Investments in science and technology have moved from being technology-driven to focusing on grand social challenges such as health, the environment and energy. Nanotechnology is one of several tools available to governments in this respect. Mr. Morrison pointed out that nanotechnology is one of the enabling technologies in which governments are investing with a view to transforming industry and creating new products and services. Nanotechnology plays a part in enabling technologies such as advanced materials, advanced manufacturing systems, photonics, and electronics. There are in fact increasingly close links among these technological options. This further complicates any assessment of the impact of nanotechnology.

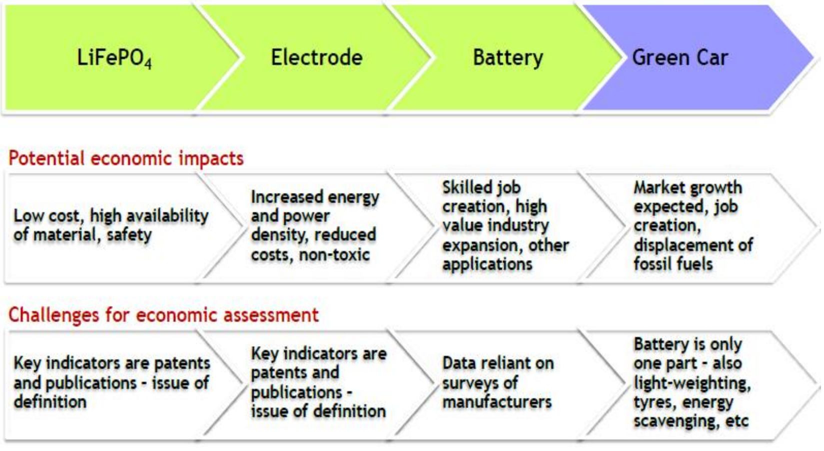
Moreover, nanotechnology may have direct or indirect impacts both on social and economic challenges and on products. For societies and economies, direct impacts would include growth of new and existing companies, job creation, new products, and wealth creation. The possible indirect impacts are more difficult to assess and have a less clear link to the original technology or underpinning science. For example, the indirect benefits of cancer treatment could include reduced mortality from cancer through early detection, fewer hospitalisations, lower treatment costs, lower state-benefit payments for people undergoing treatment, and freeing up health resources for treating other diseases. Another example is lithium ion batteries for electric vehicles, for which the indirect economic benefits might include energy security, less reliance on fossil fuels and reduced CO_2 emissions. Also, the use of nanotechnology in the development of novel display technologies could help reduce reliance on rare raw materials and lower the cost of end-of-life disposal of the products. It is important to recognise as well that nanotechnology may have negative impacts, e.g. by displacing industries and jobs.

Mr. Morrison then looked at how nanotechnology fits into product development. Nanotechnology can be part of a product's value chain and nanoscale features can be fundamental to the functionality of components in the product that may give the final product its novelty. Nanomaterials can also be ancillary to the value chain and affect the processes leading to the final products. In this case nanoscale features are not necessarily present in the final product, and the functionality and novelty of the product might be independent of nanotechnology. Mr. Morrison then identified three categories of products using nanotechnology:

- A nanotechnology product is a product for which nanotechnology is essential to its functionality.
- A nano-enabled product is one for which nanotechnology provides functionality but the final product may contain very few nanomaterials.
- Finally, there are products that utilise nanotechnology in the production process, but the final product may contain no nanomaterials and its functionality may not be altered by nanotechnology.

Because nanotechnology is part of this complex landscape, its impact is hard to assess. When trying to assess the economic impact of nanotechnology, it is important to keep the value chain in mind. Mr. Morrison used the example of the “green” car (Figure 3), a high-technology product involving many different value chains in which nanotechnology plays a role. In the power storage and release system, the material ($LiFePO_4$), component (electrode), and system (battery) are nanoproducts, and the final product (green car) is nano-enabled. That is, its performance is enhanced by the use of nanotechnology. The question is how much value the nano-battery adds to the final product. Nanotechnology may also play a role in many other systems and components of the green car; other nano-enabled developments include light weight, decreased roll resistance and energy scavenging, which help to comply with ever stricter regulations for reduced CO_2 emissions.

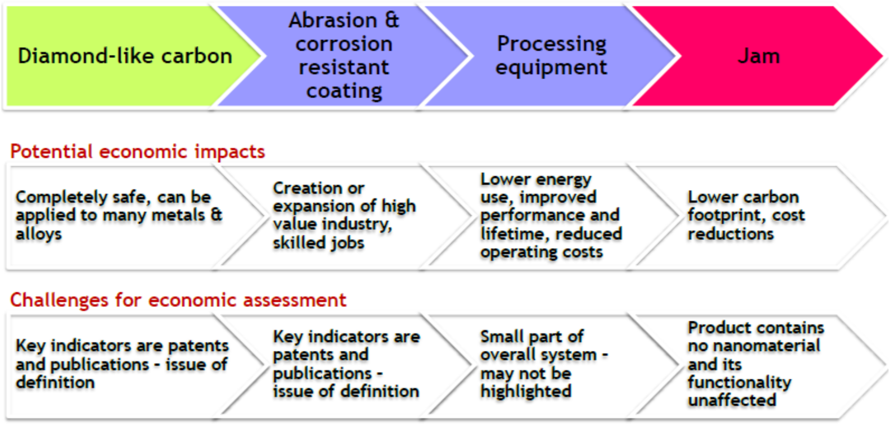
Figure 3: Value chain example: nano-battery in a green car



Source: OECD/NNI Symposium on Assessing the Economic Impact of Nanotechnology, 27-28 March 2012, Presentation by Mark Morrison Chief Executive Officer, Institute for Nanotechnology, United Kingdom.

As a second example, Mr. Morrison presented the value chain for jam production (Figure 4). The product itself, jam, contains no nanomaterial and its functionality is not altered by the use of diamond-like carbon coating in the processing equipment. However, the abrasion- and corrosion-resistant coating on the metering pistons for filling jam jars allows for reduced maintenance; its economic impact is lower operating costs.

Figure 4: Value chain example: nano-coated processing equipment used to make jam



Source: OECD/NNI Symposium on Assessing the Economic Impact of Nanotechnology, 27-28 March 2012, Presentation by Mark Morrison Chief Executive Officer, Institute for Nanotechnology, United Kingdom.

Three main types of indicators are used to assess the impact of nanotechnology, according to Mr. Morrison: input indicators such as public and private investment, infrastructure and numbers of graduates; output indicators such as publications, patents and product sales; and impact indicators such as number of companies created, number of jobs and growth of market or volume share.

Impact indicators are the most relevant but also the most difficult to collect information on. Patents are often used in nanotechnology impact assessment, but it is difficult to measure their worth as many never lead to any actual value. For example, the Observatory Nano Project of the European Union's 7th Framework Programme attempted to map the European landscape in terms of companies involved in nanotechnology. The mapping exercise started by looking at companies that had been funded through the 'Nanosciences and Nanotechnologies, Materials and New Production Technologies' (NMP) of the 7th Framework Programme and companies that were publishing and patenting in nanotechnology. About 1 540 companies were identified, but only 100 agreed to participate in the project. The challenge, said Mr. Morrison, was how to encourage those companies to share information that can be used to assess the socioeconomic impact of nanotechnology?

Investment in and impact of nanotechnology: a policy perspective

The Symposium hosted a government panel to explore common features and differences in certain OECD and emerging economies in terms of investments in nanotechnology and challenges related to measuring its impact on societies and economies. The panel was composed of representatives from Brazil, India, Japan, South Africa and the United States; the European Union was also represented. It focused on the following issues:

- What are your country's highest priorities/socioeconomic goals for investments in nanotechnology (e.g. better health, development of a high-technology industry, energy, etc.)?
- What steps has your country taken so far, if any, to try to estimate the return on investment and the broader economic impact of nanotechnology?
- What are the main challenges your country faces for estimating these returns?

The presentations and discussions showed that governments have an increasing interest in the potential impact of nanotechnology on societies and economies. Although reasons for nanotechnology investment vary depending on the country's scientific and economic specialisation, competitiveness goals, and social objectives, there is a common trend towards investing in nanotechnology because it may help deal with challenges related to population ageing and health, energy, and the environment. There was also a common view that it could support the development and/or restoration of industrial competitiveness and economic growth, in both emerging and developed economies. Whether nanotechnology has its own dedicated strategy or action plan (e.g. the South African Nanotechnology Strategy, the United States' NNI) or whether it is included in their broader agendas for science, technology and innovation (e.g. Japan's 4th S&T Basic Plan, the European Union's framework programme Horizon 2020), nanotechnology is clearly a focus of interest.

The Symposium brought out that investments in nanotechnology have been moving from a focus on technology to a focus on social and economic challenges, although basic research remains important. This challenge-driven trend is strong in both OECD and emerging economies represented on the panel.

In terms of assessing the economic and social impact of nanotechnology, governments generally appeared to have two goals: the return on their investments (in terms of industry development, patents granted, human resources, etc.), and the impact of the technology and its applications on the economy and the society. It was stressed that before conducting an impact analysis, it is crucial to define the questions to be answered and the goal of the analysis. (For instance, is it to measure returns on investments? Is it to compare nanotechnology with an incumbent technology? Is it to guide further investments in the field?) Once the goal is set, it becomes easier to identify the relevant indicators and data that need to be collected.

Other topics covered in the presentations included regulation, indicators of public opinion and acceptance, social buy-in, definitions, and definitions for multiple contexts. The following sections describe in more detail the particularities and priorities of each country represented on the panel.

Brazil

Adalberto Fazzio (Deputy Secretary and Co-ordinator of the Nanoscience and Nanotechnology Secretariat for Technological Development and Innovation, Ministry of Science, Technology and Innovation, Brazil) started by giving some historical background on developments in Brazil. Brazil has been able to react to major events and crises through rapid development of specific industry sectors. Mr. Fazzio mentioned Brazilian industries such as Embrapa, which became the third largest food exporter, and Petrobras, the world's third largest oil company. However, Brazil saw its share of GDP dedicated to manufacturing decrease from 17% to 14% between 2008 and 2011. This presented a major innovation challenge and has led to an emphasis on developing basic research, in particular in the field of nanotechnology. Brazil has created 16 science and technology institutes working on nanotechnology, and eight laboratories are dedicated to nanotechnology and have about 2500 researchers. The National Science and Technology Institute of Carbon Nanostructured Materials has 54 researchers, including physicists, chemists, biologists, and engineers. A spin-off, the Technology Centre on Carbon Nanotubes, is a platform for facilitating the transfer of new technologies. It receives USD 20 million in public funds in addition to private-sector funds. The National Nanotechnology Laboratory for Agriculture conducts a large amount of research on cellulose fibres (e.g. from sugarcane). Another laboratory supported by the Ministry of Commerce and Industry possesses very advanced facilities in terms of microscopy. In general, facilities in these institutes and centres are shared with the private sector through a variety of collaborations.

A survey was conducted to estimate the number of nanotechnology companies in Brazil. Seven hundred companies replied that nanotechnology was part of their business. But, Mr. Fazzio noted, if you look at exactly what the companies do, about 163 conduct nanotechnology R&D and most collaborate with national nanotechnology institutes and universities.

The Brazilian government is in the process of improving policy and strategy for nanotechnology. Following a ministerial order in 2012, an Inter-Ministries Nanotechnology Committee was created; it encompasses the Ministries of Science, Technology and Innovation; Environment; Health; Energy; Agriculture; Education; Industry and Commerce; Defence, and Agriculture. Also, a number of initiatives aim to optimise the functioning of laboratories working on or using nanotechnology. For example, the National Nanotechnology Labs is set up to co-ordinate and optimise infrastructure sharing. Public-private partnerships will be strongly encouraged as part of the new strategy called SisNANO.

Mr. Fazzio mentioned that strategic areas for nanotechnology have been defined: energy, environment, defence, health, aerospace, and agribusiness. Each is linked to the development of specific industry sectors. For environment, the aim is new materials from biomass involving plastic, rubber and nanocomposites. In health, especially drug development, the aim is to apply nanotechnology for treatment and diagnosis of neglected and/or tropical diseases. Another goal is the development of hygiene, perfumery and cosmetics products that apply nanotechnology for photoprotection. Yet another set of goals include increased efficiency and quality of products and processes as well as the integration of features through the development of sensors and electronic devices for sectors such as aerospace, agribusiness, energy, and defence.

The government has invested about USD 44.5 million in this nanotechnology plan. The support comes mainly from the Ministry of Science, Technology and Innovation (40%), the Ministry of Education (16.8%), and the Research Funding Foundations (13.7%).

European Union

What do policy makers want to know when they have to decide whether to invest in a technology? Herbert von Bose (Director, Industrial Technologies, DG Research and Innovation, European Commission) called attention to policy makers' need for information about impact (e.g. the number of jobs created, the effect of the technology on the environment and grand social challenges). Even if output indicators such as knowledge creation and advances in science and technology are important, they are not the main basis of assessment or at least are not sufficient to make informed policy decisions regarding investments. The impact of the technology on grand social and environmental challenges is particularly important, as investments increasingly tend to be challenge-oriented rather than technology-oriented.

Although basic research remains very important, the challenge-driven trend is very visible in the recent programmes of the European Commission (EC). Indeed, the EC has based its strategies around three pillars. The first deals with science and basic research. The second and largest addresses social challenges and will cover areas such as energy, transport, climate change and the environment, and security and society. The third pillar concerns industry. Key enabling technologies (KETs), including nanotechnology, will play a strong role here.

Five KETs have been identified as part of the nanotechnology programme: nanomaterials, biotechnology, micro- and nanoelectronics, and all cross-cutting manufacturing technologies. Mr. von Bose pointed out that it is the interaction between these technologies that is particularly important. Having people working together to develop new solutions by integrating the key enabling technologies will lead to the successes expected from these technologies. Of course, mixing these technologies and fields does not make the impact assessment of individual technologies any easier.

At the moment the EC spends about EUR 600 million a year on nanotechnology. Of this, 20% is spent on basic research, 15% on training and education, and the remaining 65% on applied nanotechnology. During the past ten years, there has been significant investment in scientific work relating to nanotechnology, but nanotechnology is now increasingly involved in applications. Mr. von Bose pointed out that it is found in every computer and is increasingly present in medical applications and energy solutions. But as nanotechnology is starting to reach the market, policy makers will not only ask about benefits and added value but also about the possible need for regulation and adaptation of the policy environment. What are the potential environmental, health and safety (EHS) issues? Out of the EUR 600 million spent by the European Commission on nanotechnology, 5% is dedicated to EHS issues.

Mr. von Bose raised the question of the level of detail needed to justify spending on R&D, in particular whether the focus should be at the level of the technology (nanotechnology) or the application (including impacts on energy and health). Von Bose argued that it is useful to look at the technology, particularly in the case of an emerging technology, because the public would be able to see what these technologies really bring to society, and public acceptance and social buy-in are essential for their uptake.

Information on the impact of nanotechnology now largely comes from surveys, according to Mr. von Bose. When using surveys, it is important to take account of the burden on administrations, research institutes and industries and to choose the best methods for gathering the information. For example, the type of information needed from industry should be better framed. Only data that are of high value for measuring impact should be sought. Mr. Von Bose then discussed the different indicators that would be needed in an impact assessment. Input indicators are important and relatively easy to collect. Activity and outcomes indicators, such as patents produced and number of publications, also are very relevant. However, those indicators have limits from an economic point of view. For example, while Europe produces 37% of patents in the area of nanotechnology and energy – there is an increasing use of photovoltaic cells, for example, in Europe – most of the products using nanotechnology for energy are produced in China. From a public funding perspective, why should governments invest in producing patents that are not used in Europe? Measuring economic impact shows another side of nanotechnology: nanotechnology is indeed the source of jobs and industries but they are not yet appearing widely in Europe.

Mr. Von Bose ended his presentation by emphasising the need for framework indicators to learn about public opinion on nanotechnology and public acceptance. This is difficult to measure but very important.

India

Mr. Ramaraju (Head of Nanotechnology Initiatives Division, Ministry of Communications and Information Technology, India) spoke about India’s nanotechnology initiatives. Two departments support nanotechnology: the Department of Science and Technology and the Department of Electronics and Information Technology. Departments that also support projects related to nanotechnology are the Department of Biotechnology, the Department of Space, and the Indian Council for Medical Research.

Mr. Ramaraju described some of these initiatives:

– The Department of Science and Technology has a plan called Nano Mission. It promotes basic research, infrastructure development, nano-applications and technology development, human resource development, and international collaborations. It has state-of-the art facilities in India and access to similar facilities abroad. It also supports the Bureau of Indian Standards and the National Physical Laboratory for Development of Standards.

– The Department of Electronics and Information Technology focuses on nanoelectronics and technology development and on nanofabrication.

The Department of Science and Technology has so far invested about USD 200 million and now invests about USD 40 million a year. The Department of Electronics and Information Technology has invested about USD 100 million over a period of eight years and now invests about USD 20 million a year. The Department of Biotechnology has spent about USD 20 million so far. It is estimated that industrial investments in India are approximately USD 250 million. Public investments cover basic research through to the support of industry.

A national task force has been set up to produce a roadmap for a regulatory framework for nanotechnology. A separate centre aims at analysing the economic impact of nanotechnology, covering what is happening in India and elsewhere. Two centres of excellence focusing on nanoelectronics have been established in Bombay and Bangalore and have international visibility. These centres are entering a Phase 2 programme with investments of USD 30 million. Their objectives are to support technology breakthroughs and the development of completely new ideas, to encourage start-ups and entrepreneurs and to support high-technology industries. In the area of education, Mr. Ramaraju highlighted the Indian Nanoelectronics Users Program (INUP) at Bangalore and IIT-Bombay. The scope of this programme is to:

- Give hands-on training in nanoelectronics to researchers in institutions across the country.
- Help initiate research in nanoelectronics across the country by allowing external users to carry out their work at these centres.
- Collaborate with research teams at other Indian centres and develop joint programmes in nanoelectronics.
- Provide a platform for researchers in nanoelectronics to come together and benefit from complementary expertise.
- Conduct workshops to disseminate of knowledge about nanoelectronics more widely.

India’s publications in the area of nanotechnology have risen by 9.1% in the past ten years. India is among the top ten publishing countries in this area. In 2010, 87 patents in nanotechnology were published by Indian assignees at the Indian Patent Office.

Mr. Ramaraju pointed out the strengths, weaknesses, threats and opportunities of the Indian national programme (see Box 2).

Box 2. A SWOT analysis of nanotechnology in India

Strengths	Weaknesses
- India performs reasonably well in scientific publications - Active community of 1 000 researchers - Good characterisation facilities - Decent fabrication facilities in a few institutions - Indian research – good value for investment	- Progress on technology front slow - Lab to commercialisation: enabling environment needs considerable strengthening - Industry reluctant to take risks - Poor job opportunities in industry for R&D personnel
Threats	**Opportunities**
- International competitiveness even in nano science will be marginalised if vigorous promotional efforts are not continued - Opportunities to exploit application potential will be lost if enabling financial, management and regulatory systems are not put in place quickly to promote technology development and commercialisation.	- Sparks of entrepreneurship now visible in a few institutions - Business community and venture capitalists desirous of investing now - Development of technologies, products and processes may pick up now if risk-absorbing schemes are put in place quickly

Source: OECD/NNI Symposium on Assessing the Economic Impact of Nanotechnology, 27-28 March 2012, Presentation by Mr. Ramaraju, Head of Nanotechnology Initiatives Division, Ministry of Communications and Information Technology, India.

Government initiatives to enhance manufacturing in India include:

- The National Manufacturing Competition Council (NMCC), which aims to provide a continuing forum for policy dialogue to energise and sustain the growth of manufacturing industries in India.
- An Incentive Package Programme (SIPS) for the Semiconductor and other electronics industry.
- An Electronics Development Fund (USD 2 billion) is proposed to promote innovation, intellectual property, R&D, product development, commercialisation of products, etc., in nanoelectronics and IT.

Japan

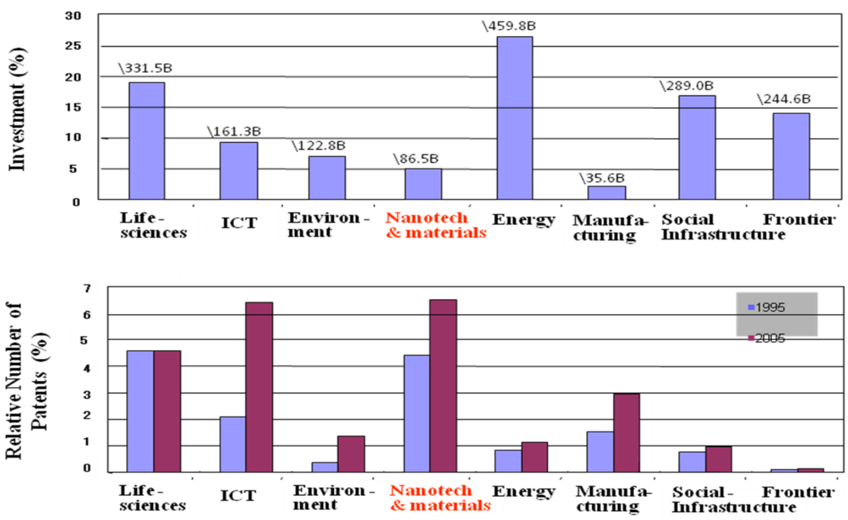
Naoya Kaneko (Fellow, Centre for R&D Strategy, Japan Science and Technology Agency, Japan) detailed the evolution of nanotechnology research and development since 1980 and looked forward towards 2020. In the “first generation”, he showed that progress had been made in the nanotechnology world in independent disciplines through top-down, bottom-up and combination processes (e.g. lithography, computer science, -omics). The second generation, starting from 2000, drew on a fusion of the nanotechnology world with other disciplines to produce new functions, materials, processes, and devices. The third generation, which is thought to have arisen in 2010, is about the integration of various “nano worlds” into functional systems (e.g. materials design, molecular electronics and theranostic medicine).

In Japan, three fields are of particular interest: green nanotechnology, nanobiotechnology and nanoelectronics. Green nanotechnology is about energy generation, transmission and storage, energy saving, and protection of the environment. Nanobiotechnology is addressed in particular through health-related programmes on innovative medical nanotechnologies, materials for regenerative medicine and the application of biological systems to other fields (e.g. IT). Nanoelectronics is about energy saving, multi-functional systems and ultra-high-speed computing. Dr Kaneko emphasised the role of these technologies for building a sustainable and eco-friendly society. Social needs are driving technology development and the creation of new fields and functional systems.

Mr. Kaneko next discussed the complexity of evaluating the impact of these technologies. He introduced some ongoing studies in the field of impact assessment, such as the market studies from Lux Research, the Project on Emerging Nanotechnologies (PEN, www.nanotechproject.org/) in the United States which has gathered statistics on the number of catalogued nanotechnology products in the world, and Chinese Taipei's NanoMark system for promoting the commercialisation of nanotechnology products. According to Lux Research, the number of nano-enabled consumer products has increased since 2008 and is expected to continue to do so. Mr. Kaneko used as a second example the growth of nanotechnology in Korea. A review of the ten years of the Korea Nanotechnology Initiative measured, among other things, investments, the number of researchers, the number of companies, dedicated departments in universities, and the number of papers. Between 2001 and 2008, investments in nanotechnology more than doubled. The number of researchers increased by a factor of four, as did the number of patents. The number of companies increased from 78 to 274.

Returning to Japan, Mr. Kaneko discussed the evaluation of the third S&T Basic Plan. This plan ran from 2006 to 2010 and had eight promotion areas: life sciences, information technology, environment, nanotechnology and materials, energy, manufacturing, social infrastructure, and frontier. The economic impact of investments in these eight areas was estimated in terms of the relative number of patent applications in each area, weighted using a concordance table between patents in the eight areas and the sales of 22 manufacturing industries in Japan. The results of this analysis were compared to investment in each area (Figure 5).

Figure 5: Investments and relative patent applications in nanotechnology in Japan



Source: OECD/NNI Symposium on Assessing the Economic Impact of Nanotechnology, 27-28 March 2012, Presentation by Mr. Kaneko, Fellow, Centre for R&D Strategy, Japan Science and Technology Agency, Japan.

Among the eight areas, nanotechnology and materials had the highest impact in terms of number of patents. Investment in nanotechnology and materials reached about JPY 90 billion in 2008. However, this was relatively low compared to investment in the seven other areas, although the ratio of investment to estimated impact was the highest.

Mr. Kaneko then presented the 4th S&T Basic Plan that runs from 2011 to 2015. It will shift from "R&D prioritisation" to "problem solving" in order to address pressing social needs such as reducing CO_2 emissions by 2020. The new plan has a number of pillars: safety, recovery and reconstruction, green innovation and life innovation, promotion of basic R&D activities, and strengthening of human capability development. Nanotechnology will be supported as part of this plan, in particular, green nanotechnology, nanobiotechnology and nanoelectronics. Mr. Kaneko pointed out that nanotechnology needs to be further promoted.

South Africa

Joseph Molapisi (Manager for Emerging Research Areas, Department of Science and Technology, South Africa) said that the development of nanotechnology in South Africa is guided by the national nanotechnology strategy, which was approved by the Cabinet in 2006. According to the strategy, nanotechnology should affect two different clusters. The first is social development. Mr. Molapisi pointed out that South Africa, as a country and as part of the African continent, faces particular challenges related to health, water and energy that nanotechnology should help address. Second, it should improve the competitiveness of industries that are strategic to the country, such as minerals and mining, chemicals and bioprocessing, advanced materials, and manufacturing. The strategy identifies specific challenges in each of the clusters. Where can nanotechnology have an impact? What needs to be done for this to happen?

Mr. Molapisi listed the aims of the strategy:

- Human capital development: researchers need to be able to conduct cutting-edge research in the field of nanotechnology. A nanosciences centre formed by a consortium of universities offers nanoscience degrees at the Master's level.
- Knowledge generation.
- Acquisition of research infrastructure in universities. At least 16 South African universities have significant research programmes in nanoscience and nanotechnology.
- Responsible development of nanotechnology: a research platform is planned to build the capacity to identify risks associated with nanotechnology. It will build on current activity in this area in different institutions and consolidate these efforts.
- Innovation: two nanotechnology innovation centres have been established to build innovation capability. They are positioned to use successful university research to develop tangible products and processes. The two centres play a key role as links between universities and industry.

In terms of public investments, Mr. Molapisi stated that about USD 77.5 million was invested between 2006 and 2011. In 2010 a study was undertaken to assess the impact of various nanotechnology programmes. The study analysed the impact in two respects: to determine if the efforts made in terms of nanotechnology development are yielding returns and to try to assess the impact of nanotechnology development on the economy.

Results from the study gave an indication of impact for the first of these. It focused on human capital development, such as the number of Master's students that have graduated from various nanotechnology development programmes. It also looked at knowledge generation in the form of publications and whether publications coming out of various programmes indicate a contribution to knowledge generation in the field. Finally the study looked at the extent to which ongoing projects address areas in which nanotechnology could make an impact and the degree of innovation from those projects. Results from the study painted a very good picture in terms of the country's progress towards tackling the country's challenges. To date, industry in South Africa has not contributed actively to the development of nano-technology.

In terms of evaluating the economic impact of the technology, it appeared that, as a late starter in this area, too little attention had so far been given to the economic impact of the technology. Moreover, there were no readily available assessment models for measuring economic impact. This limited the ability to undertake an economic assessment. However, Mr. Molapisi noted the importance of economic assessment for ensuring that the country is achieving its strategic goals. Like any investors, Mr. Molapisi said, governments need to be aware of the return on their investment. In particular, being able to show economic impact could encourage industry involvement in nanotechnology development and facilitate technology transfer. Given South Africa’s limited budget and competing priorities, it is essential to demonstrate the economic impact of nanotechnology.

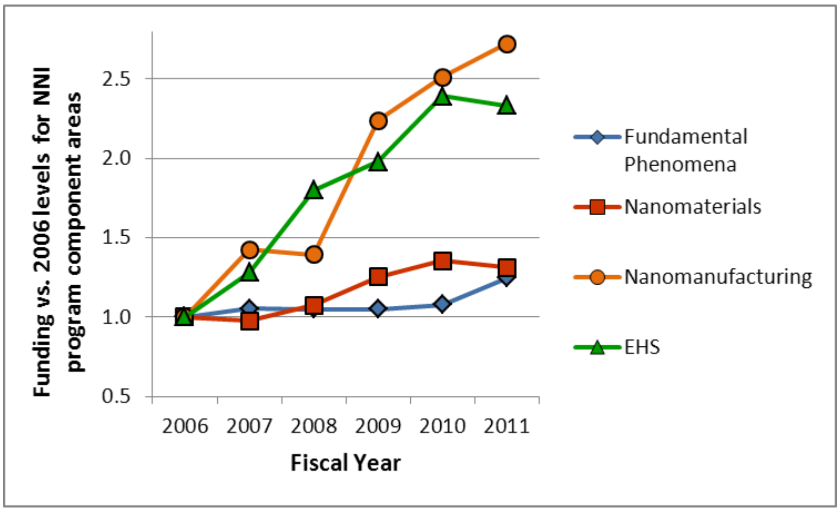
United States

The NNI vision is of a future in which the ability to understand and control matter at the nanoscale leads to a revolution in technology and industry that benefits society, said Altaf Carim (Assistant Director for Nanotechnology, Office of Science and Technology Policy, Executive Office of the President, United States). In this vision both aspects of assessment are represented: the economic impact of the technology and industry and the broader impacts on social challenges. The scope is quite broad, ranging from basic research through to development and commercialisation efforts. Some specific topics are highlighted in signature initiatives that focus on areas of particular promise. Three had been launched at the time of the symposium, one in nanoelectronics, one in sustainable nanomanufacturing, and one in solar energy. Total federal investment from the NNI is approximately USD 1.8 billion annually. The NNI is a government initiative; it is a priority area for investment across the federal government but does not have a separate budget or central management. The NNI co-ordinates 27 federal agencies and is also involved in the area of environment, health and safety (EHS).

The NNI uses the following definition: “Nanotechnology is the understanding and control of matter at dimensions between approximately 1 and 100 nanometres, where unique phenomena enable novel applications.” This definition has been used for federal co-ordination of activities and gives a consistent basis for identifying nanotechnology activities in the United States. The International Organization for Standardization (ISO) and other bodies have developed or adopted generally similar definitions. Mr. Carim pointed out that there is a reasonable degree of consensus about what nanotechnology means, but the issue is: Is this sufficient for all contexts? In the case of regulation, for example, does the definition need to be amplified?

There has been a considerable increase in annual NNI investments in the past years. In 2001 when the initiative started, USD 463 million was invested; investments are today approximately USD 1.8 billion. Since 2006, eight investment categories have tracked investments ranging from basic research to applied nanotechnology (e.g. manufacturing, materials), and investments in basic research have been maintained at a high level. The coming years will emphasise EHS and nanomanufacturing. Investments in these areas have gone up by a factor of two-and-a-half over the past six years (Figure 6).

Figure 6: NNI investments and their evolution



Source: OECD/NNI Symposium on Assessing the Economic Impact of Nanotechnology, 27-28 March 2012, Presentation by Altaf Carim (Assistant Director for Nanotechnology, Office of Science and Technology Policy, Executive Office of the President, United States).

Mr. Carim next spoke about valuing nanotechnology. Recalling the presentation of Tom Kalil, he reminded the audience of the main methodologies in place for assessing economic impact: consumer valuation, input/output models, studies of major innovations, analysis of innovation indicators, and expert reviews. He pointed out that the value of all these types of assessment methodologies largely depends on the quality and quantity of the data used. Where do the data come from? Who is responsible for data collection, data integrity and storage? So far data have mainly been collected through surveys. Surveys give information that cannot be obtained in any other way but raise issues of consistency. There is also the burden on those who answer these surveys. The quality of the assessment also depends on the suitability of the methodology used.

These are not the only challenges for assessing the impact of nanotechnology. Others are more specific to the technology and are linked to its enabling capabilities. Nanotechnology is an enabling technology for many different industries and encompasses both end products and processes. In some cases nanotechnology will make no discernible change in the end products but the nano-enabled manufacturing process will be more efficient, cheaper or otherwise improved. When end products encompass nanotechnology the issue is the part of the value of this product that can be attributed to nanotechnology. Mr. Carim took the example of energy: How far have we moved towards clean energy? This is already a hard question and becomes even harder when trying to evaluate the extent to which nanotechnology contributed to that progress.

Moreover, Mr. Carim pointed out that the economic and social impacts may be felt very far from the underlying investments. This adds another layer of difficulty. The complexity of linking inputs to outputs to outcomes adds another. There is also the temptation to rely on what can easily be measured rather than on what is the most important to analyse.

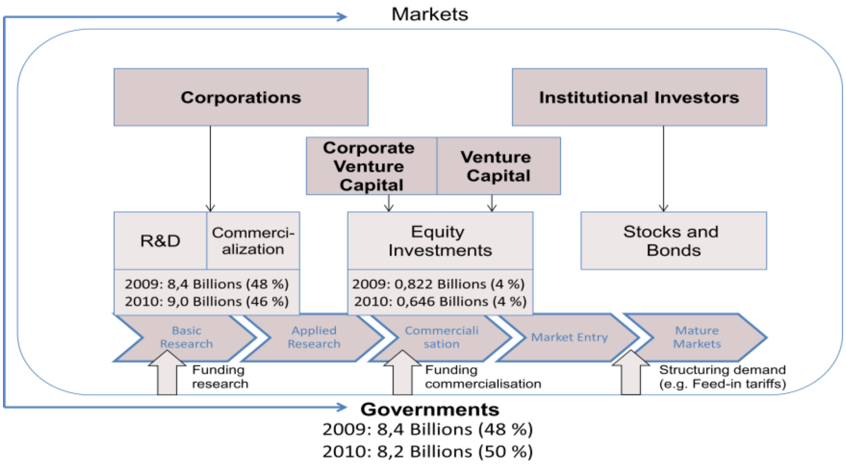
Mr. Carim made clear the need to know what should be assessed and how to measure it. He raised a number of questions: Is it to assess whether our past investments have been fruitful? Is it to compare this technology to other technologies? Is it to provide information on safety? Is it to provide information on how we can make future additional investments? He also raised the issue of when to assess: Do indicators give information about what has happened or can they be predictive?

In the discussion the question was raised of how much need there is to justify investments in a technology. It was also noted that while some people are convinced about nanotechnology and its innovation potential, especially in medicine, others are more sceptical and worry about possible risks. From a policy perspective, there is a need for data that show the technology's benefits and risks, if any. Clarity is also needed as regards regulation. The discussion turned to the issue of definition and how to develop definitions that are consistent. A shift from definition to description was suggested, which would give uniqueness and equivalence and be more flexible in terms of serving different purposes such as those of regulators.

Finance and investor models in nanotechnology

Pekka Koponen (CEO, Spinverse Ltd., Finland), author of the background paper on Finance and Investors Models in Nanotechnology (see Box 3), gave an overview of the structure of private investment in nanotechnology and highlighted the main challenges for investing in nanotechnology. Looking at the structure bridging government money and the market, Mr. Koponen identified three types of investors: corporations, venture capital and institutional investors (Figure 7).

Figure 7: Private funding of nanotechnology, USD



Source: OECD/NNI Symposium on Assessing the Economic Impact of Nanotechnology, Background paper: Finance and Investors Models, Tom Crawley, Pekka Koponen, Lauri Tolvas and Terhi Marttila, Spinverse. Figure from Lux research (2011), reprinted with permission.

Corporate investments are directed to R&D and commercialisation, the activities necessary to take a product to market. The goal of those investments is to increase revenues from new or improved products in new or current markets and to improve profitability. The metrics used to measure return on investment in R&D include number of patents, R&D intensity (R&D expenditure as a percentage of turnover), and return on investment in R&D activities. When measuring the impact of investment in commercialisation, metrics are more explicitly focused on expected return (increase in sales), costs (building production facilities, marketing), and expected payback and cost of capital. According to an analysis from Lux Research, in 2010 corporate spending exceeded government spending. This measure is often a first indication of the commercial success or viability of emerging technologies. There are sectors in which corporate spending is ten to twenty times government spending, but nanotechnology is still emerging.

"If corporate investors have found nanotechnology, venture capitalists haven't," said Mr. Koponen. Venture capital accounts for less than 5% of overall nanotechnology funding, and this seems unlikely to change soon. Venture capitalists seek to finance rapid growth with high return. In general, they invest in portfolios of companies that return money in two to three years, and they invest in a portfolio of companies because success rates vary greatly and many companies fail. The expected return is expected to be 10 to 100 times the original investment; return is typically measured in terms of listing on the stock market or sale to a large corporation. When investing in a company, venture capitalists look at various criteria, added Mr. Koponen. These include the profile of the company's management, stage of development and technology as well as the market potential, the business model, the value of the company, and a credible exit plan. In Europe, there is little nanotechnology-specific venture capital. Mr. Koponen presented figures from the European Venture Capital Organisation showing that venture capital investment dropped by 78% in the last five years, whereas venture capital investment in the United States grew by 7%. There are very few dedicated nanotechnology venture capital funds, the best known being NanoStart and NanoDimension. In all, these two funds have invested in fewer than 20 companies.

Institutional investors are the third type of possible private investors. They base their investment decisions on firms' stock market performance. The issue for nanotechnology, noted Mr. Koponen, is to have a company listed on the stock market as a nanotechnology company. The difficulty is partly due to the lack of a definition of what a nanotechnology company is. He gave the example of five companies selected from a portfolio of nanotechnology companies that was initiated around 2006. These companies cover different sectors: energy, medicine, energy/transport, and tools and instruments. For most of these companies the five-year share price decreased by about 80%. The only exception was the company involved in tools and instruments (Table 1).

Table 1. Share price performance of five largest constituents of the Invesco PowerShares Lux Nanotech Portfolio

Company	Ticker symbol	Sector	5-year share price change
Headwaters, Inc.	NYSE:HW	Energy	-86.6%
Flamel Technologies	NASDAQ:FLML	Nanomedicine	-79.9%
Valence Technology, Inc.	NASDAQ:VLNC	Energy/transport	-39.05%
Veeco Instruments Inc.	NASDAQ:VECO	Tools and instruments	+41.36%
A123 Systems, Inc.	NASDAQ:AONE	Energy/transport	-89.11%

Source: OECD/NNI Symposium on Assessing the Economic Impact of Nanotechnology, Background paper: Finance and Investors Models, Tom Crawley, Pekka Koponen, Lauri Tolvas and Terhi Marttila, Spinverse. From Lux Research (2011), Reprinted with permission.

This company obtains one-third of its revenue from selling equipment to government laboratories. It is robust as long as there is public funding going to nanotechnology. Mr. Koponen suggested that the lack of success of these companies might be due to having listed when the market was still immature and the technology subject to risks.

In sum, venture capitalists do not invest in nanotechnology; corporations, while they are now starting to match public funding, are still far from their level of investment in more mature industries. Institutional investors and the stock market do not show much interest in nanotechnology at the moment. Mr. Koponen showed some figures on public investment in Europe that compensates for the lack of private investment. It goes to small and medium-sized companies, but also increasingly to large consortia and laboratories. Examples are Inno.CNT in Germany, with investment of about EUR 90 million, of which EUR 45 million is in government funding, and Genesis in France, with a budget of EUR 107 million, of which EUR 46 million is in government funding. This public investment assumes half of the risk; it partially mitigates the risks for corporations of investing alone and enables the creation of open innovation networks. As a final example, Mr. Koponen mentioned the Russian initiative, RUSNANO, with government funding of USD 8 billion.

Box 3. Overview of symposium background paper - Finance and investor models in nanotechnology

There are many actors involved in private investments for nanotechnology. The paper sets out to explain how industry, institutional investors and venture capitalists make investment decisions and the effect on investment patterns in nanotechnology.

Corporate investments in R&D and commercialisation account for the largest share of nanotechnology funding, at USD 9 billion in 2010. Public funding plays an important role in corporate investment decisions, by partially mitigating the risk for firms investing alone. Venture capital (VC) accounts for just 4% of overall nanotechnology funding, according to figures from Lux Research. There are also significant geographical differences, with the amount of VC funding in Europe (at USD 100 million) just a fifth of the North American level. Institutional investors show their interest through their willingness to invest in venture capital funds. The existence of very few venture capital firms with an explicit focus on nanotechnology indicates that institutional investors have little interest in this sector, because of the inconsistent, and largely disappointing, performance of publicly listed nanotechnology companies.

There is room for collective action, supported or initiated by public bodies, to mitigate risk and therefore increase investment in nanotechnology. At the R&D and early commercialisation stage, more innovative approaches to pool risk and knowledge are appearing. For process innovation, collective action and public funding should be used to reduce manufacturing risk and thus encourage investment. A final area in which collective action could reduce investment uncertainty would be in the formation of patent pools for cross-licensing intellectual property to a number of firms. This mitigates the risk of individual firms blocking developments while fully exploiting the technology and would resolve some of the uncertainty around overlapping patents and freedom to operate which is currently affecting investment.

Source: OECD/NNI Symposium on Assessing the Economic Impact of Nanotechnology, Background paper: Finance and Investors Models, Tom Crawley, Pekka Koponen, Lauri Tolvas and Terhi Marttila, Spinverse.

Mr. Koponen continued by discussing the particular challenges for investing in nanotechnology. First, the technology itself presents a risk in terms of scalability from laboratory to industry, the integration of nanomaterials and components with larger systems and intellectual property. There are also risks linked to market acceptance. If existing solutions are good enough, the nano-replacement may not be needed. The technology also raises regulatory, safety and social issues. Mr. Koponen remarked that sector-specific factors have a greater impact on investment success than nanotechnology *per se*.

Mr. Koponen pointed out that nanotechnology does not have value before it is on the market. Most of the investment risk occurs at the commercialisation stage. Commercialisation is difficult because many players are involved and need to co-operate all along the value chain. Corporations still cannot bear all the risks of development and value chain integration alone and need incentives to take some of those risks. Venture capitalists require fast growth and high returns; nanotechnology companies have difficulty meeting these requirements. Mr. Koponen emphasised the need for governments to support activities that take nanotechnology closer to the market.

From his analysis, Mr. Koponen presented a number of recommendations. Governments have a central role to play in interacting with industry. Industrial investments can be encouraged by public-private partnerships and risk sharing (e.g. Inno.CNT, Genesis and RUSNANO). There is an opportunity for pooling knowledge by the corporate, SME and basic research worlds and integrating and sharing information along the value chain. There is also an opportunity to form new combinations beyond traditional industries. As the benefits of an enabling technology are shared by a number of companies, so should the costs.

Finally Mr. Koponen proposed some ways to tackle the lack of involvement of venture capitalists in nanotechnology firms. Nanotechnology will always have high capital requirements and long payback, but there might be ways of mitigating this. The skills and commercial rigour of the best venture capitalists could help accelerate commercialisation. Companies could link their facilities and financing when working on proof of concept and pilot programmes. This would reduce the amount of investment per company and establish networks of complementary expertise.

The impact of nanotechnology on green growth

Mr. Philip Shapira (Professor, Manchester Institute of Innovation Research, University of Manchester, United Kingdom, and School of Public Policy, Georgia Institute of Technology, United States) prepared a background paper with Ms. Jan Youtie (Professor, Georgia Tech Enterprise Innovation Institute, United States) for the symposium (see Box 4) and discussed nanotechnology for green growth. The key points of Mr. Shapira's presentation are:

- Nanotechnology will undoubtedly make a major contribution to green growth. One or two decades, however, may be needed before revolutionary green nano-applications arrive on the market.
- All potential green nano-applications should be carefully examined: they might create risks (e.g. health, safety and environmental risks), and their manufacture might raise issues relating to energy consumption and CO_2 emissions. Care is needed when labelling a nano-application as "green".
- More work should be done on developing green "nano-solutions" to ensure the sustainability of their manufacturing and of their recyclability.
- The increasing use and manufacture of green nano-applications in emerging economies with very different regulatory frameworks from those of OECD economies warrants particular attention.
- It is necessary to build LCAs into the development process of nanotechnology. A full economic assessment on a full lifecycle basis should be undertaken.

Box 4. Overview of symposium background paper - The economic contribution of nanotechnology to green growth

New energy sources and clean water are urgently needed in both OECD and emerging economies. This paper considers nanotechnology's potential to contribute to energy production and use, water provision, and other environmental challenges. It considers how the economic contribution of nanotechnology to green growth might be conceptualised and valued. Questions about potential issues are also raised.

Although development and diffusion of nanotechnology applications for green growth have the potential to help address green challenges and foster sustainable economic development, attention must be paid to the energy and resource requirements needed to produce nanoscale materials, to the sources of energy (renewable or non-renewable) required for their large-scale manufacture, and to the associated environmental, health, safety, and social applications throughout the life cycle. The paper suggests that an anticipatory approach that models, deliberates upon, and prepares for future developments can take account of these issues. An anticipatory approach is likely to be facilitated through a mix of measures and methods for modelling and examining different scenarios. The complications and uncertainties of predicting future technological trajectories should motivate rather than discourage efforts to evaluate the likely economic implications of green nanotechnology.

Source: OECD/NNI Symposium on Assessing the Economic Impact of Nanotechnology, Background paper: The Economic Contribution of Nanotechnology to Green Growth, Philip Shapira and Jan Youtie, nano.gov/symposium.

Mr. Shapira described the main elements needed to define and measure the impact of nanotechnology on green growth. Nanotechnology promises to contribute greatly to green and sustainable development (see Box 5). Many green nanotechnology applications are still in the lab, however, and the few green applications on the market that use nanotechnology must compete with incumbent technologies; although the balance may shift at some point in favour of nanotechnology products.

The particular properties of nanotechnology may also drive greener economic growth by improving the efficiency and performance of existing technologies. Mr. Shapira gave the example of the crude petroleum and natural gas industries; nanotechnology is already playing a significant role in the development of catalysis and nano-additives that make the refining process more efficient. Nanotechnology could also support the development of new ways of generating electricity from the sun (e.g. quantum dot technologies that reduce the cost of solar cells). The contribution of nanotechnology to green objectives may be direct or indirect but its potential contribution is clear.

Mr. Shapira pointed out that all nanotechnology applications for green development should be carefully analysed not only for their benefits but also for their costs. Such costs might be related to the energy requirements and CO_2 emissions due to manufacturing of nano-enabled systems or to the technology's potential environmental, safety and health risks. Nanotechnology will also lead to the creation of new gadgets and tools related to information and communication technologies (ICTs) that will be widely used by consumers. In large numbers, these could consume a lot of electricity. Many market forecasts do not take such potential costs into account. This led to Mr. Shapira's research on the need for an anticipatory life cycle assessment to assess fully the impact of green nanotechnology products: both how they are produced (e.g. the costs in terms of energy and CO_2 emissions) and how they are used.

Mr. Shapira recalled that, in the past ten years, the world has added about 4.6 million gigawatts of energy capabilities, almost four-fifths of which are from traditional fossil fuel, coal, crude petroleum, and natural gas production facilities. Solar and wind solutions account for a very small share of energy production to date. The world demand for electricity is expected to increase by 30% by 2020, and most of the increase will come from developing countries. To meet this demand, generating plants are already being planned or constructed and most will rely on fossil fuel. Mr. Shapira pointed out that nanotechnology is expected to have a relatively low impact on electricity production in the short term. Although many agree that nanotechnology will contribute to green growth, it is uncertain when it will play a role on a significant level.

Box 5. Green versus sustainable

Mr. Shapira's presentation highlighted the difference between green and sustainable, saying that they are different concepts. While green growth and green economy concepts highlight efficiency, waste reduction, low carbon, renewability, and recyclability, there are other elements to sustainable development, in particular, resiliency and security. There are also issues of responsibility: What is the technology for? Who is going to benefit? What about equity? Mr. Shapira mentioned that the focus in the policy world in the past years has been moving away from sustainability and towards green development, which has a an economic and environmental focus but does not fully address the social dimension.

Source: OECD/NNI Symposium on Assessing the Economic Impact of Nanotechnology, 27-28 March 2012, Presentation by Philip Shapira, Professor, Manchester Institute of Innovation Research, University of Manchester, United Kingdom, and School of Public Policy, Georgia Institute of Technology, United States.

Like other speakers, Mr. Shapira turned to the issue of definition. There is a broad definition of what nanotechnology is and a general consensus. There are definitions of green industries, green jobs and green patents. Definitions exist at the interface of nano and green. It is very difficult to use them reliably and accurately, and market forecasts vary widely. Nanotechnology is difficult to assess because it is a platform technology with many potential applications. Mr. Shapira sees markets for green nanotechnology but they are still relatively small. It is important when looking at market forecasts to understand the assumptions behind these forecasts and the level of independence of the analysis.

Acknowledging the difficulty of linking nanotechnology and green technologies economically, particularly on a global scale, Mr. Shapira suggested looking at specific applications. For example, nanostructured photovoltaics are very promising but have not yet matched the cost levels of existing silicon photovoltaic systems, particularly as prices of the latter have declined because of the market entry of large Chinese manufacturers. In several such cases, incumbent technologies with low market prices present significant impediments to the introduction of newer nano-enabled technologies.

It is difficult to grasp the situation of nanotechnology in terms of applications; it is easier to see where nanotechnology scientific activities are occurring. The R&D leaders are in OECD countries and in China, which is just overtaking the United States in number of scientific publications. China is also patenting applications under a regulatory regime very different from those of OECD countries. It is important to realise, said Mr. Shapira, that a lot of these applications will be developed and/or used in developing countries, particularly in China but also other countries where the regulatory regimes are different. Mr. Shapira pointed out that differences in regulatory frameworks must be kept in mind when thinking about the greenness of an application.

Besides market forecasts for green nanotechnology, cost/benefit analyses try to identify the benefits and costs as compared to incumbent technologies. One of the most developed cost/benefit methodologies currently in use was developed for DEFRA in the United Kingdom. It has been used to determine the cost of some of the environmental benefits of nanotechnology, particularly in terms of CO_2 reduction. In the United Kingdom, the methodology showed that relatively modest benefits can be obtained from nano-enabled green applications.

One explanation for these modest benefits is that these applications have not yet fully matured. A second is that, at least at present, it takes a huge amount of energy to manufacture some nanotechnology materials used in green applications such as the single wall carbon nanotubes in batteries. Mr. Shapira said that some studies in the literature indicate that these nano-enabled applications, if scaled-up, would take so much energy to produce that, at this point, they are uneconomical and, depending on the energy source, would probably produce more CO_2 than they would help to save in their lifetime. This does not even begin to address the question of recycling. But Mr. Shapira argued that the focus on nano-enabled systems will shift to making their manufacturing more energy-efficient and addressing in greater depth the issue of recyclability. Nanotechnology also raises potential health, environmental and safety risks. Mr. Shapira gave the example of nano-enabled solar cells containing cadmium and selenium, materials that are potentially dangerous for safety and the environment. However, there are promising applications of nano-enabled solar cells that do not use cadmium.

Mr. Shapira concluded by drawing attention to the importance of caution when labelling a nano-enabled application as green. Nanotechnology can, for example, help to reduce or stop the use of hazardous chemicals by replacing them with less harmful nanotechnology systems. This is a strong plus but the benefits should not be systematically assumed. New nano-systems need to be compared with incumbent technologies. Mr. Shapira reiterated the importance of a full life-cycle assessment of green nanotechnologies and the need for anticipatory processes in LCAs. This means building assessment early into the R&D process, into regulatory reviews and into codes of practice. As they develop new ideas, scientists should think downstream to the potential life-cycle implications.

Mr. Shapira said that much more is needed in terms of economic projections and market forecasts. There is a need for evidence and for reliable and validated data. Economic assessments should be conducted on a full life cycle basis. There is a need for an independent review of impact. Nanotechnology has been through a first phase of growth and has created great interest. However, as is the case for many emerging technologies, there comes a time when the difficulties begin to be recognised. After this period of low return on investments, nanotechnology should move into another longer-run phase of growth. There is some time before this next phase arrives to build LCAs into the development process.

Nanotechnology research directions for social needs in 2020

Mihail Roco (Senior Adviser for Nanotechnology, National Science Foundation, United States) presented the conclusions of a study, *Nanotechnology Research Directions for Societal Needs in 2020*.[2] He stated that nanotechnology is recognised as a megatrend in science and technology just as information technology and biotechnology have been. It has evolved from being a "scientific curiosity" to a general purpose technology with potential to provide essential products for society and the economy. Mr. Roco indicated that the technology is still in a formative phase in 2012.

Nanotechnology is not just about studying something at the very small scale or even about miniaturisation. It concerns a transition from fixed properties to infinite properties and functions. It is about creating new properties and functions developed at the nanoscale. It is also about connecting disciplines that were separated to simplify the understanding of phenomena. Nature is not disconnected in this way.

From 2001 to 2011, the focus in nanotechnology was on fundamental research with foundational interdisciplinary research at the nanoscale. From 2011 there has been a shift from research to applications, building on science-based design capabilities, and the use of nanotechnology is becoming increasingly complex, dynamic and trans-disciplinary. Mr. Roco identified several phases in the development of new generations of products and productive processes using nanotechnology:

- 1st generation (2000-05): passive nanostructures
- 2nd generation (2005-10): active nanostructures
- 3rd generation (2010-15/20): nanosystems
- 4th generation (2015/20-): molecular nanosystems
- Beyond: converging technologies.

As complexity increases, so do uncertainty and risk, such as the ability to control nanoscale DNA and influence the evolution of biosystems.

Mr. Roco next described funding and patenting trends over the past decade. After the NNI was created in 2000, public funding for R&D worldwide increased by 25-35% annually. After the second generation of products appeared, countries and regions, such as the Russian Federation and Europe, increased their funding for nanotechnology. Today, the United States, Europe and Japan are spending USD 6-7 per capita annually on nanotechnology. In terms of outputs, between 1990 and 2010, nanotechnology publications in the Science Citation Index grew worldwide by 16% a year. For their part, nanotechnology patent applications grew by some 34.5% a year between 2000 and 2008.

Mr. Roco then listed some of the main nanotechnology outcomes at the end of ten years: development of a foundational knowledge of nature through control of matter at the nanoscale; creation of a global interdisciplinary community for R&D and also for EHS and ELSI (ethical, legal and social implications) concerns; discoveries leading to science and technology breakthroughs; development of novel methods and tools; development of extensive multi-domain infrastructure; creation of new education and innovation ecosystems; emergence of new industries with increased added value; and development of new solutions for sustainable development.

Mr. Roco concluded his presentation with a vision for the coming years. By 2020, there will be a shift to more complex generations of nanotechnology products and a closer connection to biology. It is important to prepare for the broad application of nanotechnology. There will be more emphasis on innovation and commercialisation, with incentives for more public-private partnerships and new models for innovation. Mr. Roco also anticipates a focus on the societal benefits, institutionalised governance of nanotechnology, increased globalisation, and co-funding mechanisms. He emphasised that over the next decade, it will be crucial to focus on four distinct aspects of nanotechnology development:

- Knowledge progress: how nanoscale science and engineering can improve our understanding of nature, generate breakthrough discoveries and innovation and build materials and systems through design at the nanoscale.
- Material progress: how nanotechnology can generate economic and medical value.
- Global progress: how nanotechnology can address sustainable development, safety and international collaboration.
- Moral progress: how nanotechnology governance can enhance quality-of-life and social equity**.**

Nanotechnology, standards, socioeconomic interaction and regulation

Standards and regulatory frameworks, as well as the socioeconomic dynamics of innovation and uptake, are crucial aspects of the development, uptake and adoption of nanotechnology. They create a basis for innovation. Nanotechnology raises particular and difficult issues for standards development, regulation and economics, as Lynn L. Bergeson (Bergeson & Campbell, P.C, United States) pointed out in her introduction to this session. The following sections therefore consider why standards for nanotechnology are important, yet challenging to develop; what issues policy makers, regulators and industry face when trying to create a regulatory framework for nanotechnology; and what the main characteristics of innovation and uptake are in the area of nanotechnology.

International standards in support of nanotechnology development

Standards are important and contribute directly to the economic impact of nanotechnology. Mr. Ajit Jillavenkatesa (Senior Standards Policy Advisor, Standards Coordination Office, National Institute of Standards and Technology, Department of Commerce, United States) linked standards and nanotechnology development and discussed how they relate to economic impact. Standards play a very important role in nanotechnology development and integration, especially for commercialisation and regulation. A variety of groups are involved in developing nanotechnology standards and much progress has been made in recent years. However, some important issues remain to be addressed. Mr. Jillavenkatesa's presentation brought several issues to the forefront:

- The availability of expertise in a crosscutting field that is still at an early stage of development.
- Appropriate timing so that the knowledge available is sufficient to ensure the development of robust standards, and such that standards are not too premature to lock in technologies, nor too late to support technology development.
- Insufficient underlying research and development and validated data and methods.
- The crucial need for deeper involvement of all communities concerned (especially regulators and industry).
- The need for specificity in standards based on core, industry-specific information and commonly used measurement techniques and instruments.

Standards mean different things to different people, explained Mr. Jillavenkatesa. There are measurement standards, documentary standards, standards of conduct, etc. Mr. Jillavenkatesa discussed documentary standards, which are reached through a process of consensus. Consensus does not necessarily imply unanimity but does imply general agreement. According to ISO/IEC (International Organization for

Standardization/International Electrotechnical Commission), a standard is “a document, established by consensus and approved by a recognised body, that provides, for common and repeated use, rules, guidelines or characteristics for activities or their results, aimed at the achievement of the optimum degree of order in a given context”. A goal of standards development is to achieve some level of certainty. Mr. Jillavenkatesa discussed three aspects: the benefits of standardisation, the particular benefits for nanotechnology and the challenges in the case of nanotechnology.

Mr. Jillavenkatesa stressed that standards matter and that they pertain to almost everything we do. They reduce uncertainty in communication, thereby establishing a common language and providing a basis for technological innovation. They help protect health, safety and the environment and also reflect the state of technology. Standards provide a common platform for industry to build its product definitions. The USB (Universal Serial Bus) protocol illustrates the power of standards; because of its uptake by manufacturers, it was possible to produce with greater confidence large quantities of interoperable products at a reduced cost to the consumer.

Mr. Jillavenkatesa then turned to the relation between standards and nanotechnology. The development of standards is important because of the increasing use of nanotechnology in day-to-day products. According to the Project on Emerging Nanotechnologies, between 2006 and 2011, more than 1300 nano-based or nano-containing products arrived on the market (mainly in the health and fitness area). The growing global trade in nanointermediates and the development of new products/applications, requiring new measurement techniques, also play a role in driving standardisation. As a technology develops, certain questions arise. If a measurement is necessary, how should it be done? If results have to be expressed so that they can be used broadly, how should this be done? The development of robust standards for nanotechnology will help to answer these questions. The value for business-to-business communication and efficiency is clear and business efficiency leads to benefits for consumers. Standards support both technology development and product innovation. Regulatory compliance is another area in which standards offer clear benefits since they can reduce the burden for compliance. The impact of standards on nanotechnology ranges from technology and innovation to global competition and trade.

There are a number of difficulties for developing standards, however. One concerns timing: when is the right time to standardise? Mr. Jillavenkatesa explained that engaging in standardisation too early creates the risk of being locked into a not-yet-mature technology and the risk of insufficient knowledge to develop quality standards. For nanotechnology the data that should inform the standardisation process are still being generated. There are also issues regarding what needs to be standardised first: definitions and terminology, elements needed for business or elements needed for fundamental measurement.

One of the main groups involved in nanotechnology standardisation is ISO Technical Committee 229 (ISO/TC229), which was established in 2005. It has 34 participating countries and ten observer countries. It has a very broad scope, as reflected in its liaisons with other groups within ISO and with external organisations such as the OECD (in particular the OECD Working Party on Manufactured Nanomaterials). ISO/TC229 has four working groups: terminology and nomenclature; measurement and characterisation; health, safety and the environment; and product specification. It also has two task groups, one looking at sustainability, the other at consumer and social challenges. About 20 standards – technical specifications and technical regulations – have been published to date, with more products currently being developed. The work of ISO/TC229 has had an impact in two major areas: enabling collaboration and raising awareness of the need for standards to support industry and, where appropriate, regulations. ISO/TC229 has also allowed for partnerships between industry and the international scientific community and for dialogue with regulators to identify their needs and to find solutions.

Mr. Jillavenkatesa also referred to discussions at a joint workshop between NIST (National Institute of Standards and Technology) and ANSI (American National Standards Institute) in December 2011.3 The goal of this workshop was better understanding of issues affecting the broader use and uptake of nanotechnology standards. The workshop examined the situation for standards development for nanotechnology. Three different stakeholder groups were identified as key actors in standards development: standards developers, industry, and governments and regulators. Mr. Jillavenkatesa pointed out that each of these groups has its own perspective on standards development. The workshop discussed these different perspectives and the different challenges these groups face.

The standards developers participating in the workshop recognised that various groups are involved in developing standards. These groups have very robust processes for seeking broad input about the direction to take. However, nanotechnology standards developers face specific challenges owing to the very early stage of the technology and the lack of established or well-validated measurement and characterisation protocols. The difficulty of obtaining the underlying data that would help develop a robust standard affects the speed at which it can be developed. The cross-cutting nature of the technology is also a challenge, requiring a broad net and expertise from different groups. At present, larger manufacturers are in the very early stages of product development, and standardisation may not be their highest priority. The level of industry participation is variable: some are very involved, others are largely observers. The number of standards organisations is a positive point but also raises the issue of communication between the different groups and avoidance of duplication and overlap.

Mr. Jillavenkatesa next presented the industry perspective on the development of nanotechnology standards. For the industry representatives present at the NIST/ANSI workshop, standards, when they are done right, are very helpful for developing consistency and communication and for enabling information sharing by scientific groups and different industries. Standards improve comparability and validation of data, especially for EHS. The utility of standards for industry can depend on how they are written. If the aim is to be widely applicable, this may not suit industry if it needs very specific standards. There is also a need for greater participation of industry and regulators in standards development.

Finally, Mr. Jillavenkatesa stated that regulators use standards extensively in meeting their mission needs. The challenges for regulators in terms of standards are close to those of the industry sector: they would like more specific standards as well as a larger matrix of data on which to base informed decisions.

All the communities concerned with standards development are very much aware of the importance of having nanotechnology standards, but they all face a major challenge: the lack of underlying R&D and validated data and methods. Some groups would like to see higher prioritisation of social and regulatory issues because this is where big challenges are arising. Mr. Jillavenkatesa ended his presentation by re-emphasising the effort needed to achieve the promises of nanotechnology. Standards are essential to this development, but they require an investment of resources, in terms both of money and people, to reach the quality needed.

Nanotechnology and the race for regulatory certainty

There are many questions about how well nanotechnology is regulated, and how a regulatory system should be designed for nanotechnology, said Diana Bowman (Assistant Professor, Risk Science Center and the Department of Health Management and Policy, University of Michigan, United States). She pointed out that regulatory benchmarks are not and cannot be perfect and that emerging technologies have always been characterised by periods of under- and over-regulation. This is the so-called “pacing problem”. Views of whether a technology is over- or under-regulated will depend on a range of factors: geography, ethics, morals, history of other technology regulations, and exposure. Ms. Bowman reminded the audience that regulators are bound by their statutory mandate and the powers vested in them.

At the moment, nanotechnology-specific regulation is primarily based on the size at which the technology operates. Ms. Bowman suggested that size might not be the best characteristic on which to base a regulation. Other characteristics may be more important. The current policy context for regulation is complex and regulating nanotechnology is a challenge "which has a multitude of stakeholders showing interest, but an inability for stakeholders to agree on either the nature of the problem (to a degree that it exists at all), or on the most desirable solution to be applied". The existence of many languages and meanings in the nanotechnology sphere, especially in a regulatory context, makes progress difficult. There have been very interesting developments in opinions on how nanotechnology/nanomaterials should be defined; some parties have stated that warping a scientific definition into a policy definition is not necessarily going to push the regulatory debate forward.

Ms. Bowman said there is a tendency for some to view the European Union as taking the lead in regulating nanotechnology. In 2011, the European Union developed a draft definition of nanomaterials that created a good deal of debate. She suggested that this might be a game changer in terms of the regulatory debate. Beyond the European Union, there is a general preference to retain the regulatory status quo and rely on existing regulatory tools. She pointed to regulatory developments in the European Union, in particular the Cosmetic Regulation, the first piece of legislation including nano-specific provisions. As of 2012, there was no mention of nano in the REACH (Registration, Evaluation, Authorisation and Restriction of Chemical substances) regulation, but the ongoing debate indicates that nano-specific provisions might be included. She said that possible further developments in the REACH regulation directly affect industry players; some are holding back on R&D and commercialisation because of potential future changes in the regulation and uncertainties in the debates regarding nanotechnology. This is particularly true for small markets such as Australia. Industry is thus calling for guidance documents. Many players in industry want regulation in order to have a clear vision of the path for the next five to ten years. In the United States, issues such as potential litigation and liability are starting to reach the nanotechnology sphere.

To establish a balance among countries as nanotechnology regulation moves forward, Ms. Bowman noted that it might be necessary to think beyond the issues of strict regulation and strict size definition. More flexible and adaptable criteria might be a good step forward. Relying on risk assessment and risk management protocols based on science rather than on broader socioeconomic issues might also be useful. She emphasised that special consideration should be given to research on the monitoring and potential impact of materials, products and processes that may have the potential to cause substantial harm in a manner that is not apparent, accessible or manageable. Discussions on the need to revise regulatory frameworks for nanotechnology have principally focused on the issue of safety, but many aspects of social regulation may need as much attention. International harmonisation of nanotechnology regulation may appear difficult, but balanced development of regulation among countries, involving the various stakeholders, requires thinking about the issues mentioned above. Ms. Bowman said this is a good starting point for thinking about how to structure a regulatory framework.

At the global level, Ms. Bowman considers it important to focus on standards setting, data gathering, priority setting and provision of guidance documents. There is sufficient knowledge to begin setting regulatory pathways. Rather than trying to apply one set of standards globally, organisations such as the OECD, ISO, CODEX and FAO have been gathering information, which they can transmit to national regulators and governments for incorporation into their own system. For Ms. Bowman, the real regulatory challenges lie in the next generation of products and emerging fields under development, such as synthetic biology and neurotechnologies. She concluded that there might be a need to take a step back and think about principle-based regulation as opposed to technology-specific regulation in order to ensure an adaptable and flexible regulatory framework.

Socioeconomic dynamics of innovation and uptake

Douglas Robinson **(**Managing Director**,** TEQNODE, France) drew attention to key points to be kept in mind when analysing the impact of nanotechnology:

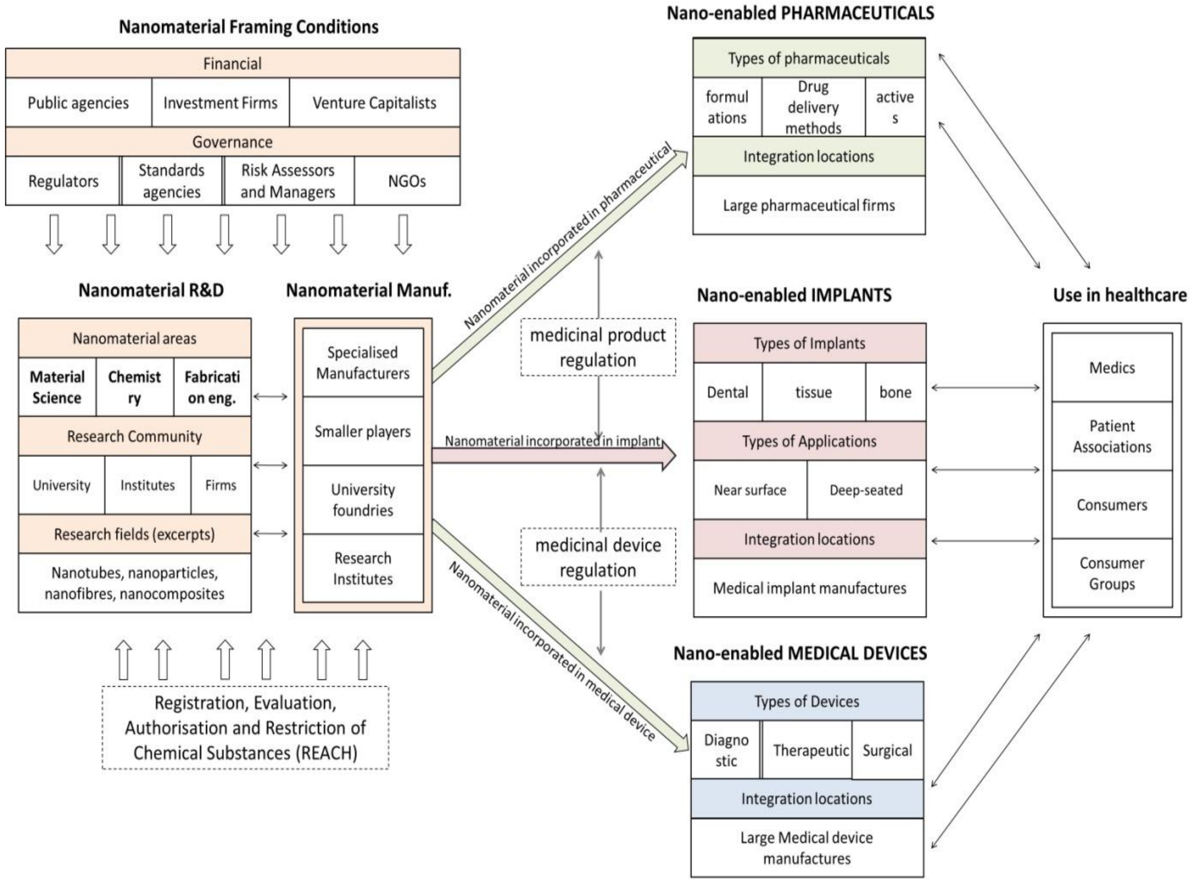
- As nanotechnology is an enabling technology, it is very important to take value chains into account.
- Its impacts are not yet fully apparent and will be distributed along value chains. It may not therefore be feasible to use simple indicators to track them.
- There is a need for bespoke indicators on innovation and embedment pathways related to the innovation context (such as packaging, health technologies, food processing, etc.).
- Qualitative indicators can be used to mitigate the problem of complexity of impact assessment, for example through technology assessment scenarios and mapping of value chains. Combined with well-targeted quantitative indicators, they can provide a better understanding of impact

The impacts of nanotechnology vary from one sector to another. This variety makes it challenging to capture impacts with simple indicators. For example, the development and use of nanotechnology in food packaging is linked to packaging innovation and related matters, such as R&D incentives for innovation in bioplastics (which can involve nanomaterials), novel food regulations, food contact regulations, etc. The innovation environment in which nanotechnology operates is complex and many factors should be taken into account when seeking to understand its socioeconomic impacts. For this reason, Mr. Robinson felt it is not possible to focus on simple indicators for measuring its economic impact. The key value of the technology may manifest itself far from the laboratory in which the scientific/technical knowledge originated. It is also important to recognise that innovation and uptake – and therefore the impact of nanotechnology – are distributed across the value chain. This makes impact analysis difficult. Uptake and eventual impact depend on many actors outside of technology developers and producers, such as health insurance companies in the case of innovation in nanomedicine. Mr. Robinson illustrated the complexity of the socioeconomic dynamics of innovation and uptake with the example of a medical application (Figure 8).

Interactions between producers and customers/users also raise difficulties, in particular relating to demand. Mr. Robinson gave the example of a technology assessment analysis involving the replacement of silicon-based electronics by organic-based electronics. On the producer side, even if technically very interesting, the analysis showed that it was too uncertain to invest in the technology without a clear demand. On the consumer side, there is little demand because the technology does not yet offer a clear advantage over existing alternatives. Mr. Robinson illustrated his point with a quote from Martin Schmitt-Lewen, manager of functional printing at Heidelberg Company[4]:

"There is no point in developing a printing kit or system when there are no existing customers ready to buy them, considering very few companies in the printed electronics market are scaling up production. Particularly in RFID and active packaging space, there is no requirement for large print press systems. (…)We want to avoid speculatively developing equipment or printed electronics products until the technology and the market are more mature."

Figure 8. Socioeconomic dynamics of innovation and uptake: medical application of nanotechnology



Source: OECD/NNI Symposium on Assessing the Economic Impact of Nanotechnology, 27-28 March 2012, Presentation by Douglas Robinson **(**Managing Director, teQnode, France)

Mr. Robinson cited the failure of lab-on-chip products to illustrate his belief that business models have to change. Investments were poured into this technology in the 1990s due to high expectations that demand could be substantial. However, the return on this technology was less than expected, and private capital was withdrawn. According to Mr. Robinson, this failure was due to the fact that demand was estimated based on the technology developer's vision of what demand should be. Mr. Robinson contrasted this with the model followed by the Medimate company in developing point-of-care diagnostics. The company developed their business model with the opinions and perspectives of stakeholders such as insurance companies, medical practitioners and end-users in mind. These were more important than those of the technology producers and developers.

Mr. Robinson pointed out the need to put the socioeconomic impacts of nanotechnology into context. Impact analysis needs to be accompanied by an assessment of changing business models as well as evolving value chains and framework conditions (e.g. regulation, investment, policy landscape). These conditions are not nano-specific but are domain-specific: bespoke indicators are necessary and should be based on innovation and embedment pathways. Such indicators will have to be developed by those involved in innovation and embedment pathways; they will likely remain indicators of "possible" or expected impact, with a significant margin of error.

Mr. Robinson concluded by mentioning the need to take into account several important issues related to the socioeconomic dynamic of innovation and uptake when assessing the impact of nanotechnology:

- Socioeconomic impacts are co-produced by users and third parties.
- Developers can anticipate and work towards desired socioeconomic impacts, productively but never conclusively, because key value is realised later.
- For indicators to be useful in strategy and decision making, they have to take into account expected impacts, thereby introducing speculation.

During the discussion, the role of policy in bridging the stakeholders involved in commercialising a product was discussed. These stakeholders are often faced with complex challenges, including long-term development, uncertain outcomes, limited access to venture capital, etc. Efforts are being made by national governments to identify important social goals and how they align with research and innovation pathways. It can be difficult to bring stakeholders along those innovation pathways.

Regarding regulation, it was pointed out that even if regulatory frameworks are still being established in the area of nanotechnology, the emerging nature of the technology still creates uncertainty. It is good that global debates on achieving efficient and flexible regulatory frameworks are taking place now rather than in five or ten years. Many technologies have come to the marketplace without such early discussion and have suffered because of it. It was also noted that it is difficult for policy makers and regulators to keep up with advances in the technology. It would be useful for jurisdictions to undertake regulatory reviews to determine how nanotechnology fits into their regulatory structures and whether there are gaps to be filled. Forecasting activities might also be useful for keeping track of technological advances. However, these activities are resource-intensive and may require a “champion” in regulatory agencies or governments to ensure they are carried out.

The first area of emphasis in standardisation is Environment, Health and Safety (EHS), which requires data on exposure and toxicology across a wide range of materials. A second area is characterisation. What is the best way to measure new classes of materials? How should data be reported? How should uncertainty and error analysis be managed? It was also mentioned in the discussion that the lack of data in these areas has not stopped efforts to start developing standards, and, as indicated previously, standards are evolving and will adapt as more knowledge is obtained.

Approaches to valuing and investing in nanotechnology

As previous sections have indicated, attempts to assess the economic impact of nanotechnology encounter various challenges. Some are intrinsic to the technology and linked to its emerging nature, others are linked to the fact that nanotechnology can have an impact all along the value chain and in many economic sectors. Still others are due to external factors (such as an evolving policy landscape and increasing interaction among technologies). Different methodologies seek to overcome these challenges. Discussions at the symposium indicated that it will be difficult to develop a “one size fits all” methodology. The data collected, and the methodology chosen, will have to be adapted to the specifics of an assessment and based on the desired measurement and the objective of the impact analysis. But such analyses will still leave some unknowns, given the early stage of market introduction of nanotechnology. The following sections look at methodologies being developed to assess the impact of nanotechnology and the issues encountered in conducting such analyses.

A conceptual and methodological framework for statistics on nanotechnology and other technological areas

Leonid Gokhberg (First Vice-Rector, National Research University "Higher School of Economics" (HSE), and Director, HSE Institute for Statistical Studies and Economics of Knowledge, Russian Federation) started by outlining two basic ways to measure technology and innovation in terms of their economic applications and limits. The first looks at a single technology and examines innovation related to it, taking an "object-oriented approach". The second is the "subject-oriented approach," which examines activities more broadly. Mr. Gokhberg focused on the latter.

The last decades have seen the emergence of technology fields such as nanotechnology, biotechnology and ICT. Areas such as clean and green technology are growing in prominence. These advances, and the corresponding desire to quantify their impacts, emphasise the need to build on existing knowledge and to produce a basic framework that would be applicable to new technological areas as they are developed. New technological areas share a number of challenges for statistical measurement: a lack of conventional definitions and classifications; horizontal applications and effects across various industries; unclear boundaries; a tendency toward convergence and multidisciplinarity; uncertainty about the degree of involvement of companies, universities and associated institutions in their development and exploitation; and the extent to which they are potentially disruptive. In addition, Mr. Gokhberg recalled that innovation follows a non-linear model including many linkages and feedbacks. All these elements need to be taken into account when establishing specific statistical approaches.

When the OECD started its work on measuring new technological areas, a number of questions arose. When do science and technology fields become suitable for statistical measurement? What are the means that can help identify those technological areas (e.g. tools from social and economic studies or specific instruments such as bibliometrics, patent analysis and foresight studies)? Which data sources are most relevant for obtaining information about those technologies? In an effort to answer those questions, the OECD Task Force on Emerging, Enabling and General Purpose Technologies is developing an integrated approach to measuring these technologies. A first step was to look at national experiences to identify best practices. A second was to develop an approach to constructing operational definitions and classifications. The Task Force started with a few countries and now covers 23 OECD and non-OECD economies. The Task Force has already dealt with some of the measurement concerns. The key relevant characteristics to be measured have been agreed:

- Emerging technologies result from advances in a field of knowledge that is developing rapidly and has high potential to lead to inventions and/or innovations with significant social and economic impacts.
- Enabling technologies can be described as inventions or innovations likely to be applied in the foreseeable future to drive radical change in the capabilities of other technologies.
- General-purpose technologies are new enabling technologies with the potential to become widely used across the entire economy.

Mr. Gokhberg emphasised that emerging technologies are usually marked by a burst of publications and patents in specific fields, which may result in the appearance of new disciplines. Scientific citations in patents are another way of detecting an emerging technology. Technologies are considered to have enabling capabilities when they are diffused into the economy and drive significant changes in economic activities and social welfare. They may be characterised by a significant share in overall R&D expenditure and technology transfer flows from academia to industry as well as registered market applications and the appearance of new goods and services enabled by those technologies. General-purpose technologies are characterised by wide penetration throughout the economy, with multiple cross-sector implications and significant employment and economic growth.

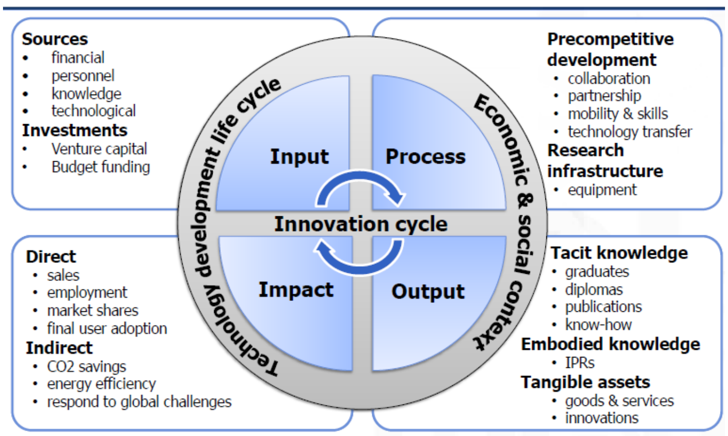
Two types of measurements can be used in traditional statistics, said Mr. Gokhberg. The first is an "early warning" measurement using bibliometrics and patents to look at R&D outputs. In the second type, regular statistical surveys can integrate new indicators into already existing surveys, specialised surveys can be launched or structural business surveys can be used when the technology is being manufactured and has a subsequent impact. Foresight studies, which anticipate emerging and enabling technologies and their possible impact, are another important source of information.

Mr. Gokhberg mentioned that the Russian Federation has an operational definition of nanotechnology for statistical purposes: "Nanotechnologies – a set of technologies related to control of the matter and processes on the nanoscale level (100 nm or less by one or several dimensions) and providing new properties of the matter to create improved materials, devices or systems which utilise those new properties." This definition encompasses major statistical prerequisites such as the field of study, the innovation potential, the qualitative characteristics, and the major areas of application. Four major classifications accompany this definition. The first is nanotechnology areas and technology use; the second is patent groups for measuring the technology's development (this fits the international patent classification classes); the third, classification by types of goods and services, is of particular importance for measuring the contribution of nanotechnology to economic indicators; and the fourth is classification of specific nanotechnology-enabled goods and services. Mr. Gokhberg pointed out that these are the basic tools for producing data on manufacturing and measuring the economic impact of nanotechnology.

Mr. Gokhberg explained that existing nanotechnology-enabled goods and services in the Russian Federation had been identified in terms of the national product classification. All available sources of external information, including market studies and various databases, were involved in developing this classification, as were extended consultations with experts in the field. Four major classes of products were identified: elementary nano-products, which are immediate products of the technology; conventional goods containing nano-components; conventional goods and services manufactured with the used of nano-enabled processes; and equipment for nanotechnology. This classification allowed the measurement of nanotechnology's market penetration.

Once a statistical definition of nanotechnology and classifications for nanotechnology statistics and nano-enabled goods and services has been established, an indicator system for statistical measurement was developed with the aim of encompassing the whole technology lifecycle (Figure 9).

Figure 9. Indicator system for measuring nanotechnology



Source: OECD/NNI Symposium on Assessing the Economic Impact of Nanotechnology, presentation by Leonid Gokhberg (First Vice-Rector, National Research University "Higher School of Economics" (HSE), and Director, HSE Institute for Statistical Studies and Economics of Knowledge, Russian Federation.

Mr. Gokhberg indicated that the Russian Federation has started to develop this type of system. Several major surveys have integrated indicators on nanotechnology-related R&D and innovation activities and manufacturing. Beyond this, a pilot survey addressed issues specific to nanotechnology that are not necessarily covered in traditional statistical surveys, such as technology transfer and linkages between different segments of the national innovation system. For example, the Russian statistical office has included a specific module on manufacturing sales of nano-enabled goods and services in structural business surveys since 2010. This has resulted in data on sales of nano-enabled goods and services by types of products. The overall sales of nano-enabled goods and services are estimated at about USD 6 billion a year, with a major contribution provided by conventional rather than elementary products.

Finally, Mr. Gokhberg presented information about nanotechnology R&D expenditure in Russia by sector in 2010 (Figure 10). Half of R&D expenditure is concentrated in the business and enterprise sector, the rest being divided almost equally between the higher education and government sectors.

Figure 10. Nanotechnology R&D expenditure and personnel in Russia by sector in 2010

Source: OECD/NNI Symposium on Assessing the Economic Impact of Nanotechnology, presentation by Leonid Gokhberg (First Vice-Rector, National Research University “Higher School of Economics” (HSE), and Director, HSE Institute for Statistical Studies and Economics of Knowledge, Russian Federation).

Models, tools and metrics to assess the economic impact of nanotechnology

Ben Walsh (Senior Consultant, Oakdene Hollins, United Kingdom) presented the methodology developed by DEFRA (United Kingdom Department for Environment, Food, and Rural Affairs) for valuing nanotechnology. The methodology is detailed in the background paper that Mr. Walsh wrote for the symposium, along with other models, tools and metrics that can be used to assess the economic impact of nanotechnology (see Box 6). Mr. Walsh outlined some important points to consider when valuing a technology:

- The goal and objectives of the valuation exercise should be defined first in order to determine which methodology to use or develop. It is also important to determine who will benefit from the valuation exercise and to whom it will be of use.
- In some cases there is a lack of information; in others it is difficult to extract usable and meaningful information from complex systems.
- It is important to put nanotechnology into context and compare it with other technologies and solutions, instead of viewing it in isolation.
- It is important to understand the full product lifecycle and how it overlaps with and affects the technology.

Box 6. Overview of symposium background paper - Models, tools and metrics available to assess the economic impact of nanotechnology

Research and development, funded by both public and private investment, have a large role to play in the growth of the economy. Technology-based economic development strategies are an increasing priority, with nanotechnology as one area of policy importance. The ability to evaluate the economic impact of nanotechnology initiatives and investment is also playing an increasingly essential role in the creation of optimal investment strategies.

Owing to the relative infancy of nano-enabled technology, few valuation models are specifically focused on this technology area, and there is no definitive model. This report focuses on two main methodologies: i) the DEFRA model based on performing a comparative valuation of a nano-enabled product against an incumbent product; and ii) the STAR METRICS database approach, which uses an input/output (I/O) approach to perform an inter-industry analysis in order to understand the outputs achieved by federal funding in the science and technology sector. Both models have their merits, and both require assumptions in the analysis.

The DEFRA model is comparative and, as such, requires the identification of an incumbent product. The model takes an *ex ante* approach to valuing a nano-enabled product, and it highlights as considerations the assumptions about how the technology will react in the market, including issues such as the diffusion and life cycle of the product. The DEFRA approach is best used for a broadly defined market because it is intended for use at the product or application level rather than at the sectoral outcome or aggregate product group levels. In contrast, the inter-industry approach of STAR METRICS is more relevant and accurate at a macro level. This methodology relies heavily on real-life case studies to populate the model and requires large datasets to generate high-level data. The use of I/O models is widespread and generally sets a precedent for this type of modelling. The STAR METRICS approach is, however, not nano-specific but encompasses all science and technology research areas across the United States.

Various models attempt to value technologies other than nanotechnology. They use a variety of techniques, from the extended cost/benefit analysis used in valuation of information technology to the further use of I/O models in the biotechnology sector. The methodologies for each of these require making some assumptions and the use of proxies. The technological sectors studied can, to some extent, be compared to nanotechnology because any new, emerging or innovative industry will have similar issues with data collection and lack of precedent. The nature of nanotechnology makes the application of a single economic model difficult; nanotechnology can be described as both an enabling and a disruptive technology; it also extends beyond a specific industry and spans multiple applications. The application of an economic valuation technique to nanotechnology in this way is an emerging research area. Thus, regardless of the methodology applied, there will always be unknowns to consider.

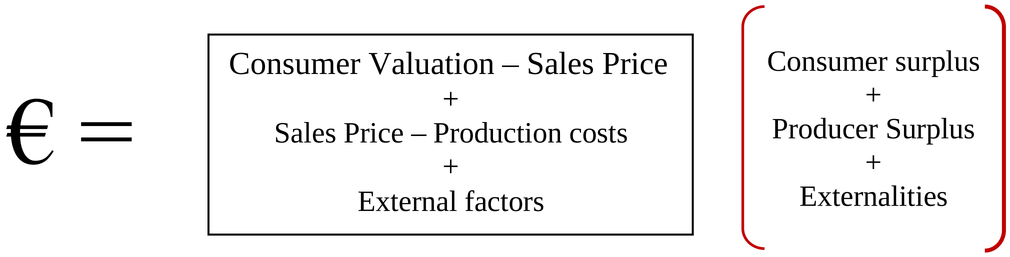
With economic growth, human welfare and international competition dependent on constant technological progress, convergence of technologies may be a primary area for innovation in the coming years. This should be considered in the application of any economic model in the area of nanotechnology, as this will allow for better representation of interactions between technology sectors.

Developing a single model that incorporates all aspects relevant to nanotechnology is not likely to be possible. In order to analyse the economic aspects of nanotechnology, it will be necessary to continue to collect data and develop metrics that facilitate rigorous analysis of nanotechnology in terms of economic indicators and socio-environmental impacts. It is important to consider how current models and methodologies can best minimise assumptions and the use of proxy data.

Source: OECD/NNI Symposium on Assessing the Economic Impact of Nanotechnology, Background paper: Models, Tools and Metrics Available to Assess the Economic Impact of Nanotechnology, Katherine Bojczuk and Ben Walsh**,** Oakdene Hollins. nano.gov/symposium.

Mr. Walsh indicated that the DEFRA methodology does not look explicitly at the whole value of nanotechnology. It looks at specific uses of nanotechnology and compares these with incumbent technologies to try to extract the value that the nanotechnology adds relative to that of the incumbent technologies. Mr. Walsh noted that methodologies to evaluate any innovation or technology rely on the value to consumer; the value to the producer; and the value to other parties. In economic terms it relies on consumer surplus, producer surplus and externalities that can be positive or negative (Figure 11).

Figure 11. The DEFRA Valuation Model



Source: OECD/NNI Symposium on Assessing the Economic Impact of Nanotechnology, Presentation by Ben Walsh, Senior Consultant, Oakdene Hollins.

Consumer surplus represents the value that the consumer places on an object minus the real value (sales price) of that object. Producer surplus represents the sales price of an object minus the production costs. Externalities represent a technology's benefits or negative impacts beyond those directly involved. The greatest challenge is to determine the value of a technology to a person or to an entity of any description.

Mr. Walsh then explained that the methodology is based on a comparison of nano-enabled products with incumbent technologies because it is very difficult to give consumer value to something that has no precedent or that cannot be compared with any other existing products. Mr. Walsh gave the example of the development of the Walkman® in the 1970s. It was the first product of that sort to reach the market at the time, and no one could anticipate its market size and value to society. However, the iPod could be valued because it had the Walkman as a precedent. By correctly choosing an incumbent technology and comparing it with a nano-enabled technology, the methodology allows for developing a partial estimate of the potential value of the nano-enabled technology. A simplified spreadsheet, only requiring the entry of 10 to 15 values, was developed for the methodology, and the approach also allows for analysis of a single product.

Mr. Walsh pointed out that this methodology could be most useful for industry as it largely focuses on the market size of the incumbent technology, the price of the incumbent, its unit cost, and the size of the current market. In addition, the methodology is useful for geographical analysis, which is particularly important for policy makers. For a country with an industrial base relying on a specific technology that might be superseded by nanotechnology, the methodology would allow some estimate of how this might affect economic activity in these sectors.

The methodology was tested on a series of nano-enabled products that are either currently on the market or in the pipeline. The results showed that their actual net value to the UK economy was quite modest. There may be various reasons for this, such as the size of the UK market or the small incremental benefits compared to the incumbent. Mr. Walsh emphasised that the overall market for the nanotechnology might be significantly greater, but the methodology only looks at the incremental benefit and the value added of the nanotechnology.

In a second part of his presentation, Mr. Walsh looked at other methodologies that are available to value technologies. They largely fall into two categories: i) they are based on an input-output model (such as the STAR METRICS methodology in the United States); or ii) they are based on cost/benefit analysis. In any case, it will be difficult to have a "one size fits all" methodology. The methodology used to value a technology will very much depend on the aim and objective of the assessment exercise. Mr. Walsh proposed that three elements should be defined before starting to use or develop a certain methodology:

- The aim of the valuation exercise and the audience: Who is actually going to have to use the methodology? Who would benefit from the assessment?
- The output: What figures are wanted? The desired results could be monetary value and GDP growth or impact on environmental and social benefits (which are high on the list of government priorities). Is the analysis to be retrospective or prospective? Is it going to evaluate value at some points in the past, or is it going to look at the value going forward of a particular intervention or a particular set of nanotechnology improvements?
- The measure: What is being measured? Is it the output of a particular research grant?

Assessment exercises need to have a well-defined goal; the methodology should fit the established goal and objectives.

Science of science and innovation policies applied to nanotechnology

The following sections present methodologies developed in Brazil and in the United States for providing information on publicly funded science and innovation, including nanotechnology, with the particular aim of informing policy decisions.

The Lattes platform in the Brazilian ST&I system

Esper Cavalheiro (Advisor to the President of the Centre for Strategic Management and Studies, Brazil) introduced the Brazilian Lattes platform, which aids in the design of science, technology and innovation policies and helps to understand the social and economic impacts of previous investments. Mr. Cavalheiro explained that in 1995, a time when research budgets were very low, the Ministry of Education wanted more information on the country’s estimated 5000 PhD holders, including who they were, what they were doing and what they wanted to do. The idea was to have a single platform for following both the younger generation of researchers and the scientific community more generally.

Prior to the development of the Lattes platform, it was difficult to get information on the number of scientists in the country, their employment or their outputs, such as scientific papers. Different ministries and regional agencies had their own systems of information, which also complicated the process of applying for government funding for researchers. It was decided to bring all this information together in a single system at the Foundation for the National Research Council of Brazil (CNPq).

The creation of Lattes started by uploading researchers’ résumés (CVs) onto a web-based platform. There was some initial resistance from academics, but when it became compulsory to use the platform to obtain research funding, the number of participating scientists rose from 20,000 to almost a million. For the first time it was possible to understand the population and to determine the number of engineers, doctors or biologists. There are now more than 3 million CVs on the platform.

The platform can be accessed via an identification number that is unique to each scientist. Researchers access their personal page and load information such as papers, articles, patents, and number of PhD students. Although it represented a challenge, data can be shared between ministries and between federal, state and city governments. No personal information is available on the platform unless it is supplied voluntarily by the researcher. Ministries can use the Lattes platform to examine a particular scientific field and see what networks exist in that area. For instance, it is possible to locate all researchers working on nanotechnology in Brazil or to examine the connections between individuals. Several other countries have now adopted the system, which is available in Portuguese, Spanish and English, making it an international collaboration.

Mr. Cavalheiro explained that Lattes can also be used as a tool for institutional policy – universities can access the platform to see what research is being undertaken at their institution. The platform has also opened up the conduct of science. It has become easier to find collaborators, and new networks have appeared. The governance of science and innovation has also become easier, owing to more accurate information.

A new addition is the Innovation Platform, which collects data from industry. Industries that seek partnerships with universities, receive research funds from the government or enter other types of agreement are required to be listed and to maintain information on this platform. Ministries, agencies and industrial associations are being placed on the same platform to facilitate transparency. The aim is eventually to use this instrument to understand the overall funding and impacts of science, technology and innovation at any given moment. There is still a need to better understand how public money is changing society and how to help the next generation of researchers maximise the impact of their research. However, Mr. Cavalheiro suggested that within five years it will be easier to answer the questions raised in this symposium. In summary, Lattes began as a response to the Brazilian government’s need for information and has now become a main source of information for individuals and agencies. The platform does not represent central control but rather is a way of improving policies.

Putting the science in science measurement: the case of nanotechnology

Julia Lane (Program Director, Science of Science and Innovation Policy, National Science Foundation) provided some insight into U.S. activities under the Science of Science and Innovation Policy (SciSIP) initiative, including why measurement is difficult in the United States and other countries.

Ms. Lane explained that good management of science and research is hard because of the complexity of the conceptual framework. This framework is different from a production function framework and has a large number of inter-related processes. The relevant data are dispersed across a wide range of parties. Funding agencies hold information on the research grants they issue, while universities and research institutions hold information and data on researchers’ work and the conduct of science. Information on outputs such as papers is held by another set of institutions and patent data are collected by patent offices. This creates challenges for accessing data and making sense of the different units but also, most importantly, understanding the links between the different parts.

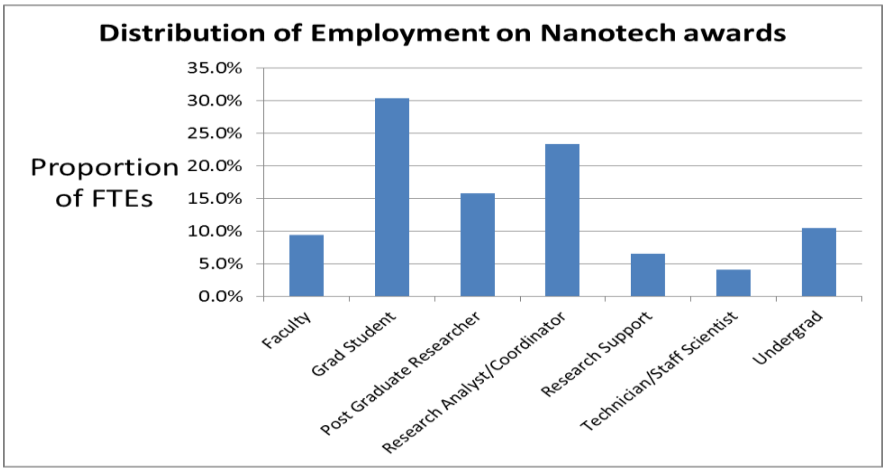
Ms. Lane explained that economic impact has a very specific meaning; it refers to the impact of an investment relative to alternative uses of public funds. This is a major challenge. The aim of the SciSIP initiative, therefore, has been to build a data infrastructure that will help enable the scientific community to start to deal with this question. It builds on the recommendations of the White House Science of Science Policy Interagency Working Group, which issued a Roadmap in 2008; one of the major barriers to making evidence-based decisions was the lack of a data infrastructure

In this context, the Science of Science Policy Program was created in 2006. A 2009 pilot of STAR METRICS (Science and Technology in America’s Reinvestment – Measuring the EffecT of Research on Innovation, Competitiveness and Science) attempted to determine a way to develop more balanced capacity across agencies to respond to the ARRA (American Recovery and Reinvestment Act) (stimulus) reporting requirements. The pilot was successful and was expanded in 2010. The first part of the pilot looked at science funding recipients, which was the narrowest focus of ARRA, and the second at the broader results of science investments. The main unit of analysis in STAR METRICS is the individual scientist, a definition that encompasses principal investigators, post-doctoral researchers and graduate and undergraduate students working on public grants. The goal is an open and automated data infrastructure that is commonly available, generalised and replicable, while the longer-term objective is to allow the analysis of the relationship between inputs, outputs and outcomes of the research process. The programme is designed to draw on the substantial investments made in the SciSIP programme, which has developed data, models and tools to better understand the scientific enterprise.

As a result, the STAR METRICS programme has made use of modern ICT tools in order to collect data on the conduct of science as well as its outputs and outcomes. The approach to capturing information on the science being performed (rather than the programmes that fund science) has been to use natural language processing and topic modelling. This technique captures the description of projects via clusters of co-occurring words. Patent data are collected using different sets of tools to automatically link researchers with patents that are granted from the U.S. Patent and Trademark Office (USPTO). Similarly, workforce data can be captured automatically from the human resource records of research institutions. To capture the scientific workforce, a total of 14 data elements can be put together to show who received support over time and in which areas. It was stressed that the key characteristic of this data collection exercise was that it could be prepared at no cost to researchers or employees in research offices. Ms. Lane suggested that such automated data collection tends to be of higher quality, particularly on outcomes that can occur many years after research grants are awarded.

Ms. Lane demonstrated some of the results of this exercise with specific reference to nanotechnology. One immediate observation, shown in Figure 12, is that the number of faculty working on a topic underestimates the number of people actually engaged in nanotechnology research, as large numbers of graduate students or post-doctorates are also involved. Using the various tools that have been developed, it is also possible to examine sub-awards and sub-contract information that result from nanotechnology research grants (Table 2). The information on vendors that support the nanotechnology research enterprise provides one indicator of the dissemination of knowledge and a new source of information on this technology area.

Figure 12. Distribution of employment on nanotechnology awards



Source: OECD/NNI Symposium on Assessing the Economic Impact of Nanotechnology, Presentation by Julia Lane (Program Director, Science of Science and Innovation Policy, National Science Foundation).

Table 2. Distribution of nanotechnology award expenditures

DISTRIBUTION OF SUB-AWARD AND VENDOR JOBS BY INDUSTRY:	Rolling 12 months thru 9/2011		
Industry	**Subawards/ Subcontracts**	**Vendors**	**Grand Total**
Accommodation and Food Services	0.0%	2.7%	0.1%
Arts, Entertainment, and Recreation	0.0%	0.1%	0.0%
Construction	1.3%	0.0%	1.3%
Educational Services	93.6%	0.9%	88.9%
Information	0.0%	0.5%	0.0%
Manufacturing	0.0%	25.7%	1.3%
Other Services (except Public Administration)	0.0%	2.9%	0.1%
Professional, Scientific, and Technical Services	5.1%	42.9%	7.0%
Retail Trade	0.0%	1.6%	0.1%
Transportation and Warehousing	0.0%	0.1%	0.0%
Wholesale Trade	0.0%	22.6%	1.1%
Grand Total	**100.0%**	**100.0%**	**100.0%**

Source: OECD/NNI Symposium on Assessing the Economic Impact of Nanotechnology, Presentation by Julia Lane (Program Director, Science of Science and Innovation Policy, National Science Foundation).

Similar tools can also be used to describe research and development funded by science agencies. Ms. Lane demonstrated this using the online STAR METRICS Portfolio Explorer, which allows examination of projects being undertaken and the distribution of the actual topic areas, rather than simply the programme element codes, that describe the distribution of funds. Using this tool it is possible to see how much has been invested in different fields of science and to examine the data in more detail, including the patterns of individual awards, individual researchers and patents. It is also possible to identify co-occurring fields; this makes it possible to explore possible convergence and collaboration issues in nanotechnology research.

A separate part of the tool provides the link between NSF-funded researchers and the USPTO patent database in each scientific area (although there is no judgement regarding causality at this stage). The automated collection is an advantage over manual grant reporting because most patents are awarded some time after the research grant expires.

In general, it is important to collect information on a range of additional factors, including publications, social impacts, workforce training, and firm information, which could in time be accessible on the same platform. The ultimate goal of the SciSIP initiative is to create an analytical tool set that gives science policy the same technical quality as labour, health or education policy, which have benefited from the development of data infrastructure. Opening up this evidence base will allow researchers to study science and technology policy.

Redesigning science and innovation systems

In his presentation, Tateo Arimoto (Director General, Research Institute of Science and Technology for Society, Japan) spoke about changes in the context of science and technology since the end of the Cold War. Despite rapid technological advances, the world faces a number of global challenges, most recently the global economic crisis. Tackling these challenges requires more from science and innovation systems as well as social innovation.

Interest in the impacts of science, technology and innovation (STI) has typically focused on profits and GDP. However the wider benefits of STI – well-being, quality of life, safety, security, social cohesion, sustainability and resilience – are now receiving more attention in Japan, particularly following the Japanese earthquake and nuclear accident in March 2011. Better accounting for these benefits requires redesigning science and innovation systems locally, nationally and globally. In addition, surveys have shown that in Japan distrust of science and the science community has increased rapidly since March 2011. It is likely to take some time to reverse this trend, and the government will have an important role in disseminating information. Another challenge is conducting science with smaller budgets; this requires more efficient use of science funds. Putting these trends together, a range of factors are likely to necessitate redesigning science and innovation systems.

Turning to new perspectives for science, technology and innovation, Mr. Arimoto argued that the centre of scientific activity is rapidly moving to developing countries. Other globalisation trends include global and regional governance of science and new innovation models, including disruptive innovation, "reverse" innovation and frugal innovation. It is necessary to find ways to restructure STI systems, such as managing a shift towards problem-solving STI policies.

Mr. Arimoto mentioned the ideas set out in the OECD Innovation Strategy, *Getting a Head Start on Tomorrow*. Complex global issues, such as climate change, have resisted conventional governmental solutions, such as support for innovation and conventional market solutions. There is a challenge for policy makers to link social demands with the research agenda.

Following the earthquake of March 2011, the Japanese government decided on new innovation policies that look beyond discipline-based innovation towards issue-based innovation policies. These policies require communication and public participation to bridge the gap between science and society and to promote the science of science, technology and innovation policies. Japan's research funding system has shifted to issues-based innovation in order to bridge the gap between science and society and between science and the market. This kind of policy change is now spreading to other countries such as France.

Japan's "science of science and innovation" policy is based on the need for evidence-based policy formulation and a growing expectation for science to adapt to local and national social change. The programme aims to investigate three main topics: understanding the social and economic impacts of STI policy, understanding the dynamics of the STI system, and understanding the policy formulation process and its interaction with society. The aim is a rational policy-making process that is transparent and accountable. Public sharing of knowledge and collaboration among stakeholders are important aspects of the plan. The programme is overseen by a national steering committee and comprises four main pillars: mission-oriented investigation and research, a competitive research grant programme, data infrastructure, and universities and networks for human resource development. The programme recognises that science should be independent and free from government interference. At the same time, science advisors must recognise that science is only part of the evidence base that governments must consider when directing policies. Scientific integrity is at the core of the science of science policy programme to ensure objectivity.

In conclusion, Mr. Arimoto stressed the need for a closer relationship between science and policy, and he proposed an outline for a new social contract for nanotechnology in the coming decades. On the evolution of nanotechnology, Mr. Arimoto covered the different stages of nanotechnology over 30 years. The stages were characterised as "progress", "fusion" and "systems". The last of these stages, the integration of nanotechnologies into functional systems, has begun. In this sense, nanotechnology is progressing from a scientific phenomenon to being embedded in society. Nanotechnology should serve knowledge, peace and sustainability and should be fully integrated in society as well as directed to society. Mr. Arimoto described how nanotechnology should be socially trusted and socially embedded, shape new values and transform society, fuse intellectual disciplines, and enable young students to go beyond traditional boundaries.

The discussion with the audience touched on the plausibility of countries collaborating internationally to develop a common platform for documenting investments and outputs in science and technology. The panellists agreed this was an admirable aim worthy of a concerted effort, and remarked that there has been co-operation between the United States, Japan, Brazil, and the European Union. They also stressed, however, that such international endeavours necessarily take a long time and are not a realistic expectation in the short term. It was also suggested that privacy laws in some countries would not allow some aspects of the initiatives discussed during the session. The issue of checking the accuracy of user-uploaded information was also raised, and the Brazilian Lattes system was cited as an example of how users can be incentivised to provide checks.

Another topic discussed was how realistic it is to estimate a counterfactual. It was noted that there is a large literature on the issue in other areas of policy, and it is conceptually straightforward to leverage the statistical approaches used in those areas. One approach, for example, for science policy may be to search for natural experiments. The issue of broader measures of economic impact was also raised, including how to capture data on the impact of science beyond publications and patents, the extent and implications of open innovation and more detailed analysis of the supply chain. Studies being funded by the NSF SciSIP programme look at administrative data, the movement of people from academia to industry and open access to medical knowledge.

Exploring the qualitative and quantitative dimensions of the economic impact of nanotechnology

On each afternoon of the symposium, breakout sessions were organised to explore qualitative and quantitative dimensions of the economic impact of nanotechnology in particular sectors: transport and aerospace, nanomedicine, electronics, energy, advanced materials, and food and food packaging.

On day one, the groups were tasked with examining the qualitative dimensions of the economic impact of nanotechnology in the context of broader government objectives for investments in nanotechnology. On the second day, the same groups were asked to consider tools and methods for assessing the economic impact of nanotechnology, taking particular note of those identified in Session 5 “Approaches (new and established) to assess the effects of technology investment” (See Annex for the agenda). In most sessions, there were two presentations of approximately 20 minutes each followed by a discussion period of 1 hour and 20 minutes. The following sections summarise the presentations and subsequent discussions, including the readouts to the plenary by the co-chairs of each group. Electronic copies of the actual presentations are available at www.nano.gov/symposium/.

Transport and aerospace

Nanotechnology impact: driving the materials revolution

Travis Earles (Advanced Materials Nanotechnology Initiatives, Lockheed Martin, United States) began by stating that he would only touch on a small part of Lockheed Martin’s R&D portfolio. Transport is a major focus of Lockheed Martin’s products for global security, but its overall R&D effort is much broader. Nanotechnology at Lockheed Martin falls into four business areas: aeronautics, IT, electronics systems, and space systems. Nanotechnology research is further distributed into five focus areas/approaches: materials/structures, energy, sensors/electronics, modelling/simulation, and harnessing the power of nature. The clear overlap of focus areas with multiple business units necessitates co-ordination of R&D efforts within the company. Mr. Earles emphasised that the company’s assessment of R&D investments does not explicitly focus on nanotechnology, but is concerned with business end results (e.g. revenue, cost savings). He did, however, provide four specific examples of the impact of nanotechnology: new lightweight composites from early-stage nanotechnology that lead to substantial cost savings; carbon-nanostructures (multi-functional materials) grown on a variety of substrates (at scale, at speed); lithium-ion batteries to reduce weight for soldiers in the field as well as improve battery performance; and space platforms that begin to assess the flight status of the pilot, replacing bulky environmental sensors with one, all-inclusive (small) sensor.

Mr. Earles concluded by noting Lockheed Martin's interest in pursuing partnerships (e.g. universities and start-ups) and in expanding into other fields/sectors.

Tyres and nanomaterials

Francis Peters (Materials and Raw Materials Project Director, Michelin Worldwide, France) spoke about the "strong interest" of the tyre industry in new nanomaterials. He began by explaining that current tyre technologies incorporate aggregating nanomaterials, carbon black and amorphous silica. These nanomaterials have increased tyre durability and have led to substantial cost savings. However, with the number of cars on the world's roads expected to more than double by 2030, the supply of raw materials (e.g. rubber) for tyre production would also have to double unless new technology is developed. In 2005, the CEOs from the 11 largest tyre companies, including Michelin, decided to join their efforts towards sustainable development, and in 2006 the Tyre Industry Project (TIP) was formally launched at the World Business Council on Sustainable Development. Its goals are to divide by a factor of two the rolling resistance of tyres in order to reduce vehicles' CO_2 emissions and to divide by a factor of two the speed of tyre wear and/or tyre weight such that the current supply of raw materials will be sufficient in 2030. The development and incorporation of new nanomaterials could help to achieve these goals, provided that potential risks to human health and the environment are properly assessed. In 2011, the TIP and the OECD initiated a collaboration to examine the potential social benefits of tyres manufactured with advanced nanomaterials and to develop a guide on best practices for their use over the full life cycle.

Commercialisation of nanomaterials

Lance Criscuolo (President, Zyvex Technologies, United States) began with a timeline of major milestones for Zyvex Technologies, starting with its founding in 1997 as the "world's first molecular nanomaterial company". Zyvex develops and licenses nano-chemistry technology and also designs and builds products for customers. It has a portfolio of commercial products that leverage advanced materials (e.g. carbon nanotubes, nano-graphene platelets). With regard to the commercialisation of nanomaterials, Mr. Criscuolo felt that the most important metric is their level of profitability. Given the approximately ten years needed to bring nanomaterials to market, partly due to inherent difficulties in overcoming the "valley of death," most nanotechnology companies fail before they ever reach this point. He emphasised that government could help drive commercialisation by developing innovative competitions or "Tier 1" SBIR (small business innovation research) grants for small companies with an established record of generating revenue. Other mechanisms for commercial success involve the partnering of small and large companies for their mutual benefit. Zyvex has adopted such a model through its collaboration with Airbus, and they are aiming to have nanocomposites on commercial planes within three years. Mr. Criscuolo concluded with a selection of metrics for assessing impact: net job creation; number of companies formed; rate of failure with respect to other industries/technologies; and number of university degrees awarded related to nanotechnology. While acknowledging the importance of publications and patents, he questioned their direct correlation with economic growth.

The role of venture capital

Vincent Caprio (Executive Director, NanoBusiness Commercialization Association (NBCA), United States) provided a brief overview of the venture capital (VC) market before highlighting some of the specific challenges for funding companies working on nanotechnology. The ten-year annual return (October 2001 to September 2011) was 0.9% for early-stage venture capital funding compared with 2.8% and 3.3% for S&P and NASDAQ indices across all emerging technologies. According to the NanoBusiness Commercialization Association, the return on investment for nanotechnology-focused companies was typically negative and resulted in reluctance to make additional investments. In fact, VC commitments dropped from USD 105 billion in 2000 to USD 18.2 billion in 2011. VCs often only see a return on their investment when a company goes public. However, in the last ten years, only six nanotechnology companies have held an initial public offering (IPO), and most have since lost value, the most prominent example being A123 Systems, a lithium ion battery manufacturer. Mr. Caprio noted that without government support many companies would have failed. For example, the top 25 nanotechnology companies in the United States all received NNI funding at some stage of their development. Interestingly, in the transport and aerospace sector all the major players (e.g. Lockheed Martin) have nanotechnology R&D programmes, but it is unclear how much of their revenue is nanotechnology-related. He speculated that this information is hard to acquire because it is linked to funding for classified programmes or because it is not in the interest of these companies to divulge it for competitive reasons.

Discussion

While nanotechnology is beginning to be explored in automobile and aircraft components (e.g. wiring, lightweight composites, tyres), the group debated how best to account for differences in application-specific value chains and within various industry production models (i.e. all production in-house versus assembly of subcomponents). Participants felt that it is necessary to understand consumer needs and use these to generate technology challenges for R&D. The group also discussed the role of trade barriers (which have limited access to, or significantly increased the price of, critical materials) in driving efforts to develop new materials. However, the integration of these materials is often slow owing to long timelines for design platforms and for regulatory compliance (e.g. aviation authorities).

Given that economic impacts already exist, the group then discussed the replacement of traditional materials and composites with nanotechnology-based materials. Specific drivers for this trend are increased or novel performance; cost and availability of traditional raw materials and the possibility of more efficient manufacturing. It is crucial to their uptake that these materials are designed so that they can be “dropped into” manufacturing production processes with minor modifications. When addressing the question of what benefits or impacts could be expected over the next five years, participants felt that this time frame was somewhat short, but they identified a number of potential impacts: measurable environmental impacts, such as reduction of carbon footprint/climate change; more design flexibility by building multi-functionality into a material system; more efficient transport (e.g. reduced vehicle mass, increased fuel economy, lightweight magnetic components and wiring); and enhanced safety through nano-enabled sensors and energy absorption materials.

Participants identified two specific metrics to assess impact: number of standards produced (e.g. international, internal, national, consortia) and number of industry consortia formed. Some of the challenges for assessing economic impact are the difficulty of calculating the cost savings due to inclusion of nanotechnology and of assessing indirect benefits. Recognising the complexity of transport in aerospace markets, attendees proposed dividing markets into the components that the value chains are serving (e.g. structural systems, drive systems, support systems). However, efforts to capture data on these value chains are further complicated by their length and by restricted access to information on defence-related projects.

Some specific indicators to assess impact were suggested: R&D funding, publications, patents, jobs created, and companies formed. These are not unique to the transport and aerospace sector. Participants noted that academic output (e.g. publications, patents) often lacks economic impact if it is not linked to industry R&D. They also identified the difficulty of determining which companies should be counted as nanotechnology companies and the importance of repeating these counts at regular intervals.

In general, when asked if sufficient data and methods were available, the answer was no; current assessments fail because they are not an indication of commercialisation and therefore not of economic impact. When addressing what is currently not being captured by metrics, the following approaches were suggested: assessment of changes/increases in technology-readiness levels (TRLs); translation of measureable environmental and health benefits into economic benefits (e.g. decrease of carbon footprint, increase in safety, increase in energy efficiency); number of cases where nanotechnology was best in class for a non-specific problem; and number of products and services that would not exist without nanotechnologies.

Nanomedicine

Changing the way we treat cancer with CYT-6091 (Aurimune®): a model cancer nanomedicine

Lawrence Tamarkin (President and CEO, CytImmune Sciences, United States) gave an overview of the Aurimune™ product line, its clinical impact, and its underlying manufacturing strategy. Aurimune™ is designed to target the blood vessels supporting tumour growth. It is based on a polyethylene glycol (PEG)-coated colloidal gold nanoparticle system that is 27 nm in diameter. The drug component of this system, recombinant human tumour necrosis factor (TNF) alpha, is presented on the nanoparticle surface and is a known tumour-killing agent. The size of this drug delivery system allows it to reside preferentially in the circulation through leaky, newly formed vasculature at tumour sites; it was previously shown to pass selectively through gaps in blood vessel walls. Most importantly, the drug delivery system allows for a significantly higher exposure to TNF anti-tumour agents in the body without dose-limiting toxicities.

Mr. Tamarkin stated that the drug is currently in Phase 2 of clinical trials and will be evaluated in combination therapies with other chemotherapeutic drugs. Aurimune™ will be evaluated for treating pancreatic cancer, melanoma, soft tissue sarcoma, ovarian, and breast cancer in patients followed by standard of care chemotherapy for each indication. CytImmune Sciences was able to overcome the manufacturing challenge associated with large-scale synthesis of Aurimune™ by following current good manufacturing practices (cGMP) regulations. The proprietary manufacturing process was scaled up by Ben Venue Laboratories to ensure cost-effectiveness, uniform coating of each nanoparticle of gold by linear pieces of PEG and TNF, and a consistent shelf life for the drug of at least three years.

Nanotechnology for medical devices: challenges, changes and risks

Joerg Vienken (Vice President BioSciences, Fresenius Medical Care, Germany) presented challenges, changes, and risks related to nano-enabled medical devices. The size scale of nanomaterials is relevant to the biological scale of viruses and enzymes and, therefore, provides for better, but possibly uncontrolled, interaction with physiological systems than other classes of materials. It is important to note that effects of nanoscaled medical devices are determined by their surface dimensions rather than their volume or mass dimensions. This notion is not yet recognised by various normative rules, (e.g. for "substances of very high concern (SVHCs)"), where the mass of an individual entity is the determining factor.

A significant amount of funding has been allocated to nanotechnology research; in 2006, global government spending on nanotechnology was almost USD 6 billion. Yet, despite the optimism regarding the potential benefits of nanotechnology in biosciences, some scientists have expressed significant concerns about the environmental, health, and safety risks associated with the field. From an industry perspective, ISO specifications are still limited for nanotechnology; more standards need to be developed to improve the success of nanomaterials in the marketplace (e.g. standardised manufacturing and test procedures for risk analysis).

Nanomaterials present unique opportunities in the field of nanomedicine mainly owing to the unique surface effects (see above) that dictate their interactions with biosystems such as proteins and cells. Yet, these same properties can also introduce an element of risk. Recent research has indicated the potential for nanomaterials to be hazardous through processes such as frustrated phagocytosis, granuloma formation, and acute cell toxicity. Considering the unique properties and risks associated with nanotechnology, the industry will face growing challenges relating to standards, regulations, investor relations, clinical trials, and workplace safety. In 2010, there were almost 1000 German companies in the nanomedical field with a total of 60,000 employees; 97% of these were considered small and medium-sized enterprises (SMEs) with fewer than 250 employees, and 83% were less than 15 years old. In 2007, 38% of these companies focused on metrology, 27% on biomaterial and implants development and 25% on drug delivery. The future success of nanoscaled medical devices will be driven by harmonisation of regulatory policies regarding the approval of new technologies, improved understanding of the acute and chronic toxicity effects of nanomaterials, refined definitions of nanomaterials, and better funding mechanisms for SMEs.

Measuring the economic impact of R&D investments

Richard Clinch (Director of Economic Research, Jacob France Institute, University of Baltimore, United States) discussed measuring the domestic impact of investments in research and technology. Economic impact analysis uses an input/output model to provide estimates of the impact on a regional economy of transactions between economic sectors. The impacts measured include overall business activity (related to goods and services produced in the economy), employment, and earnings. The model used was RIMS II (from the Bureau of Economic Analysis); it is relatively inexpensive and easier to use than other models. It was used to analyse data on the National Institutes of Health (NIH) extramural research awards to 50 states in 2007, and the spending was adjusted to reflect differences in purchasing power using the Biomedical Research and Development Price Index (BRDPI). The results indicate that NIH spent USD 22.8 billion in grants and contracts in fiscal year 2007. According to Mr. Clinch's analysis, extramural research generated a total of USD 50.5 billion in new state business activity. In addition, NIH grants and contracts created and supported more than 350,000 jobs that generated wages in excess of USD 18 billion in the 50 states (an average annual wage of USD 52,000). This represents an overall multiplier (business activity generated per dollar of funding) of about 2; Texas led with 2.49.

Using the Human Genome Project as a case study, the evaluation of a multiplier effect from funding associated with human genome sequencing involves a mix of expenditure and functional impacts. In 2010, genomics generated about USD 67 billion in U.S. economic output, USD 20 billion in personal income and 310,000 jobs, for an overall multiplier averaging over 5.

It is important to recognise that science investments are currently viewed as a factor of economic growth; investments in science are no longer made solely with a view to the public good. For nanotechnology, more work is needed to evaluate multipliers and the overall economic impact of such investments.

Exploring the quantitative dimensions of the economic impact of nanomedicine

Bertrand Loubaton (Director, Pharmaceutical & Academic Collaboration, GE Healthcare; Chair, European Technology Platform on Nanomedicine, France) summarised the challenges for measuring the economic impact of nanomedicine. In the wake of a transformation in medical practice and the development of a new healthcare market model, three fundamental issues should be addressed: rising costs, changing demographics, and quality of life. The new healthcare market model has shifted from the dominance of "blockbuster" drugs to the emergence of "nichebuster" drugs and personalised medicine. Although the nanomedicine market is still at an early stage, governments and established corporations have made significant investments in R&D. The United States represents about 33% of all publications and 50% of patent filings. Over 70 nano-enabled medical products are currently in clinical trials, and there are 44 nano-delivery products on the market, 18 nano-pharma products, and 15 imaging/diagnostic biomaterials. The global market for nanomedicine will be approximately USD 630 billion in 2016, a little less than 20% of the overall pharmaceutical market, with a compound average growth rate of 9.4% from 2008 to 2016. Finally, some 200 companies produce products identified as nanomedicine, in addition to 159 start-ups and SMEs.

Yet, healthcare spending is unsustainable; a crucial economic impact of nanotechnology could come from improved cost-saving measures. Technology-dependent costs currently account for a maximum of 20% of total costs in marketed therapies. Nanomedicine can reduce future healthcare costs if the technology reduces major costly diseases, improves therapeutic efficacy with lower side effects (due to improved targeting), reduces inpatient care, and contributes to improved patient wellness.

Discussion

The recent rise of personalised medicine has demonstrated that the classic process of developing blockbuster drugs may no longer be viable. The healthcare industry is changing, and this shift is catalysed by novel treatments such theranostic drug delivery systems, improved biosensing, and more effective therapies; all potentially enabled by nanotechnology.

This change in the healthcare ecosystem is reflected in the reluctance of pharmaceutical companies to fund the development of new drugs and to focus instead on the acquisition of mature products or firms (e.g. the acquisition of Genentech by Roche), or to shift from Phase 1 and Phase 2 models to a demonstration/validation model for drug discovery.

In light of current economic constraints, nanotechnology could potentially catalyse this shift in global approaches to disease treatment through reduced costs, better patient monitoring, personalised therapies, and more effective vaccines. Ultimately, this would help address the growing medical needs of patients and society.

Several new opportunities in nanomedicine were discussed on the first day: the potential for improved partnerships between large companies and SMEs, or between industry and academia; the possibility of reinvestigating previously abandoned drugs using nanomaterials as a delivery system; the significant growth in research publications and patents; and the potential for improved manufacturability of certain drugs. In some cases, there is already significant growth in drug delivery systems that are in clinical trials. Ultimately, improved standardisation and accelerated regulatory recognition and approval will be needed to help transfer these technologies to the market.

Nanomaterials provide unique opportunities for improving quality of life, lowering healthcare costs, and facilitating the redistribution of economically oriented values to focus more on social needs. In this context, the definition of healthcare benefits in the new age of personalised medicine and how the related costs are covered needs to be revisited.

The following approaches to assessing the economic impact of nanomaterials were proposed:

- Improve size-related definitions of nanotechnology: the market size for nanomaterials is between 100-1000 nm (there are significantly fewer products at 100 nm).

- Improve transparency in the private sector: companies do not specifically identify products in the pipeline as nano-enabled.

- Current measures of economic progress should capture, among others: spillover effects, economic multipliers for a particular sector enabled by nanotechnology, and the adoption of nanomedicine into standard of care by insurance companies.

A three-to-five-year objective for assessing the economic impact of nanomaterials should include re-categorisation of current treatment and diagnostic modalities in the market owing to integration of nanotechnology. It should also cover case studies on advances in treatment and diagnostics. This would help predict potential economic impacts such as improvements in life expectancy and reduced hospital stays.

Electronics

Measuring the economic impact of nanotechnology in electronics – the New York State Investment Strategy

Ji Ung Lee (Director, Institute for Nanoelectronics Discovery and Exploration [INDEX], College of Nanoscale Science and Engineering, SUNY Albany, United States) discussed the impact of nanotechnology investments in New York. He began by stating that the changing nature of innovation requires a new technology development paradigm, one that is faster, collaborative, democratic, and global. The interdisciplinary nature of nanotechnology, encompassing physics, chemistry, engineering, material science, etc., requires closer coupling of R&D and manufacturing and the mechanism of industry as a partner with universities and government. As an example, he cited the New York State Investment Strategy, which has a technology hub/manufacturing node at its core. Since its inception in 1997, this strategy has led to a thriving open innovation eco-system and multiple expansions of shared user facilities. By leveraging know-how and equipment, clients benefit from shorter development time and lower investment. This has also led to major investments in the region by industry leaders such as Global Foundries (USD 6.5 billion for a chip factory) and IBM (USD 1.7 billion expansion of existing facilities). Mr. Lee emphasised that workforce development, starting in middle and high schools and continuing through to community colleges and doctoral programmes, was critical to the success of this strategy. He concluded by discussing the important role of technology clusters in developing new industries.

The International Iberian Nanotechnology Laboratory (INL)

José Rivas (Director General, International Iberian Nanotechnology Laboratory [INL], Portugal) presented the INL and its part in (nano) electronics research and industry in Europe. The INL is located in Braga, Portugal and has approximately 200 scientists in 40 laboratories. Its major research areas are nanomedicine, environmental monitoring and food control, nanoelectronics, and nanomanipulation. It is an inter-governmental organisation linking Spain and Portugal with activities in other European countries and with strong connections to Latin America. Mr. Rivas stressed the importance of the electronics sector to the world economy, noting that it contributed some 10% to global GDP in 2009. Yet, Europe's unfavourable cost structures have increasingly shifted semiconductor manufacturing to Asia, despite the inclusion of micro- and nanoelectronics in Europe's 2020 strategy[5]. Between 2006 and 2010 the market share of European companies decreased by 40%; although this was partially offset by an increase in the market share of European semiconductor equipment manufacturers. Mr. Rivas said that INL aims to play a leading role in the European electronics sector in automotive and transport, communication and digital lifestyles, energy efficiency, health and the ageing society, and safety and security. Mr. Rivas concluded with four points related to measuring the nanoelectronics industry's evolution in Europe: nanoelectronics are expected to have a higher impact in a variety of industries across Europe; the evolution of this industry needs to be measured and actions taken soon; reliable and consistent metrics have been on the agenda of European policy makers for a long time; and it is difficult to produce such metrics.

Economic impact of nanotechnology: case study on LED lights

Chang-Woo Kim (Director General, National Nanotechnology Policy Centre, Korea Institute of Science and Technology, Korea) presented a case study on the economic impact of nanotechnology on lighting. As nano-enabled products increasingly enter the market, more data are needed. At present, the statistics available are not sufficient and there are too few studies. Using the method developed by DEFRA (see presentation by Ben Walsh and associated background paper), Mr. Kim's institute performed a quantitative study of the impact of LED lights on the Korean market (2011-20) using market data. The study uses an economic benefit assessment, with the economic benefit defined as being equal to the consumer's surplus plus the producer's surplus plus externality. The producer's surplus is calculated by multiplying the unit price margin by the size of the market. The analysis compares the substitution of LED lights for numerous product classes: incandescent lamps, halogen lamps, compact fluorescent lamps, and others. The externality variable was defined as the savings in electricity. The study concluded that the application of nanotechnology resulted in electricity savings; the nanotechnology product also had a longer life and a value-added component.

Economic impact of nanotechnology in electronics: (semi) quantitative assessments

Celia Merzbacher (Vice President for Innovative Partnerships, Semiconductor Research Corporation [SRC], United States) discussed the economic impact of the electronics industry on the US and world economy. Metrics assessing the economic impact of nanoelectronics on the US semiconductor industry and, in turn, the industry's impact on the US economy – such as research publications and patents, jobs, and value-added growth in production and consumption – have shown positive results over the past 50 years. The technology has enabled the creation of smaller, lower-cost products that provide better performance, thereby increasing market value. The US semiconductor industry has a significant direct impact on the US economy. It represents approximately half of the global sales, which last year were nearly USD 300 billion, accounts for more than 200 000 direct US jobs and many more that are indirect, and is one of the largest US exporting industries. Moreover, studies have shown that semiconductor use in other sectors contributes directly to US growth, productivity and energy efficiency.

Ms. Merzbacher further stated that the SRC has funded substantial research in academia in new technologies, has promoted collaboration and technology transfer, and has generated many measurable outputs, such as technical documents, patents applied for and granted, and students educated. One SRC programme, the Nanoelectronics Research Initiative (NRI), launched in 2005, has federal, state and local partners and seeks, among other things, to discover the technology that can replace the CMOS FET as a logic switch in the 2020 timeframe.

Discussion

The group discussed the impacts of nanoscale electronics on society and the specific metrics needed for this and similar fields. In terms of impact on production and performance of devices and systems, large-scale integration and size reduction down to the nanoscale have decreased transistor costs and improved performance exponentially. This has led to dramatic market growth, with the market for semiconductors valued at USD 226 billion and the electronics industry as a whole valued at over USD 1 100 billion in 2009. The ubiquity of electronics is evidence of their impact on modern society (e.g. quality of life, education, relationships, culture) and on many fields (e.g. medicine, robotics, energy). Several studies[6] have pointed to large investments in informatics and communication technologies, particularly in the United States, as drivers of productivity growth.

Regional economic impacts across a country or countries were discussed in the context of outcomes from the International Iberian Nanotechnology Laboratory (INL) and the College of Nanoscale Science & Engineering (CNSE), SUNY Albany. The INL, jointly funded by Spain and Portugal, maximises its resources through participation in the Association for European NanoElectronics Activities (AENEAS) and the ENIAC Joint Undertaking, a public-private partnership focused on strengthening European competitiveness in nanoelectronics. Despite initial predictions to the contrary, European integrated device manufacturers lost significant market share between 2006 and 2010, while European semiconductor manufacturers increased theirs. Cases such as this, in which indicators are neither correlated nor accurate, caution against long-term predictions. Participants considered the open innovation ecosystem of the CNSE as an important factor in its success in attracting industry partners. Shared user and manufacturing facilities lower investment costs, leverage know-how and shorten development times. The economic impact of its over 300 industry partners is very large; more than USD 14 billion have been invested in the region since 2001 and more than 2 700 people are employed in high-wage R&D positions that further stimulate the economy.

Participants mentioned the need for more data on the impact of nanotechnology. They discussed the results of a recent study[7] that surveyed businesses on the effect of nanotechnology on a range of indicators. Successful companies found that nanotechnology had a high impact on sales revenue, market launch and market entry. Case studies on a specific technology, such as the presentation on LED lighting, were considered a good tool since they can show benefits to the end user, the seller and to society overall. Participants noted in particular that social implications must be considered and evaluated in order to justify government investments in the field.

Energy

Quantum dots: assessing the impact within lighting and displays

Seth Coe-Sullivan (Co-founder and CTO, QD Vision Inc., United States) opened with an overview of QD Vision and its products. He observed that his company, like many other nanotechnology-based companies, replaces an existing technology instead of producing a new technology. As he put it, QD Vision is “improving the wheel”, not reinventing it. The company grew out of scientific research at MIT and now has 95 employees in five locations around the world. QD Vision has the industry’s largest capacity quantum dot fabrication facility. The quantum dots are incorporated in light-emitting diodes (LEDs) to improve the quality of the colour of the light produced without a loss in efficiency. The company also produces quantum dot-enhanced backlights for liquid crystal display (LCD) monitors and TVs.

For the quantum dot industry, Mr. Coe-Sullivan listed three types of economic impact: direct impacts that can be measured now, direct impacts that can be measured in the future, and indirect impacts. Direct impacts that can be measured now include jobs created, capital raised, corporate value, and products. For example, Mr. Coe-Sullivan predicted that quantum dots would be embedded in products worth almost USD 10 billion by the end of 2013. The direct impacts that can be measured in the future include quantum dot materials and components that are incorporated into larger products and enter emerging markets, such as LED lighting and displays. The indirect effects associated with the quantum dot industry include the replacement of rare-earth materials, gains in energy efficiency and energy security. As quantum dots continue to evolve and improve, they will be used more frequently to replace rare-earth materials in products. At present, lighting accounts for 22% of building electricity, but nano-enabled technologies, such as LEDs, have the potential to drastically reduce this share.

Nanotechnology in the energy sector

Hilary Flynn (Senior Analyst, Lux Research, United States) described how Lux Research, a technology scouting, market assessment and consulting firm, began in 2004 with a focus on nanotechnology. Today, however, it specialises in emerging technologies but does not focus on nanotechnology because it views nanotechnology as an enabling technology instead of an independent sector. Ms. Flynn reviewed several global trends in nanotechnology investment, products and jobs. The United States and Japan outpace the world in corporate spending on nanotechnology, but many Asian companies are vastly increasing their investments. The United States also leads in government spending on nanotechnology, while the Russian Federation and the People's Republic of China have increased their spending over time. Ms. Flynn presented an analysis of global revenue for nanomaterials, nanointermediates and nano-enabled products (e.g. carbon nanotubes, a nanotube-based composite, and a nano-enabled golf club that incorporates the composite, respectively). Nano-enabled products accounted for almost 90% of global nanotechnology revenue in 2009. European Union countries are expected to overtake American companies in the production of nano-enabled products by the middle of the decade.

Ms. Flynn next addressed the implications of nanotechnology for the energy sector. She provided an analysis of the solar, battery and transparent conducting film (TCF) markets. The organic photovoltaic (OPV) market illustrates some of the broader challenges, including competition from China, an expensive product development process, and well-established existing technologies, which affect the entire solar industry. Based on these factors, Lux Research rated every OPV company analysed as a "long shot". The market for nano-enabled batteries for electric vehicles is characterised by a lack of differentiation between nanotechnology companies and traditional companies. Many battery companies use nanotechnology in their products, but it is not their primary focus. Ms. Flynn remarked on the large supply and small demand for batteries in electric vehicles, which demonstrates the need to focus on realistic demand scenarios. Finally, Ms. Flynn outlined the possibility for nanotechnology – metal nanoparticles, metal nanowires or carbon nanotubes – to replace indium tin oxide (ITO) as TCFs. The industry would like to move away from ITO because it is expensive, vulnerable to shortages and price fluctuations, and brittle. In conclusion, Ms. Flynn predicted that nanotechnology will have the greatest impact on the energy sector when it is incorporated into existing manufacturing lines to produce incremental improvements and when companies produce products for which there is genuine demand.

Foresight on the economic impact of nano-industry in the Russian Federation

Oleg Karasev (Deputy Director, Foresight Centre, National Research University "Higher School of Economics," Russian Federation) first gave a broad overview of nanotechnology. In general, nanotechnology is not used to address large challenges directly; instead, nanomaterials are used to enhance current products and processes. Thus, the indirect impacts of nanotechnology are currently larger than the direct effects. Currently, nano-enabled products are a relatively small market. For example, less than 5% of markets in the Russian Federation involve nanotechnology. According to Mr. Karasev's analysis, nanotechnology will have the greatest impact on the electronics sector in the next three to five years, but nanomaterials will be incorporated into products in other sectors over time. By 2030, nanotechnology will have an impact on many different industries, including food, pharmaceuticals and energy.

Mr. Karasev next presented a detailed analysis of the energy sector and the use of nano-based catalysis in the crude petroleum and natural gas industries to reduce the volume of gas that is flared. He described a sector that is currently dominated by carbon-based energy but is moving towards alternative/renewable energy with an emphasis on energy efficiency. As the technology improves and shifts towards new energy sources, nanotechnology will have a larger role to play. Mr. Karasev used the installation of LED bulbs by Russian Railways to illustrate the fact that new technologies often have important associated benefits that must be taken into account. Before the new bulbs were installed, Russian Railways was the largest institutional consumer of electricity for lighting in the Russian Federation. The replacement bulbs are expected to save the Railways USD 3 million in electricity costs, and the maintenance costs will also be significantly reduced over the entire Russian Railways system because the bulbs have a much longer lifetime.

Mr. Karasev closed his talk with a discussion of methodologies used to assess the economic impact of nanotechnology. At present, there is no ideal source of the necessary information, so several different approaches should be combined to give a fuller picture. Additionally, directly measureable impacts do not give an overall picture. Social effects, likely policy scenarios, impacts of related industries, and the costs of introducing new technologies should also be accounted for.

Discussion

The energy sector is complex, with a number of different markets, including energy generation, storage, transformation, transmission, use and efficiency. Nanotechnology has the potential to have a positive impact on all of these. In the short term, nanotechnology is likely to have the greatest impact in the areas of energy efficiency and energy storage. However, nanotechnology is not tied exclusively to renewable energy technologies. Nanocoatings, nanostructured catalysts, and nanomembranes have been used in the extraction and processing of fossil fuels and in nuclear power.

Participants noted that legislative and regulatory frameworks play a particularly important role in the energy sector. These policies affect a range of issues, including energy security, technology development and technology adoption. For example, Germany has set a target to to reduce CO_2 emissions by 30% in 2030. This has triggered the development of technologies, such as thermoelectric materials and nanoinsulation, that otherwise would not have been competitive.

Participants repeatedly noted the difficulty of identifying which aspect of a complex system contains nanotechnology and the effect of that component on the product as a whole. One exception was suggested by Mr. Coe-Sullivan's presentation on the impact of quantum dots on LEDs. Nano-enabled LEDs showed no increase in efficiency but an increase in colour quality, with an additional increase in cost to the consumer. A direct sales comparison between the standard LED and the nano-enabled LED allows for a fairly straightforward evaluation of the value added by the nanotechnology.

When the discussion turned to specific metrics that could be applied to the energy sector, participants emphasised that there is no perfect metric for any case. For example, the value of a nano-enabled drill bit can be measured as the value of the drill bit or as the amount of crude petroleum produced with that bit relative to that produced with a non-nano bit. The metric chosen for a particular study depends on the audience, the goal of the analysis and what is being measured. Further, the choice of metrics will evolve as new knowledge and new means of analysis become available.

Over the course of the breakout sessions, two categories of metrics received particular attention: economics and sustainability. Several participants voiced the opinion that the most relevant economic metric is the value added of a nano-enabled product relative to that of the incumbent technology. However, the economic impact is more than a simple calculation of sales figures. Factors, such as jobs, taxes and technical performance also play a role and should be built into the full analysis.

The group spent some time discussing sustainability as a qualitative metric for the energy sector. Sustainability is a broad topic, involving environmental impacts, product lifetimes, water usage, carbon output, and use of critical materials, and the definition of sustainability will likely change over time. For example, indium is getting a lot of attention as a rare-earth element, but other materials may become more important depending on availability and use.

Finally, participants discussed the availability and quality of data. Reliable data are scarce because of the long development cycle and relatively recent emergence of nanotechnology. While traditional energy industries, such as natural gas and nuclear, rely on hard data and detailed analyses, emerging technologies, such as solar and wind, may need to make use of softer data, e.g. expert surveys, to get a rough idea of important trends in the field. As a result of the scarcity of data, several participants suggested a need for harmonised data and modelling methodologies in the next three to five years.

Advanced materials

The economic impact of nanocellulose

Reinhold Crotogino (Network Director, ArboraNano, Canada) said that ArboraNano is a network of centres of excellence that foster the creation of innovative products from nanocellulose. Mr. Crotogino noted that cellulose is the most abundant polymer available. ArboraNano is funded by the Canadian government, provincial governments and industry, and it, in turn, funds many downstream sectors that use nanocellulose, including reinforced biopolymers, automotive products, paints, adhesives, nanocomposites, cosmetics, pharmaceuticals, catalysts, building products, and printed films.

Mr. Crotogino described the numerous social, economic and environmental advantages nanocellulose offers global forest industries, downstream customers and consumers. Canada – with its substantial forestry industry – has an important stake in developing nanocellulose. Declining demand for traditional Canadian forest products has led to a drop in employment and an increasing amount of available forestry biomass that can be used for nanocellulose. Downstream companies thus gain secure supplies of new "green" materials and new business opportunities (e.g. reusable and/or compostable products). Consumers benefit from increased environmental stewardship, "exciting new products" and employment prospects.

Mr. Crotogino emphasised that the driving force behind nanocellulose is value creation. He said testing has confirmed that nanocellulose is non-toxic ("similar to table salt") and Canada has approved its use "without restrictions". Work is currently under way to harmonise standards and develop rapid scalability. Mr. Crotogino concluded that nanocellulose has substantial potential for economic growth.

Economic impact of nanomaterials – CNT

Péter Krüger (Head of Working Group on Nanotechnology, Bayer Chemical, Germany) started by recalling that numerous technological and social challenges – such as environmental concerns about the availability of resources and the reduction of greenhouse gases; continued growth in energy consumption and the need for innovative healthcare solutions – are driving innovation. He said that Bayer increasingly concentrates on the entire value chain, from R&D to commercialisation, of innovative solutions, integrating existing building blocks into new systems.

Mr. Krüger then turned to the global supply of and demand for carbon nanotubes (CNTs) and their uses and advantages, particularly for applications in the energy sector (e.g. wind turbines). He said that while CNT demand will likely outpace production capacity by 2017, there is currently a significant oversupply. Issues being addressed include cost and safety as well as developing production processes for products with desired/optimal qualities. He emphasised the importance of the customer and the forces driving consumption (e.g. performance, cost). He said that CNT producers need customer feedback to adapt and optimise processes and products, particularly those that compete with existing products. Life-cycle analysis is also an important part of the value chain, as is risk-benefit analysis. He cited the efforts of the Innovation Alliance CNT, funded in part by the German government, in promoting cross-sectional platform technology for applications.

Economic analysis and regulation at US Environmental Protection Agency (EPA)

Kristen Loughery (Economist, EPA, United States) reported that the Toxic Substances Control Act (TSCA) gives the EPA the authority to require reporting, record keeping and testing and to set restrictions relating to chemical substances and/or mixtures. The basis of all EPA regulation is to protect human health and the environment. The EPA treats the impact of nanotechnology like that of other products. She noted the need for a study of the economic impact of regulation on the industry in addition to the economic impact of carbon nanotubes, adding that cost/benefit assessments of regulations (including social costs) enhance economic efficiency. Ms. Loughery also mentioned that U.S. statutes call for assessment of the economic impact of regulations on small businesses.

Council for Chemical Research and the assessment of the economic impact of nanotechnology

Seth Snyder (President, Council for Chemical Research [CCR], United States) summarised the work that the CCR has done over the past ten years to assess the economic impact of the chemicals-related sciences and industry. Mr. Snyder, a research scientist at Argonne National Laboratory (Department of Energy, United States), serves on a voluntary basis as the president of the CCR. The CCR was created in 1979 when executives at the Dow Chemical Company convened the first meeting of research executives from the largest U.S. chemical companies and research institutions. The aim of the CCR is to improve R&D collaboration by industry, academia and government labs. The CCR conducted studies on chemical R&D in 2001, 2005 and 2012. Mr. Snyder said that the studies concluded that an R&D investment of USD 1 generates USD 2 in operating income, chemical companies with strong patent portfolio indicators tend to exhibit consistently strong financial performance and commercialisation can take about 15 years. The studies also found that federal R&D funding is important to the industry and that the U.S. economy gains roughly USD 40 in GDP growth and USD 8 in increased tax revenues for every USD 1 of federal R&D funding. In conclusion, he stated that innovation alone does not create value. Critical factors include timing, education and translation of invention to innovation.

Discussion

The main point raised in the discussion was the importance of the whole value chain for the development of commercial applications and the need for networks. Companies need to know which value chains they should pursue, whether commercial applications of nanocellulose, for example, can increase companies' market shares and growth and whether customers will be willing to pay for the resulting product(s). Producers need to continue to change/adapt products and technologies based on customer feedback and on economic analysis of the value of the product/technology to the customer. Government funding and matching of partners can facilitate movement along the value chain.

Timing is an important factor in economic analyses. If companies assess products too early in the life cycle, the necessary data may not be available. Products need to be commercialised in order to obtain the data needed for an assessment; the semiconductor industry might be mature enough for such analysis. Another challenge relates to future regulations in light of existing technology levels, given scale-up considerations and lengthy development cycles. Customer uptake of new technologies and products also influences economic analysis and markets.

Participants had varied views on the questions of what is not currently being captured by metrics but should be, and of what the optimal time frame is for such measurements. For the first question, responses included assessments of unsuccessful products, nanoproducts versus existing products, the impact of chemistry on other fields, economic values associated with patents versus non-patented proprietary technology (e.g. trade secrets), and the impact of international harmonisation of regulations. With regard to timing, 5-10 years was generally considered an optimal period for measurements, but other time periods were cited for different measures.

Food and food packaging[8]

Overview of Embrapa Instrumentação

Victor Bertucci Neto (Researcher, Embrapa Instrumentação, Brazil) described the work of Embrapa Instrumentação on nanotechnology as it relates to agriculture. Embrapa is publicly owned but is modelled after a private company. It employs over 2 000 scientists, has a budget of USD 1.2 billion, and encompasses over 46 research centres throughout the country. Before Embrapa was founded, Brazilian agriculture produced few agricultural products and yields were small. The organisation worked to move away from "agriculture applied to the tropics" to "tropical agriculture". Embrapa's research efforts, coupled with appropriate public policies and institution building, have made Brazil the world's second largest exporter of agricultural products.

The National Instrumentation Centre for Agriculture, under Embrapa, has a programme, Nanotechnology Applied to Agribusiness, which runs from 2006 to 2014. The first phase of the project concluded in 2010 and covered three areas: sensors and biosensors for applications in food and agriculture; films and coatings for food packaging and direct coating of foods; and new applications of fibres and residues from agriculture-based materials. The second phase focuses on expanding the research network and incorporating new research, such as bionanocomposites, technology transfer, and safety and toxicological effects of nanotechnology. The project has produced nanocellulose from coconut fibre, a sensor that can differentiate coffee quality or detect microcyatin toxin in water, and an electrically conductive cellulose/polyaniline nanocomposite that may have food packaging or anti-microbial applications. Research is also being done on a sensor to quantify ethylene gas concentration in mature fruit and on a genetic bar code in algae species for breeding purposes.

Embrapa is interested in assessing the impact of its nanotechnology research and has a team to analyse its impacts in the agricultural sector. They are considering two types of potential impact: economic and social/environmental. The economic impact analysis will evaluate the value chain and all related aspects. The analysis of the social and environmental effects is subjective and consists of interviews with stakeholders all along the value chain, including new technology adopters as well as rural and industrial producers. Mr. Neto concluded his presentation by emphasising that the application of nanotechnology to agribusiness will keep Brazil competitive in this sector.

Potential economic impacts of agri-nanotechnology

Kalpana Sastry (Principal Scientist, National Academy of Agricultural Research Management, India) began by describing challenges facing the Indian agriculture system: a growing population, low production levels, climate change, and market risks from flooding or drought. These factors play a role in food availability and food security concerns. She noted also that agriculture and rural development are prominent emerging sectors in India. In fact, India is the largest global producer of many agriculture products, and there is huge potential for market growth. Few agricultural products are processed in India despite the fact that this is a critical step in the value chain. Ms. Sastry then described opportunities for the Indian agriculture system in the areas of processed food, value chain innovation, production and quality improvements on the farms, quality certification, and efficiency improvements along the entire chain.

Nanotechnology is slowly entering the agricultural sector through applications such as pathogen and contamination detectors, product tracking and smart treatment delivery systems (e.g. devices in livestock or crops that can test for pathogens and/or release treatment). Because nanotechnology is relatively new to the agricultural sector, it is difficult to undertake economic impact assessments. Ms. Sastry and her colleagues developed a database that maps nanotechnology research areas to thematic agri-food areas along the food value chain. The database uses information on publications, patents and products to estimate scientific, technological and commercial performance, respectively. An empirical study of agricultural patents showed that nanotechnology is most frequently applied in food processing and packaging. Ms. Sastry anticipates that the packaging market will continue to grow at a compound annual rate of 13% through 2013.

At this point, nanotechnology-based innovation in the agricultural sector is in the early stages. As research progresses, patent filings are expected to increase across the value chain. According to Ms. Sastry, patent-based litigation could hinder the technology transfer process, but patent pools or patent commons are a potential solution. However, building a portfolio of patents may be challenging for some agriculture-based companies. It is essential for researchers and institutions to be knowledgeable about material transfer, confidentiality and licensing agreements. In addition to intellectual property concerns, the food and agriculture sector must take account of regulations, environmental, social, and ethical issues, and food safety.

Economic impact and commercialisation

Lynn L. Bergeson (Principal, Bergeson & Campbell, P.C., United States) argued that the economic impact of nanotechnology is directly related to the commercialisation of nano-enabled products. This in turn hinges on regulations because the EPA and the U.S. Food and Drug Administration (FDA) have authority for pre-market approval for many sectors in which nanotechnology may be commercialised, and a new product must demonstrate a clear benefit before approval is granted.

The EPA has pre-market authority for new chemicals and new uses of existing chemicals, including new nanoscale chemical substances, under the Toxic Substance Control Act (TSCA), and it has pre-market authority for pesticides and anti-microbials under the Federal Insecticide, Fungicide and Rodenticide Act (FIFRA). Both of these statutes base their approval of a product on a cost/benefit analysis. A company must prove that its product has economic value that outweighs any potential risk. The EPA has clear definitions and extensive models for what risks are allowed, but there are few models for capturing the economic value. According to Ms. Bergeson, the absence of a clear benefit model is a problem. For example, it took six years for the first antimicrobial textile with nanosilver to receive approval.

The FDA has pre-market approval for direct and indirect food additives, such as bisphenol A, which is used in the lining of food cans, under the Federal Food, Drug and Cosmetic Act (FFDCA). Under this law, a food additive is prohibited until it is deemed safe. It is unclear how the FDA defines "safe" for these purposes, but it certainly includes the concept of benefit. Ms. Bergeson asserted that the methods used by regulators are crucial, but unclear. She argued that new tools that are transparent, rational and easy to apply are needed. An additional challenge lies in the lack of data and the need for consensus on the data needed for the models.

Methods for assessing the quantitative impacts of nanotechnology

Rosalie Ruegg (Managing Director, TIA Consulting, Inc., United States) began by describing how logic models can be used to depict the design of an investment programme in nanotechnology, including its resources, activities, outputs, users, interim outcomes, and long-term impacts. She related evaluation to the logic model, illustrating the kinds of questions that might be addressed through evaluation from inception through implementation to outputs, outcomes and ultimate impacts. Ms. Ruegg then linked the choice of metrics to the questions to be addressed and the analysis approach used. For example, surveys can show which industries are adopting a technology in the short term as well as the percentage of industry users who have adopted the technology in the long term. Ms. Ruegg listed many of the methods and supporting quantitative techniques available to evaluate investments in nanotechnology, but she focused on patent tracing and cost/benefit analysis because these techniques have produced useful results in assessing other technologies with similar characteristics.

Patent citation analysis can be used to trace forward to assess the downstream influences of an R&D programme in nanotechnology on a variety of users in diverse application areas. It can be used also to trace backward from an outcome of significance, such as a successful product that embodies a nano-material, to assess the role of a given nano-funding programme on the outcome. As an evaluation method, patent analysis has the advantages of being non-obtrusive and producing objective results. However, patent analysis does not present a complete picture; the resulting patents and their citing do not provide a measure of economic impact.

Traditionally, cost/benefit analysis was applied at the project level. But in recent years it has been expanded, first by the U.S. Advanced Technology Program and now further by the U.S. Department of Energy, to examine broader portfolios of projects and programmes and to account for a wider array of benefits. The newer versions of cost/benefit analysis have been used successfully to evaluate the economic returns on public investments in technologies similar to nanotechnology.

It should be possible to use patent and cost/benefit analyses in a complementary way to provide a comprehensive picture of the results of a portfolio of investments in nanotechnology, such as applications of nanotechnology in food processing. The patent analysis will provide a partial assessment of knowledge benefits and a tracing of paths of knowledge dissemination. The cost/benefit analysis will provide measures of return on investments in nanotechnology.

Discussion

The use of nanotechnology in the agriculture, food and food packaging sector is in the early stages and has not been widely adopted. Yet it has the potential to produce the following improvements:

- Increased production efficiency: nano-enabled fertilisers could improve crop yields and potentially reduce reliance on resources such as water.
- Reduced waste: Incorporating nanotechnology into packaging materials could extend shelf life and reduce loss of food due to spoilage.

- Improved safety: Nano-scale anti-microbial products and controlled-release coatings could reduce pathogens and contribute to fewer food contamination outbreaks. Additionally, nanosensors could be used to monitor food quality or to detect pathogens, chemicals or contaminants in food.

Currently, consumer acceptance of nanotechnology in food products is low, although it is more widespread in food packaging. It was suggested that consumers' concerns about nanotechnology in the food sector could be addressed through appropriate regulations and standards, rigorous analysis of the economic and safety benefits, and educating the public about the benefits. Several participants noted that it is particularly important to develop benefit assessment methodologies because there are well-established risk assessment techniques, but more needs to be done to develop approaches for assessing the benefits.

The food industry faces some challenges that are unique to the sector: including a complex value chain and small profit margins. The value chain in the food sector is very long and has sub-components ranging from small rural producers to industrial processing facilities. This makes it difficult to assign the value added by incorporating nanotechnology into a product. Furthermore, the costs of developing, transferring and analysing the impacts of a new technology are high relative to the small profit margins in this industry. This can hinder the adoption and deployment of new technologies.

Participants noted a clear lack of data, quantitative methods, and metrics in this sector. Several people recommended that metrics in the short term should focus on economic, social and environmental impacts. Recognising that the choice of metric depends on the maturity of the technology and the market, the suggestion was made to focus on publication and patent measures early in the innovation process and on more specific metrics, (e.g. reduction in food spoilage due to improved packaging), for more developed products. However, the technology is still emerging and has not achieved widespread adoption. Thus, initial analyses in this sector should have a narrow scope and rely on softer techniques, such as surveys. A concerted effort should also be made to collect more high-quality data.

NOTES

1. Ehlers, Vernon J. (1998), Unlocking Our Future: Toward a New National Science Policy, A Report to Congress by the House Committee on Science, Washington, D.C., GPO, www.gpo.gov/fdsys/pkg/GPO-CPRT-105hprt105-b/pdf/GPO-CPRT-105hprt105-b.pdf

2. Roco M.C., C.A. Mirkin, M.C. Hersam (2011), Springer, www.wtec.org/nano2/

3. International Workshop on Challenges to Increased Use of Nanotechnology Standards (2011), 13-14 December, Washington, DC, http://gsi.nist.gov/global/index.cfm/L1-8/L2-33/A-598.

4. Between the lines: what is Heidelberg's real plan for printed electronics? (2009), Plastic Electronics Magazine, Vol.1, Issue 6, pp. 32-39

5. For further information see: http://ec.europa.eu/digital-agenda/en/news/innovation-future-europe-nanoelectronics-beyond-2020

6. For a survey of the literature see Kretschmer T. (2012), "Information and Communication Technologies and Productivity Growth: A Survey of the Literature," OECD Digital Economy Papers, No. 195, http://dx.doi.org/10.1787/5k9bh3jllgs7-en.

7. Viinikka, E. et al. (2009), "Best practices in investment and commercialisation of nanotechnology in Europe and worldwide", NanoCom Deliverable D2.3, www.nanocomeu.org/NanoCom/Dissemination.html.

8. It was suggested that agriculture should be added as a sector description alongside food and food packaging.

ANNEX I: SYMPOSIUM AGENDA
(Affiliations as of March 2012)

Tuesday, March 27, 2012

8:00 – 8:30 **Registration and Coffee**

8:30 – 9:00 **Welcoming Addresses**
Alan I. Leshner, CEO, American Association for the Advancement of Science; Executive Publisher, *Science*, United States
Thomas Kalil, Deputy Director for Policy, Office of Science and Technology Policy, Executive Office of the President, United States
Ken Guy, Head of the Science and Technology Policy Division, OECD

Session 1: Setting the Scene

Moderator: **Richard Johnson**, Senior Counsel and Senior Partner (Ret.), Arnold & Porter LLP; Chairman or Vice-Chairman, OECD/BIAC Nanotechnology, Biotechnology, and Technology Committees, United States

9:00 – 9:20 **The OECD, WPN and the Assessment of the Economic Impact of Nanotechnology**
Françoise Roure, Chair, OECD Working Party on Nanotechnology; Head of the Technology and Society Section, Ministry of Economy, Finance and Industry, France

9:20 – 9:40 **Economic Rationales and Strategies for an Advanced Manufacturing Sector**
Gregory Tassey, Chief Economist, National Institute of Standards and Technology, United States

9:40 – 10:00 **Challenges for Governments in Evaluating Return on Investment from Nanotechnology and its Broader Economic Impact – Overview of Background Paper 1**
Mark Morrison, Chief Executive Officer, Institute for Nanotechnology, United Kingdom

10:00 – 10:30 **Break**

10:30 – 12:30 **Government Panel Discussion**

Moderator: **Françoise Roure**, Chair, OECD Working Party on Nanotechnology; Head of the Technology and Society Section, Ministry of Economy, Finance and Industry, France

Adalberto Fazzio, Deputy Secretary and Coordinator of Nanoscience and Nanotechnology Secretariat for Technological Development and Innovation, Ministry of Science, Technology and Innovation, Brazil

Herbert von Bose, Director Industrial Technologies, DG Research and Innovation, European Commission

G. V. Ramaraju, Head of Nanotechnology Initiatives Division, Ministry of Communications and Information Technology, India

Naoya Kaneko, Fellow, Center for R&D Strategy, Japan Science and Technology Agency, Japan

Joseph Molapisi, Manager for Emerging Research Areas, Department of Science & Technology, South Africa

Altaf Carim, Assistant Director for Nanotechnology, Office of Science and Technology Policy, Executive Office of the President, United States

12:30 – 1:30 **Lunch**

Session 2: Exploring the Qualitative Dimensions of the Economic Impact of Nanotechnology

Moderator: **Steffi Friedrichs**, Director General, Nanotechnology Industries Association, Belgium

1:30 – 1:50 **Finance and Investor Models in Nanotechnology – Overview of Background Paper 2**
Pekka Koponen, CEO, Spinverse Ltd., Finland

1:50 – 2:10 **Economic Contributions of Nanotechnology to Green and Sustainable Growth – Overview of Background Paper 3**
Philip Shapira, Professor, Manchester Institute of Innovation Research, University of Manchester, United Kingdom; Professor, School of Public Policy, Georgia Institute of Technology, United States

2:10 – 2:30 **Discussion**

2:30 – 2:45 **Introduction to Parallel Breakout Sessions**
Steffi Friedrichs, Director General, Nanotechnology Industries Association, Belgium

2:45 – 4:45 **Parallel Breakout Sessions**

- Transportation & Aerospace
  Co-chair: **Steffi Friedrichs**, Director General, Nanotechnology Industries Association, Belgium
  Co-chair: **Michael Meador**, Nanotechnology Program Manager, National Aeronautics and Space Agency, United States
  - Speaker: **Travis Earles**, Senior Manager, Advanced Materials Nanotechnology Initiatives, Lockheed Martin, United States
  - Speaker: **Francis Peters**, Project Director, Materials and Raw Materials, Michelin Worldwide, France

- Nanomedicine
  Co-chair: **Piotr Grodzinski**, Director, Nanotechnology for Cancer Programs, National Cancer Institute, United States
  Co-chair: **Alexander Pogany**, Research Policy Expert, Federal Ministry for Transport, Innovation and Technology, Austria

  - Speaker: **Lawrence Tamarkin**, President and CEO, CytImmune, United States
  - Speaker: **Joerg Vienken**, Vice President Biosciences, Fresenius Medical Care, Germany

- Electronics
  Chair: **Mihail Roco**, Senior Advisor for Nanotechnology, National Science Foundation, United States
  - Speaker: **Ji Ung Lee**, Director, Nanoelectronics Research Corporation's INDEX Center; Professor, University at Albany – SUNY, United States
  - Speaker: **Jose Rivas**, Director General, International Iberian Nanotechnology Laboratory, Portugal

- Energy
  Co-chair: **Ingo Höllein**, Deputy Director of New Materials, Nanotechnology, Federal Ministry of Education and Research, Germany
  Co-chair: **Andrew Schwartz**, Program Manager, Office of Basic Energy Sciences, Department of Energy, United States
  - Speaker: **Seth Coe-Sullivan**, Founder and CTO, QD Vision, United States
  - Speaker: **Hilary Flynn**, Senior Analyst, Lux Research, United States

- Advanced Materials
  Co-chair: **Markku Lämsä**, Senior Technology Adviser, TEKES, Finnish Funding Agency for Technology, Finland
  Co-chair: **World Nieh**, National Program Leader, Forest Products and Wood Utilization, U.S. Forest Service R&D, United States
  - Speaker: **Reinhold Crotogino**, President and CEO, ArboraNano, Canada
  - Speaker: **Peter Krueger**, Head of Bayer Working Group Nanotechnology, Bayer Material Science AG, Germany

- Food & Food Packaging – Revelle Room
  Co-chair: **Knut Berdal**, Senior Advisor, Department of Food Policy, Ministry of Agriculture and Food, Norway
  Co-chair: **Hongda Chen**, National Program Leader, Bioprocessing Engineering/Nanotechnology, U.S. Department of Agriculture-National Institute of Food and Agriculture, United States
  - Speaker: **Victor Bertucci Neto**, Embrapa Instrumentacao Agropecuria, Brazil
  - Speaker: **Kalpana Sastry**, Principal Scientist, Agricultural Research Systems Management and Policies Division, National Academy of Agricultural Research Management, India

4:45 – 6:00 **Report Back and Synthesis Conversation**

Moderator: **Ken Guy**, Head of the Science and Technology Policy Division, OECD

6:00 **Reception**

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8:30 – 9:00 **Nanotechnology Research Directions for Societal Needs in 2020**

Mihail Roco, Senior Advisor for Nanotechnology, National Science Foundation, United States

Session 3: Nanotechnology, Economics, and Regulations

Moderator: **Lynn** L. **Bergeson**, Bergeson & Campbell, P.C., United States

9:00 – 9:20 **International Standards Supporting Nanotechnology Development**
Ajit Jillavenkatesa, Senior Standards Specialist, Global Standards and Information Group, National Institute of Standards and Technology, United States

9:20 – 9:40 **Socio-economic Dynamics of Innovation and Uptake**
Douglas Robinson, Managing Director, teQnode, France

9:40 – 10:00 **The Hare and the Tortoise: Nanotechnologies and the Race for Regulatory Certainty**
Diana Bowman, Assistant Professor, Risk Science Center and the Department of Health Management and Policy, University of Michigan, United States

10:00 – 10:30 **Discussion**

10:30 – 11:00 **Break**

Session 4: Science of Science and Innovation Policies Applied to Nanotechnology

Moderator: **Charles Wessner**, Director, Technology Innovation and Entrepreneurship, The National Academies, United States

11:00 – 11:20 **Redesigning Science & Innovation System and Nanotechnology**
Tateo Arimoto, Director-General, Research Institute of Science and Technology for Society; Deputy Director-General, Center for R&D Strategy, Japan Science and Technology Agency, Japan

11:20 – 11:40 **Putting the Science in Science Measurement: The Case of Nanotechnology**
Julia Lane, Program Director, Science of Science and Innovation Policy, National Science Foundation, United States

11:40 – 12:00 **The Lattes Platform in the Brazilian ST&I System**
Esper Cavalheiro, Advisor to the President of the Centre for Strategic Management and Studies, Brazil

12:00 – 12:30 **Discussion**

12:30 – 1:30 **Lunch**

Session 5: Approaches (New and Established) to Assess the Effects of Technology Investment

Moderator: **Stephen Campbell**, Group Leader, Impact Analysis Group of the Technology Innovation Program, National Institute of Standards and Technology, United States

1:30 – 1:50 **A Conceptual and Methodological Framework for Statistics on Nanotechnology and other Technological Areas**
Leonid Gokhberg, First Vice-Rector, National Research University "Higher School of Economics"; Director, HSE Institute for Statistical Studies and Economics of Knowledge, Russian Federation

1:50 – 2:10 **Models, Tools and Metrics Available to Assess the Economic Impact of Nanotechnology – Overview of Background Paper 4**
Ben Walsh, Senior Consultant, Oakdene Hollins, United Kingdom

2:10 – 2:30 **Discussion and Introduction to Parallel Breakout Sessions**

Session 6: Exploring the Quantitative Dimension of the Economic Impact of Nanotechnology

2:30 – 4:30 **Parallel Breakout Sessions**

- Transportation & Aerospace
  Chair: **Steffi Friedrichs**, Director General, Nanotechnology Industries Association, Belgium
  - Speaker: **Lance Criscuolo**, President, Zyvex Technologies, United States
  - Speaker: **Vincent Caprio**, Executive Director, NanoBusiness Commercialization Association, United States

- Nanomedicine
  Co-chair: **Piotr Grodzinski**, Director, Nanotechnology for Cancer Programs, National Cancer Institute, United States
  Co-chair: **Witold Łojkowski**, Professor, Institute of High Pressure Physics PAS and Bialystok University of Technology, Poland
  - Speaker: **Richard Clinch**, Director of Economic Research, Jacob France Institute, University of Baltimore, United States
  - Speaker: **Bertrand Loubaton**, Director Pharmaceutical & Academic Collaboration, GE Healthcare; Chair, European Technology Platform Nanomedicine, France

- Electronics
  Chair: **Mihail Roco**, Senior Advisor for Nanotechnology, National Science Foundation, United States
  - Speaker: **Chang-Woo Kim**, Director-General, National Nanotechnology Policy Center, Korea Institute of Science and Technology, Korea
  - Speaker: **Celia Merzbacher**, Vice President–Innovative Partnerships, Semiconductor Research Corporation, United States

- Energy
  Co-chair: **Ingo Höllein**, Deputy Director of New Materials, Nanotechnology, Federal Ministry of Education and Research, Germany

Co-chair: **Andrew Schwartz**, Program Manager, Office of Basic Energy Sciences, Department of Energy, United States

- Speaker: **Oleg Karasev**, Deputy Director, International Foresight Centre, HSE Institute for Statistical Studies and Economics of Knowledge, Russian Federation

- Advanced Materials

  Co-chair: **Markku Lämsä**, Senior Technology Adviser, TEKES, Finnish Funding Agency for Technology, Finland

  Co-chair: **World Nieh**, National Program Leader, Forest Products and Wood Utilization, U.S. Forest Service R&D, United States

  - Speaker: **Kristen Loughery**, Economist, Office of Pollution Prevention and Toxics, Environmental Protection Agency, United States
  - Speaker: **Seth Snyder**, President, Council for Chemical Research, United States

- Food & Food Packaging

  Co-chair: **Knut Berdal**, Senior Advisor, Department of Food Policy, Ministry of Agriculture and Food, Norway

  Co-chair: **Hongda Chen**, National Program Leader, Bioprocessing Engineering/Nanotechnology, U.S. Department of Agriculture-National Institute of Food and Agriculture, United States

  - Speaker: **Lynn** L. **Bergeson**, Bergeson & Campbell, P.C., United States
  - Speaker: **Rosalie Ruegg**, Director, TIA Consulting, United States

Session 7: What We Learned

Moderator: **Stephen Campbell**, Group Leader, Impact Analysis Group of the Technology Innovation Program, National Institute of Standards and Technology, United States

4:30 – 5:00 **Report Back and Synthesis Conversation**
Breakout Session Co-Chairs

5:00 – 5:30 **Concluding Remarks and Next Steps**
Sally Tinkle, Deputy Director, National Nanotechnology Coordination Office, United States
Ken Guy, Head of the Science and Technology Policy Division, OECD

ANNEX II: PARTICIPANT LIST

(Affiliations as of March 2012)

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Mark Morrison, Institute for Nanotechnology

Jacqueline Mout-Leurs, The Netherlands' Ministry of Education, Culture and Science

Elizabeth Nesbitt, U.S. International Trade Commission

Victor Bertucci Neto, Embrapa Instrumentação Agropecuária

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Kate von Holle, British Embassy

Ben Walsh, Oakdene Hollins Ltd

Jan Wauters, Consulate General of Belgium

Charles Wessner, The National Academies

Jay West, American Chemistry Council

Jan Youtie, Georgia Institute of Technology

Moises Zavaleta, Ministry of Economy of Mexico

ANNEX III: BACKGROUND PAPERS

Integral to the success of the Symposium were the four background papers commissioned by the OECD. These were posted on the Symposium website (www.nano.gov/symposium), and participants were encouraged to download and read them in advance of the meeting. As noted on the agenda, each of the lead authors presented their findings during the Symposium.

- Challenges for Governments in Evaluating Return on Investment from Nanotechnology and its Broader Economic Impact

  Eleanor O'Rourke and Mark Morrison, Institute of Nanotechnology, United Kingdom

- Finance and Investor Models in Nanotechnology

  Tom Crawley, Pekka Koponen, Lauri Tolvas & Terhi Marttila, Spinverse, Finland

- The Economic Contributions of Nanotechnology to Green and Sustainable Growth

  Philip Shapira (1, 2, 3) and Jan Youtie (3, 4)

  1. Manchester Institute for Innovation Research, Manchester Business School, University of Manchester, UK
  2. School of Public Policy, Georgia Institute of Technology, Atlanta, GA, United States
  3. Center for Nanotechnology in Society, Arizona State University, Tempe, AZ, United States
  4. Enterprise Innovation Institute, Georgia Institute of Technology, Atlanta, GA, United States

- Models, Tools and Metrics Available to Assess the Economic Impact of Nanotechnology

  Katherine Bojczcuk and Ben Walsh, Oakdene Hollins, United Kingdom