New York's Nanotechnology Model: Building the Innovation Economy: Summary of a Symposium

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Charles W. Wessner, Rapporteur; Committee on Competing in the 21st Century: Best Practice in State and Regional Innovation Initiatives; Board on Science, Technology, and Economic Policy; Policy and Global Affairs; National Research Council

New York's Nanotechnology Model

BUILDING THE INNOVATION ECONOMY

Summary of a Symposium

Charles W. Wessner, Rapporteur

Committee on Competing in the 21st Century:
Best Practice in State and Regional Innovation Initiatives

Board on Science, Technology, and Economic Policy

Policy and Global Affairs

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Preface

Responding to the challenges of fostering regional growth and employment in an increasingly competitive global economy, many U.S. states and regions have developed programs to attract and grow companies as well as attract the talent and resources necessary to develop innovation clusters. These state and regionally based initiatives have a broad range of goals and increasingly include significant resources, often with a sector focus and often in partnership with foundations and universities. These are being joined by recent initiatives to coordinate and concentrate investments from a variety of federal agencies that provide significant resources to develop regional centers of innovation, business incubators, and other strategies to encourage entrepreneurship and high-tech development.

PROJECT STATEMENT OF TASK

An ad hoc committee, under the auspices of the Board on Science, Technology, and Economic Policy (STEP), is conducting a study of selected state and regional programs to identify best practices with regard to their goals, structures, instruments, modes of operation, synergies across private and public programs, funding mechanisms and levels, and evaluation efforts. The committee is reviewing selected state and regional efforts to capitalize on federal and state investments in areas of critical national needs. This review includes both efforts to strengthen existing industries as well as specific new technology focus areas such as nanotechnology, stem cells, and energy in order to improve our understanding of program goals, challenges, and accomplishments.

As a part of this review, the committee is convening a series of public workshops and symposia involving responsible local, state, and federal officials

and other stakeholders. These meetings and symposia will enable an exchange of views, information, experience, and analysis to identify best practice in the range of programs and incentives adopted.[1]

Drawing from discussions at these symposia, fact-finding meetings, and commissioned analyses of existing state and regional programs and technology focus areas, the committee will subsequently produce a final report with findings and recommendations focused on lessons, issues, and opportunities for complementary U.S. policies created by these state and regional initiatives.[2]

THIS SUMMARY

The symposium reported in this volume convened state officials and staff, business leaders, and leading national figures in early-stage finance, technology, engineering, education, and state and federal policies to review challenges, plans, and opportunities for innovation-led growth in New York. These symposium participants assessed New York's academic, industrial, and human resources, identified key policy issues, and engaged in a discussion of how the state might leverage regional development organizations, state initiatives, and national programs focused on manufacturing and innovation to support its economic development goals. The conference agenda, listing the speakers and their presentations, is found in Appendix A of this volume. Appendix B provides the biographies of these speakers. A full list of participants is found in Appendix C of this report.

This conference, as with any single meeting, was necessarily limited in its scope; it did not (and indeed could not) describe the full variety of industries present in the state. The focus on the emerging partnerships among academia, industry, and government in nanotechnology, however, illustrates the high level of commitment by New York's political and industry leaders to grow the state's innovation ecosystem.

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[1]The Committee convened meetings to review state and regional programs in Arkansas, Hawaii, Michigan, Ohio, and Illinois. Summaries of these meetings have been prepared. See for example, National Research Council, *Building the Arkansas Innovation Economy: Summary of a Symposium*, C. Wessner, Rapporteur, Washington, DC: The National Academies Press, 2012. See also National Research Council, *Building Hawaii's Innovation Economy: Summary of a Symposium*, C. Wessner, Rapporteur, Washington, DC: The National Academies Press, 2012. The Committee has also convened meetings to review federal and state policies to encourage the development of innovation clusters. See National Research Council, *Growing Innovation Clusters for American Prosperity: Summary of a Symposium*, C. Wessner, Rapporteur, Washington, DC: The National Academies Press, 2011.

[2]The committee has prepared a consensus report, based on this study. See National Research Council, *Best Practices in State and Regional Innovation Initiatives: Competing in the 21st Century*, C. Wessner, ed., Washington DC: National Academies Press, 2013.

New York's Nanotechnology Model: Building the Innovation Economy
Summary of a Symposium
Statement of Task

The committee will cooperate with Rensselaer Polytechnic Institute and other members of the Nano Consortium, including the College of Nanoscale Science & Engineering (CNSE) of the University at Albany-SUNY, to conduct a symposium to highlight the accomplishments and growth of the innovation ecosystem in New York, while also identifying needs, challenges, and opportunities. Participants will include state officials and staff, business leaders, and leading national figures in early-stage finance, technology, engineering, education, and state and federal policies. The event will review the development of the Albany nanotech cluster and its usefulness as a model for innovation-based growth, while also discussing the New York innovation ecosystem more broadly. The event will help identify areas where federal, state, university, and non-profit contributions could generate positive synergies and also draw attention to the scale and focus of foreign competitive programs and consider their implications for New York and the nation. An individually-authored summary of the symposium will be published.

This summary report includes an overview that highlights key issues raised at the meeting and a summary of the meeting's presentations. This workshop summary has been prepared by the workshop rapporteur as a factual summary of what occurred at the workshop. The planning committee's role was limited to planning and convening the workshop. The statements made are those of the rapporteur or individual workshop participants and do not necessarily represent the views of all workshop participants, the planning committee, or the National Academies.

THE CONTEXT OF THIS PROJECT

Since 1991, the National Research Council, under the auspices of the Board on Science, Technology, and Economic Policy, has undertaken a program of activities to improve policymakers' understandings of the interconnections of science, technology, and economic policy and their importance for the American economy and its international competitive position. The Board's activities have corresponded with increased policy recognition of the importance of knowledge and technology to economic growth.

One important element of STEP's analysis concerns the growth and impact of foreign technology programs.[3] U.S. competitors have launched substantial programs to support new technologies, small firm development, and consortia among large and small firms to strengthen national and regional positions in strategic sectors. Some governments overseas have chosen to provide public support to innovation to overcome the market imperfections apparent in their national innovation systems.[4] They believe that the rising costs and risks associated with new potentially high-payoff technologies, and the growing global dispersal of technical expertise, underscore the need for national R&D programs to support new and existing high-technology firms within their borders.

Similarly, many state and local governments and regional entities in the United States are undertaking a variety of initiatives to enhance local economic development and employment through investment programs designed to attract knowledge-based industries and grow innovation clusters.[5] These state and regional programs and associated policy measures are of great interest for their potential contributions to growth and U.S. competitiveness and for the "best practice" lessons that they offer for other state and regional programs.

STEP's project on State and Regional Innovation Initiatives is intended to generate and share a better understanding of the challenges associated with the transition of research into products, the practices associated with successful state and regional programs, and their interaction with federal programs and private initiatives. The study seeks to achieve this goal through a series of complementary assessments of state, regional, and federal initiatives; analyses of specific industries and technologies from the perspective of crafting supportive public policy at all three levels; and outreach to multiple stakeholders. The overall goal is to improve the operation of state and regional programs and, collectively, enhance their impact.

ACKNOWLEDGMENTS

On behalf of the National Academies, we express our appreciation and recognition for the insights, experiences, and perspectives made available by the

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[3]For a review of growth of national programs and policies around the world to support research and accelerate innovation, and the resulting challenges facing the United States, see National Research Council, *Rising the Challenge: U.S. Innovation Policies for the Global Economy*, C. Wessner and A. Wm. Wolff, eds., Washington, DC: The National Academies Press, 2012.

[4]For example, a number of countries are investing significant funds in the development of research parks. For a review of selected national efforts, see National Research Council, *Understanding Research, Science and Technology Parks: Global Best Practices—Report of a Symposium*, C. Wessner, ed., Washington, DC: The National Academies Press, 2009.

[5]For a scoreboard of state efforts, see Robert Atkinson and Scott Andes, *The 2010 State New Economy Index: Benchmarking Economic Transformation in the States,* Kauffman Foundation and ITIF, November 2010.

participants of this meeting. Their support and interest were instrumental to the quality and high-level participation of the conference. Special thanks are also due to McAlister Clabaugh of the STEP staff, for his many contributions to the organization of the conference.

We are also indebted to Alan Anderson for preparing the draft introduction and summarizing the proceedings of the meeting, as we are to Sujai Shivakumar for his substantive contributions and editorial skills.

ACKNOWLEDGMENT OF REVIEWERS

This report has been reviewed in draft form by individuals chosen for their diverse perspectives and technical expertise, in accordance with procedures approved by the National Academies' Report Review Committee. The purpose of this independent review is to provide candid and critical comments that will assist the institution in making its published report as sound as possible and to ensure that the report meets institutional standards for quality and objectivity. The review comments and draft manuscript remain confidential to protect the integrity of the process.

We wish to thank the following individuals for their review of this report: Kathleen Kingscott, IBM Research; David Rooney, Center for Economic Growth; Hany Shawky, University at Albany, State University of New York; and Jan Youtie, Georgia Institute of Technology.

Although the reviewers listed above have provided many constructive comments and suggestions, they were not asked to endorse the content of the report, nor did they see the final draft before its release. Responsibility for the final content of this report rests entirely with the rapporteur and the institution.

Mary L. Good Charles W. Wessner

I

OVERVIEW

Overview

Over the last two decades, a broad partnership of public, academic, and industry leaders in the Albany, New York, region have built "Tech Valley," a cluster of the most advanced semiconductor manufacturing operations in the world and one of the nation's preeminent centers of nanotechnology R&D.[1] Developed around the nucleus of significant state and private sector investments in nanotechnology research facilities, Tech Valley has already drawn major semiconductor firms and organizations to the New York's Capital District.[2] The impact of this cluster on regional economic development and employment has attracted widespread attention. *Forbes* magazine has ranked the region as having one of the nation's highest concentrations of high value jobs.[3]

As a part of its study of state and regional growth strategies, the National Academies STEP Board convened a conference in Troy, New York to learn more about how New York's Capital District is renewing its economy. The conference brought together the leading academic institutions and the state's business and political leaders, along with high-level U.S. government officials and others positioned to help drive innovation, business formation, and growth. These participants brought their own unique perspectives on the

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[1]Members of the cluster include SUNY-Albany of the State University of New York, and one of its campuses, the new College of Nanoscale Science and Engineering (CNSE); IBM, the initial industry member to engage in the Albany region; the SEmiconductor MAnufacturing TECHnology consortium, of SEMATECH, formed in 1987 as a public-private partnership to strengthen the U.S. semiconductor industry; GlobalFoundries, one of the world's largest and newest semiconductor production facilities; and Rensselaer Polytechnic Institute (RPI), the country's oldest technological research institute.

[2]"New York's Capital District, also known as the Capital Region, is a region in upstate New York that generally refers to the four counties surrounding Albany, the capital of the state: Albany County, Schenectady County, Rensselaer County, and Saratoga County. Often the other counties of the Albany-Schenectady-Amsterdam Combined Statistical Area and Greene County are included, especially for economic and demographic compilations and regional planning." Source: Wikipedia.

[3]See *Forbes*, "The Best Cities for Jobs," May 2, 2011. The Brookings Institution has also recognized the region as having the highest concentration of clean-tech jobs in the nation. See Mark Muro, Jonathan Rothwell, and Devashree Saha, "Sizing the Clean Economy, National and Regional Green Jobs Assessment," Washington DC: The Brookings Institution, 2011.

Box A
Albany's Industrial Tradition

The current flurry of activity in and around Albany, NY might not surprise those who view economic development through the lens of history. Albany was first claimed for a European power by Dutch explorer Henry Hudson in 1609, it is the longest continuously chartered city in the United States. Rapid regional growth began during the years after the Revolutionary War, when new residents sought its political stability and the advantages of life on the Hudson River and trade with New York, only a few days' sail downriver.

The city became the state capital in 1797, and in the 19th century a hub of transportation and industry. In his conference keynote address, U.S. Rep. Paul Tonko vividly described "the blue-collar workers of the Erie Canal," "the capacity for work as part of our DNA," and "the banks of the canal giving birth to a necklace of mill towns" that became the epicenters of invention and innovation. Joseph Henry, regarded by many as the foremost American scientist of the 19th century, built the first electric motor while teaching at Albany Academy; the corporate headquarters of General Electric has long been located in nearby Schenectady; and Erastus Corning 2nd, member of the famed Corning glass company, was Albany's longest-serving mayor, 1942 to 1983. "This was the cradle of the industrial revolution," observed Rex Smith, editor of the *Albany Times-Union* and moderator of the conference panel on the New York Nanotechnology Cluster.

From 1810 until the Civil War, Albany was one of the 10 most populous cities in the country. It had the largest lumber market in the nation in 1865, and the Mohawk and Hudson railroad was the first steam-powered train line in the country to run regular service. In 1908 Albany opened the first municipal airport in the United States, and it was one of the first cities anywhere to install public water, sewer, natural gas, and electricity.

As the automobile came to dominate transportation and steel dominated industry, however, Albany's fortunes declined along with the traffic on its canals and rivers. During the 1950s, '60s, and '70s, the population dwindled, as it did in other cities of the northeastern "rust belt," falling from 130,000 to below 100,000.

accomplishments and growth of the nanotech cluster in the Capital Region and its contributions to the innovation ecosystem throughout New York, while also identifying future needs, challenges, and opportunities. This volume summarizes the unique presentations from the conference and provides an overview of key issues raised over the course of this event.

REVIVING THE REGION

The revival of Albany did not begin until the early 1990s, a result of conscious efforts by members of a "triangle of technology": Rensselaer Polytechnic Institute (RPI) to the north in Troy, the corporate headquarters of General Electric in Schenectady to the northwest, and the R&D center of IBM in Yorktown Heights to the south. New projects were funded at SUNY-Albany's spacious site near downtown, which gained focus with then-Governor George Pataki's decision to wager the region's success on nanotechnology. A key strategy, according to Pradeep Haldar of the College of Nanoscale Science and Engineering (CNSE), was "to partner with industry instead of doing it ourselves." Recalling how far the region has travelled, Dr. Haldar noted that there was "virtually nothing" on the current CNSE site, and little of interest in Albany at that time.

Building the Research Base

The development of Albany's nanotechnology cluster began with the founding in 1993 by researchers at the University at Albany's Physics Department of the Center for Advanced Thin Film Technology (CATFT). Established to expedite the commercialization of thin-film technologies, CATFT developed a significant network of nanoelectronics, nanotechnology, bioelectronics, and telecom companies in New York. Supported initially by a $1 million grant from the State, CATFT attracted over $200 million by 2001 in funding from federal, state, and private sector partners.

Through the leadership of Alain Kalayeros, then a physics professor at the University at Albany and director of CATFT, the School of Nanosciences and Nanoengineering at the University at Albany was established in 2001. In April of that year, New York State selected the University at Albany to host the Center of Excellence in Nanoelectronics and Nanotechnology (CENN), with the requirement that every dollar of the state's investment be matched by $3 in private sector investments. Using $50 million in funding from the state and $100 million from IBM, CENN built a state of the art 200mm/300mm clean room facility for research, development, and prototype manufacturing.

In 2004, the University of Albany launched the College of Nanoscale Science and Engineering (CNSE) to train a specialized nanotechnology work force. Under the leadership of Alain Kaloyeros, CNSE had grown from an initial enrollment of 10 graduate students to over 300 graduate and undergraduate students today studying curricula in NanoBioscience, NanoEconomics, NanoEngineering, and NanoScience. It operates 800,000 square feet of facilities space which will be augmented by another 500,000 square feet:

Table 1 lists these and other major milestones in the development of the nanotechnology cluster in the New York Capital Region. It shows that the public

TABLE 1 Major Milestones in the Development of CNSE*

Year	Description	Initial Investment (Millions of Dollars)
2001	Center of Excellence in Nanelectronics and Nanotechnology (CENN) is announced at UAlbany	150
2002	International SEMATECH Research Center	405
2002	Tokyo Electron (TEL) established the TEL Technology Center America. Its first R&D center outside of Japan.	300
2004	College of Nanoscale Science and Engineering established, awarded first Ph.D.	
2005	ASML established research center for next generation lithography	400
2005	Multi-partner Center for Semiconductor Research was established to improve next generation chip design, demonstration, and testing. The university-based R&D centers brought new partners to the CNSE including AMD, SONY, Toshiba, and Applied Materials	500
2005	CNSE established a collaborative center for nanolithography research with AMD, ASML, IBM, and Micron Technologies	600
2005	Applied Materials establishes a CNSE-based research center	300
2006	Institute for Nanoelectronics Discovery and Exploration (INDEX) is announced. Partners include Harvard, Yale, MIT, CalTech, Columbia, Georgia Tech, RPI, Intel, AMD, IBM, and Texas Instruments	435
2006	Vistec Lithography Inc relocates its global headquarters and manufacturing from Cambridge, UK to Watervliet Arsenal Campus in neighboring Watervliet, NY and R&D operation to CNSE	155
2007	CNSE partnered with Einhorn Yaffee Prescott to establish the National Institute for Sustainable Energy marking CNSE's expansion into alternative energy technologies	3.5
2007	International SEMATECH announced it will relocate its headquarters from Austin, TX to Albany, NY	760

Year	Description	Initial Investment (Millions of Dollars)
2008	IBM announces expansion of operations at CNSE and throughout upstate NYS	1,640
2009	CNSE announced new undergraduate degrees in Nanoscale Science and Engineering	
2009	CNSE forms a Computer Chip Hybrid Integration Partnership (CHIP) with SUNY Institute of Technology (Utica, NY) and industrial partners IBM, SEMATECH and Intel. The partnership establishes an incubator to support small and medium sized nanocompanies to support innovation, education, and commercialization of computer chips solutions in Upstate, NY	225
2010	M+W Group announces it will relocate its U.S. headquarters to the Watervliet Arsenal Campus and expand its R&D operation at CNSE	250
2010	CG Power, a power transmission company headquartered in India, and CNSE establish the CG Center for Intelligent Power at CNSE for the development of clean energy and smart grid technologies	20
	Total	6143.5

Sources: AT Kearny Report. (2007). Delivering on the promise of New York State: A strategy for economic and growth and revitalization. Available at <*http://www.atkearney.com/index.php/Publications/deliveringon-the-promise-of-new-york-state.html*>; Office of the State Comptroller. (2010). Fuller road management corporation and The Research Foundation of the State University of New York: Use of State Funding for Research into Emerging Technologies at the State University of New York at Albany: Nanotechnology. Report Number: 2010-S-4. Available at <*www.osc.state.ny.us/audits/allaudits/093010/10s4.pdf*>; CNSE website (cnse.albany.edu); Playing big role in a tiny world. (2001). Albany times union, Albany, NY 5 Jan. 2001: A1. New York State Newspapers. Web. 24 May 2010; Chip facility bound for Albany: $403M research center expected to attract high-tech firms, jobs. (2002), Albany times union. Albany, NY, 18 July 2002: A1. New York State Newspapers. Web. 24 May 2010; $2.7B boost for Tech Valley. (2005). Albany times union. Albany, NY, 5 Jan. 2005: A1. New York State Newspapers. Web. 24 May 2010; Big hopes pinned on science of small; Planned expansion of UAlbany nanotech venture seen as economic boost. (2007). Albany times union. Albany, NY 11 May 2007: A1. New York State Newspapers. Web. 24 May 2010; A sweet IBM deal; $1.6B expansion could create new jobs upstate. (2008). Albany times union, Albany, NY, 15 July 2008: A1. New York State Newspapers. Web. 24 May 2010.

*Reprint of Table 1 from p. 552 of Laura I. Schultz, "Nanotechnology's triple helix: a case study of the University at Albany's College of Nanoscale Science and Engineering," *Journal of Technology Transfer*, 36(5):546-564, 2011. With kind permission from Springer Science and Business Media.

investments of approximately $900 million over a decade at CNSE have been matched by over $5.2 billion in private investments by industrial partners.[4]

IBM's Early Investment

IBM, which had a major research facility in Yorktown, NY, played a significant role in the development of the regional cluster. As noted above, IBM was the initial partner for the nanoelectronics center at CNSE. It had just built its own 300 mm wafer fabrication facility in East Fishkill, but saw sufficient potential at Albany to pledge $100 million over three years to help construct the nation's only university-based facility to design and manufacture ultrathin 300mm wafers, to which the state added $50 million. IBM's role in this has been absolutely critical," said Michael Liehr of CNSE. "Without its presence, and its collaborative nature, CNSE would not be what it is, and Global Foundries would not be here. That is a sustainable advantage that has enabled us to be what we are."

Growth of the Cluster

Adding to this critical mass, International SEMATECH announced in 2002 the development of a $405 million research center, followed by an announcement by Tokyo Electron Ltd of the development of a $300 million research center in the region. During and after 2005, new investments by microelectronics companies in the Albany area snowballed. In 2005, ASML, one of the world's largest makers of semiconductor manufacturing equipment, announced a $325 million investment in Albany. IBM, Advanced Micro Devices, Micron Technology and Infineon joined in a $600 million consortium ($180 million provided by the state) to integrate the technical capabilities of the companies to develop lithography, a project dubbed INVENT. In September 2005, IBM and Applied Materials committed to joint new investments of $300 million in nanotechnology research in the Albany area.[5] In 2008, IBM concluded a $1.6 billion deal with New York State that included establishment of a 120,000 square foot, 675-employee, R&D center dedicated to semiconductor packaging technology that would be owned and operated by CNSE.[6] In 2010, SEMATECH indicated it would move most of its remaining workers from its base in Austin, Texas, to Albany or replace them with new hires.[7]

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[4]Laura I. Schultz, "Nanotechnology's triple helix: a case study of the University at Albany's College of Nanoscale Science and Engineering," *Journal of Technology Transfer* 36(5):546-564, 2011.
[5]"U Albany Ready to Organize Itself in Nanotech Research," *The Daily Gazette* February 26, 2006.
[6]"Region Wins $1.6 Billion IBM Pact," *The Times Union* July 16, 2008.
[7]"Key SEMATECH Program, Jobs Moving to New York," *Austin American-Statesman* October 13, 2010.

The Arrival of GLOBALFOUNDRIES

The groundbreaking in Malta, NY for GLOBALFOUNDRIES' large fabrication facility in 2009 was a major development, one that validated and capitalized on a variety of state and private sector investments. The State played a critical role by providing an initial incentive of about $680 million in tax exemptions to offset the expenses of developing the GLOBALFOUNDRIES site. This was followed by the Empire Zone Benefit Program, which complemented additional investments by GLOBALFOUNDRIES. Additional reasons for locating the plant in the United States, observed Mike Russo, included strong intellectual property protection and access to supply chains. The benefits of this strategy include as many as five thousand direct and ancillary jobs. He said that some 200 companies have either located in the Capital Region or have increased their hiring since the arrival of GLOBALFOUNDRIES.

Dr. Ajit Manocha, the Chief Executive Officer of GLOBALFOUNDRIES, noted in his keynote address that his company began operations in December 2011 by producing 32 nanometer silicon-on-insulator chips for IBM, with which it has a close working relationship. Within a year it had launched 48 nm, 40 nm, and 14 nm semiconductor chip technology as well. He noted that chip features as small as 14 nm are very difficult to realize, comparing it for illustration with the width of an average human hair, which is about 75,000 nanometers. This ability, he continued, is a result of not only GLOBALFOUNDRIES' expertise, but also its close relationships with IBM, CNSE, RPI, the community colleges, and other partners. "This is called a true partnership," he said, "and because of it we have been extremely successful."

The Role of the State's Leadership

The state's leadership has played a key role in reviving the region's fortunes. As GLOBALFOUNDRIES' Mr. Russo observed, "The state made the strategic decision as long ago as the mid-1990s to invest in this [nanotechnology] sector, led by then-Governor Mario Cuomo and State Assembly Speaker Sheldon Silver." The original investments led to development of CNSE, and under Governor George Pataki and State Senate Majority Leader Joseph Bruno. Subsequent investments grew into the "richest public-private partnership in history" to bring in a big semiconductor fabrication facility. He noted that the political leadership had understood the value of the project to not only the regional economy, but also to national economic security. Current Governor Andrew Cuomo has continued to support this effort, recognizing its long-term benefits for the region, state, and the nation.

This willingness by the state to wager the region's success through substantial and sustained investments is a distinguishing feature of New York's nanotechnology model. As noted above, IBM and SUNY-Albany cooperated in the early 2000s to create the world's only 300-mm wafer nanoelectronics R&D and prototyping complex. The state followed up with large-scale grants to

develop research infrastructure for semiconductors, initiatives which were met with a strong matching response from industry and, in some cases, the federal government:

- The state provided $85 million of a total public/private commitment of $185 million to create the center of excellence in collaboration with IBM.
- The state committed $100 million to a $300 million-total project with Tokyo Electron Limited at the Albany Center of Excellence to develop semiconductor manufacturing technology.
- The state invested $35 million to support the Interconnect Focus Center for Hyper-Integration, concentrating on nano-scale interconnect technology, a project co-funded by DARPA and the Microelectronics Advanced Research Corporation (MARCO).

THE FOCUS ON NANOTECHNOLOGY

The decision by New York's political, academic, and business leadership to focus on nanotechnology reflected both their vision and a willingness to accept some risk in investing in a rapidly emerging technology.

A Platform Technology

While activities that fall under the term nanotechnology are many, said Timothy Killeen, vice-chancellor for research at SUNY, the CNSE decided to focus on building structures at the nanoscale. "When you can do that," he said, "you open up incredible new areas in sensors, photonics, biological systems, and fluidics. The challenge is getting more expensive, but the promise lies in multiple applications." In retrospect, Nanotechnology was chosen not only for its cross-cutting nature, but also because it reflected the passion and influence of SUNY-Albany's Alain Kaloyeros, a physicist specializing in materials science who was active in the field and argued tirelessly and persuasively for its adoption. His skill in advocating his vision was a key element in bringing together the state, industry, and university partners.

A Growing Market

This focus on nanotechnology appears to be paying off. According to Thomas Guevara of the Economic Development Administration, the worldwide market for nanotechnology products in 2009 was about $254 billion, and by 2020 is estimated at about $3.2 trillion. The United States is forecast to hold a little over a third of this share—which could provide an enormous number of

Box B

The Region as a Focus of Development

Early planners of the Albany revival concentrated on building a technology cluster led by business. In this they followed the model of the "legacy innovation hubs" around the country, especially Silicon Valley, Route 128 outside Boston, and Research Triangle Park in North Carolina. Many other regions have also begun to build new clusters, including northeast Ohio, Arkansas, Hawaii, and Evanston, Illinois.[a] All emphasize strong leadership, shared investments in infrastructure, supply chain growth, public-private partnerships, and links with national research laboratories or other assets. The principle drivers of these clusters, as described by RPI President Shirley Ann Jackson, have been innovation, trained people, and financial capital.

Jason Miller, Special Assistant to the President for Manufacturing Policy, stressed the importance of diverse and complementary strengths. "What is most important in building a technology cluster such as Albany's," he said, "is that multiple actors join in solving challenges. I am talking about government at all levels, the private sector, the academic institutions, and the organizations."

Fortunately, by the time the cluster in Albany began to take shape, its organizers had many models to draw from, and experienced leaders in both technological innovation and economic development. When Governor Pataki convened a group of stakeholders to formulate a plan for economic resurgence, he had abundant precedent in focusing on an integrated effort in R&D, sustained investment in education, and a commercial strategy built around a Governor's Center of Excellence.

[a]See National Research Council, *Best Practices in State and Regional Innovation Initiatives: Competing in the 21st Century*, C. Wessner, ed., Washington, DC: The National Academies Press, 2013.

jobs for those with the required training.[8] Recent investments—IBM's $2.5 billion fab in East Fishkill and now Global Foundries' $6.6 billion fab in Malta—reflect this growing market.

[8]M.C. Roko, C.A. Mirkin, and M.C. Hirsam, eds., *Nanotechnology Research Directions for Societal Needs in 2020,* National Science Foundation/Word Technology Evaluation report, Springer, 2010.

A Strategic Industry

The first sector to feel a substantial impact from New York's commitment to nanotechnology was the semiconductor industry. In 1993, Alain Kaloyeros helped persuade the state to invest in semiconductors by funding a Center for Advanced Thin Film Technology at SUNY-Albany. This choice was a natural one for planners of a world-level technology cluster, given the involvement of IBM and the enormous importance of semiconductors in transportation, environment, energy, consumer products, and defense.

Indeed, Mike Russo of GLOBALFOUNDRIES called semiconductors "the most strategic industry on the planet," one that it is exceeded only by aerospace among U.S. export sectors. According to Ken Adams of the Empire State Development Corporation, the industry shipped over $110 billion worth of products in 2010, and employed almost 200,000 people. New York State has invested about $1.3 billion in building the sector, beginning with a "down payment" of $150 million for SUNY-Albany's Nanotechnology Center of Excellence, often called SUNY NanoTech.

Long-Term Prospects

Some have warned that the "age of semiconductors" is drawing to a close as the feature sizes of semiconductor chips approach the dimensions of atoms. According to Gary Patton of IBM, however, the innovations that have led the industry past such technological "brick walls" in the past are likely to continue. Speaking at the conference, he described the pattern of growth for the semiconductor industry as periods of steady improvement that end at a technical brick wall, only to experience a disruptive innovation allowing the industry to enter another period of improvement—until the next brick wall.

In the 1980s, for example, IBM built its system with bipolar transistors, which were very fast but power-hungry. Complex packaging reduced power demand, but engineers soon met a power limit, which was overcome by planar CMOS technology, including a new lithography tool for patterning smaller features. Around the year 2000 came the gate oxide limit, a key roadblock at about three atomic layers. This feature could not shrink any further, he noted, because "atoms don't scale." It appeared that scaling had ended—until the use of "silicon under strain" was shown to accelerate the movement of electrons in a wafer. "Strain engineering," along with dynamic random-access memory, allowed placement of billions of transistors on a chip, and enabled the power, memory, and cost gains of personal computing and smart phones for the past decade.

The primary driver of this growth, he said, is economics. The price of a transistor has fallen since 1980 by about five orders of magnitude, while the relative consumption of integrated chip transistors has risen by about six orders of magnitude. As engineers make smaller devices, consumers have better

Box C
Partnerships as a Three-Legged Stool

Most speakers at the Albany conference seemed to agree with Dr. Patton's optimism. As Andrew Matonak, president of Hudson Valley Community College put it: "We have great evidence that things are happening here in the Capital Region." Several participants quoted President Obama's 2013 State of the Union address as they expressed the conviction that Albany is doing something of national significance: "How do we attract more jobs to our shores, how do we equip our people with the skills needed to do these jobs, and how do we make sure that hard work leads to a decent living?"

The answer, said numerous participants, lay in the workings of a cluster dynamic they referred to as a three-legged stool. In her conference keynote, RPI President Shirley Ann Jackson observed that, "Scientific discoveries and technological innovations all rest on strong collaborations among academia, government, and industry. And all three legs are closely linked: The higher education institutions and their globally competitive research; the state government and its agencies; and the investments of private industry. Over the years, especially since the end of World War II, this three-way partnership, with the federal government as the key partner, has created an innovation ecosystem that has driven the U.S. economy. This is the way original ideas from Rensselaer students and faculty can lead to commercial success—but only when academia, government, and the private sector play their respective roles."

performance and lower cost, which enables more applications and larger markets.

Today, said Dr. Patton, we have reached another "inflection point" indicating the end of planar CMOS technology, which prompts some people to assume the "game is over; "if so," he added, 'it would seem that Albany is putting its eggs in the wrong basket." Dr. Patton disagreed with this prognosis, seeing further innovations in the form of 3D devices, 3D chip stacking, and "finFETs," a new transistor design that allows even smaller microprocessors and memory cells. The present barrier, he predicted, would be followed by another around 2020 that requires devices at the nanoscale, such as carbon nanotubes and silicon nanowires. He was confident that once again, the innovations will be there. "And they will bring us true wearable electronics, for example, and connectivity everywhere, and scaling through materials innovations."

ACADEMIA AT THE CORE OF THE CLUSTER

In 1997, Alain Kaloyeros and other professors from SUNY and RPI met with state lawmakers and laid out a vision for the next generation of

semiconductor chip design, supported by advances in nanotechnology, as a regional economic driver. They made it plain that such a vision would require the state to step up its investment in R&D by well over an order of magnitude. Their emphasis on commercialization, and forecasts of the economic potential of nanotechnology, caught the interest of both the governor and the statehouse, where everyone felt the public's pressure to revive the region's moribund economy. Remarkably, the lawmakers agreed, and provided some $15 million in grants.

Over the next year, university and state leaders developed more regular and trustful relationships. This closer collaboration helped the University at Albany secure a designation as one of four national research "focus centers," which had been established by the Department of Defense and the Semiconductor Industry Association to improve the speed and performance of chips.[9] At the same time, SUNY's Center for Environmental Science and Technology Management opened. With these developments, New York Governor George Pataki saw more evidence of the potential for economic development growing out of the universities, and both the state and IBM continued to strengthen the Albany campus with funding for infrastructure, postdocs, and other needs.

Building the College of Nanoscale Science and Engineering (CNSE)

Over the next several years, Alain Kaloyeros, and others came to the conclusion that the development of nanotechnology at SUNY-Albany required a core institution to provide leadership. Their idea found acceptance, and the College of Nanoscale Science and Engineering (CNSE) was created to fill that role with Dr. Kaloyeros as the head. "With a publically organized and managed partnership like this," said Dr. Killeen, "the core is usually a university; it's unusual for a college like CNSE to manage it. But we try not to go back and look at old models. This is a new one." The governor continued to advocate for matching funds with the support of the state assembly and senate.

As Dr. Killen recounted in his presentation, the CNSE campus then began to grow quickly with the International Center for Nanolithography, a large public-private partnership, in 2002; the arrival from Texas of International

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[9]The Focus Center Research Program (FCRP) "is administered by the Defense Advanced Research Projects Agency (DARPA) and the Semiconductor Research Corporation, DoD provides $20 million in funding and leaders from the semiconductor industry match that amount, for a total of $40 million annually that is used directly for university research in physical sciences. Industry partners include Applied Materials, Freescale, GLOBALFOUNDRIES, IBM, Intel, Micron Technology, Novellus Systems, Raytheon, Texas Instruments, United Technologies and Xilinx." Semiconductor Industry Association, "The Focus Center Research Program, A Public-Private Partnership," July 2012. Access at <*http://www.semiconductors.org/clientuploads/One%20Pagers%20July%202012/Focus%20Center%20Research%20Program_FINAL.pdf*>.

SEMATECH in 2003; NanoFab South in 2004; the Center for Semiconductor Research, another public-private partnership, in 2005; the Institute for Nanoelectronics Discovery and Exploration in 2006; the Computer Chip Hybrid Integration Partnership in 2009, along with NanoFab East and NanoFab Central. In 2011 the NanoFab Xtension consortium was formed and construction began on the world's first 450mm wafer production facility.[10]

CNSE itself has also expanded at a very rapid rate. It officially began with less than a half-dozen faculty and about three dozen students in one building. Today it teaches about 300 students at the bachelor's, master's, and PhD levels in nanoscale science or engineering, "the first time this kind of major has been offered in any college," according to Dr. Haldar. It also offers majors in nanoeconomics and nanobioscience, but prides itself on being "truly interdisciplinary, with no silos."

With the 450mm wafer expansion, the CNSE will have close to 150,000 square feet of clean rooms, more than any other college or university, and doubly attractive to global companies. "This will mean that the Capital District will be the hub for developing the next generation technology of these larger wafers," predicted Dr. Killeen. According to Dr. Haldar, the ability of CNSE to manage these multiple projects and collaborate effectively with a fast moving industry has played a key role in its success.

The total investment in infrastructure over last dozen years has been about $14 billion, said Dr. Haldar. With the Global 450 Consortia announcement in September 2011, New York State put up $400 million as an opening contribution, and was rewarded by $4.4 billion in pledges from IBM, Intel, TSMC, Global Foundries, and Samsung. In addition, Intel announced that it would establish its East Coast headquarters in Albany to manage its 450mm development. As a result of this consortium, Albany-based enterprises will be able to work with leading-edge companies on a variety of semiconductor and related technologies. "We want to be a one-stop shop," said Dr. Killeen, "from the lab to the fab."

SUNY's Focus on Economic Development

Building on these successes, SUNY is seeking to sustain and broaden its mission to foster regional development. In her conference remarks, SUNY Chancellor Zimpher noted that SUNY in recent years has focused on economic development as "a defining aspiration for the system." According to Dr. Zimpher, "It is also a stake in the ground. We are not only for innovation and entrepreneurship, but we can contribute to a healthier New York, an energy-smart New York, and an educated New York, because we have campuses within

[10]Timothy Killeen, "New York's Nanotechnology Model: Building the Innovation Economy," April 3, 2013, symposium presentation.

30 miles of every New Yorker." She noted that SUNY's objectives also form an important part of Governor Cuomo's NY SUNY 2020 plan, which includes more funding for academic research and innovation hubs. "With a system like ours," she said, "you can reward campuses that choose to grow in high-need fields" related to workforce demands.

Echoing this point, Dr. Killeen noted in his remarks that because of its enormous size, the SUNY system can be a powerful force in economic development. Its impact on local and regional economies is estimated at about $19.8 billion. It carries out nearly a billion dollars' worth of sponsored research each year, and employs more than 2,000 high-tech employees. It supports six centers for advanced technology, including CNSE; eight centers of excellence; and 17 business incubators. Through the Research Foundation for SUNY, it plays a significant role in developing public-private partnerships at the CNSE.

Research Infrastructure to Nurture Start-ups and Support the Supply Chain

Dr. Killeen added that SUNY's leaders are conscious of the potential power of the nano cluster to advance several parallel missions. "By leveraging its partnerships with business and government, CNSE supports the acceleration of workforce training and commercialization leading to job creation and economic growth." At the center of the CNSE-SUNY paradigm is the presence of industry partners co-located on campus, and the installation of expensive infrastructure that attracts companies and enables an open innovation ecosystem. To help launch and develop spinoffs that form on the site, CNSE maintains a business incubator, with the support of the New York State Energy Research and Development Authority (NYSERDA). [11]

"With the larger companies here," said Dr. Killeen, "we can nurture the smaller startups in place, instead of losing them to other regions. In its public-private partnerships, the CNSE operates as an inter-regional technology hub that provides infrastructure and consulting that would not be available to most small technology companies. Rather than replicate research that the companies do themselves, CNSE stands ready to help with the more difficult pilot/prototype research and the manufacturing scale-up phase. In most situations, small companies have to borrow money to build a factory before they have a market for their product. The CNSE provides the equivalent of a factory for small firms to work on the proof of concept, development, and scale-up."

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[11] Established in 1975 as a public benefit corporation, "NYSERDA offers information and analysis, programs, technical expertise, and funding aimed at helping New Yorkers increase energy efficiency, save money, use renewable energy, and reduce their reliance on fossil fuels. NYSERDA collaborates with businesses, industry, the federal government, academia, the environmental community, public interest groups, and energy market participants to reduce energy consumption and greenhouse gas emissions." Source: Wikipedia.

He added that the transition from research to development has always been difficult, time-consuming, and high-risk work. "The reason is that 90 percent of the cost and risk occur after the research phase." The college's state-of-the-art infrastructure "allows it to support not only short-term manufacturing challenges, but to involve the supply chain in the development phase, and to catalyze consortial activity for long-term research."

Another important part of SUNY's strategy is its affiliated corporations that can achieve goals beyond the reach of SUNY or its research foundation. At the same time, they provide a dedicated corporate structure to ensure alignment with SUNY's missions of research and education. The first of these, Fuller Road Management Corporation, was incorporated in 1993, at the outset of discussions about the nascent innovation cluster. Fuller Road manages a land lease with SUNY, designs and constructs facilities, provides financing for construction, and issues debt for facility construction, with the research foundation as the credit tenant. It also provides access to research programs and facilities, owns and operates the facility itself, and leases office space to industry.

Institutions of higher education in Albany and elsewhere in upstate New York have also created numerous partnerships. One is a $40 million agreement recently announced between Albany Molecular Research Inc., a drug discovery, development, and marketing company at the SUNY-Albany campus, with the BN Medical Campus of Buffalo and Niagara. Also, CNSE has created a new partnership with SUNYIT, or SUNY Information Technology, which is constructing the Quad-C Campus in Utica. CNSE is moving into photovoltaics as a member of the Solar Energy Development Center, at Halfmoon, New York, about half-way between CNSE's campus and GLOBALFOUNDRIES site in Malta. And most recently the Smart Systems Technology Center is being developed at CNSE to explore micro-electro-mechanical systems (MEMS), in partnership with Lockheed Martin, at the Syracuse Electronics Park. "We have helped more than 200 companies like these," said Dr. Haldar, "which have raised over $200 million in funding."

Collaborative Programs at Rensselaer Polytechnic Institute (RPI)

In addition to CNSE, semiconductor and other high tech companies locating in the Albany area have benefitted from the presence of the nation's oldest technical university, Rensselaer Polytechnic Institute (RPI) in nearby Troy, New York.[12] In her conference keynote address RPI's President, Shirley Ann Jackson, emphasizes that the institution's core mission is the preparation of students for careers in the sciences and engineering. RPI is also very active in

[12]Rensselaer Polytechnic Institute was founded in 1824 by Stephen Van Rensselaer and Amos Eaton for the "application of science to the common purposes of life" and is the oldest technological university in the English-speaking world.

forging collaborative programs within the Albany cluster. Its Computational Center for Nanotechnology Innovation, CCNI, was established as a $100 million partnership with IBM and New York State. Each partner contributes one-third of the cost, allowing it to host one of the world's most powerful university-based supercomputers. The CCNI has had 800 discrete users and 25 corporate partners.

For 10 years, beginning in 2001, the Rensselaer Nanotechnology Center hosted the NSF Nanoscale Science and Engineering Center for the directed assembly of nanostructures. Directed assembly is a fundamental gateway to the eventual success of nanotechnology because it allows the control of functional properties and ultimate applications of nanomaterials for use in electronics, medicine, and consumer products. [13]

RPI hosts the Molecularium Project,[14] which educates students from kindergarten through college in the fundamentals of physics, chemistry, and biology.[15] It also built the Center for Biotechnology and Interdisciplinary Studies with funding from New York's Genesis Program, the New York State Office of Science, Technology, and Academic Research (NYSTAR), and the New York Department of Health and Mental Hygiene. Finally, she said, the Rensselaer Interconnect Focus Center, also supported by Empire State Development, works collaboratively with universities and businesses globally to increase the power and speed of computer chips at the heart of the nanoelectronics revolution.

SUSTAINED SUPPORT FROM THE STATE GOVERNMENT

In his conference keynote, U.S. Representative Paul Tonko noted that an unusual feature of the Albany cluster has been the limited participation by the federal government. Although he identified several federal programs that he said are contributing valuable support to developing the region's innovation ecosystem—including the EDA's iHUB at SUNY-Buffalo, which connects entrepreneurs with the university, and the more recent DoE participation in the photovoltaics research program—Mr. Tonko noted that the state had recognized the value of this cluster of business and research, and had taken the lead in making substantial investments to develop the research infrastructure and the higher education base in the Tech Valley.

Importantly, the state's role has been sustained by a bipartisan consensus through successive state administrations. Speakers, including Ken

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[13]Shirley Ann Jackson, "New York's Nanotechnology Model: Building the Innovation Economy," April 3, 2013, symposium presentation.

[14]One its website, the objective of the Molecularium Project is described as "expanding science literacy globally by exciting young minds about molecular science through experiential learning and unprecedented visualizations in immersive and interactive media."

[15]<*http://www.molecularium.com*>.

Adams and Mike Russo, noted that the state's leaders have understood not only the value of strong R&D in the areas of nanotechnology and semiconductors, but also the need to offer a consistent and favorable business environment in attracting or establishing SEMATECH, the GLOBALFOUNDRIES facility, the Global 450 Consortium, and other initiatives.

The Role of New York's State Development Agencies

In his conference remarks, Ken Adams of the Empire State Development Corporation noted that the state government has been a prime mover in support the nanotechnology sector, he said. Over the years it has invested approximately $1.3 billion in this sector, beginning with $150 million in the Nanotechnology Center of Excellence, $100M to specific companies several years ago, help for Tokyo Electron's R&D program, $75 million for the state-of-the-art 300mm wafer clean room, and $20 million to help relocate SEMATECH from Austin, "which was huge news in 2011. When you bring the leading industry research consortium here, with its 100 or so high-tech jobs, it says something about our global position."

The Empire State Development Corporation, he said, had found that state incentives could not only attract private industry to the region, but also that they could incentivize multiple investments after they arrived. "If you think about that $1.3 billion in investments, this has had a leveraging effect in attracting or supporting over $20 billion from world leaders in the industry."

Drawing on state data, Mr. Adams said that about 20 percent of state's high technology workforce, or about 12,000 jobs, were now located in Tech Valley, including various partnerships. One example was IBM's $2.5 billion fab in East Fishkill, New York. The latest investment, GLOBALFOUNDRIES' $6.6 billion fab in Malta, New York, "showed the tremendous power of leveraging the parts of this three-legged stool."

By the time GLOBALFOUNDRIES expressed interest in an Albany site, the state government had gained substantial experience in partnering with technology enterprises of global scale. According to Mike Russo, New York has managed to provide GLOBALFOUNDRIES with almost $680 million in tax exemptions to offset the expenses of developing the Malta site for the multi-billion dollar investments in its fabrication and research facilities. This was followed by a state Empire Zone Benefit Program, which used a grant formula based on such outputs as capital expenditures and number of jobs created. "To our knowledge," said Russo, "this is the largest public-private partnership in history."

Speaking at the conference, Frank Murray of NYSERDA noted that his organization was a partner in helping guide innovators during early commercialization. Mr. Murray noted that this agency, founded to carry out

certain core missions, such as consulting on energy efficiency, has developed into become a critical part of the overall economic development team.[16]

Two other state-funded centers for advanced technology have been active throughout the emergence of the cluster. The Center for Automation Technologies and Systems (CATS) and the Center for Future Energy Systems are both supported by Empire State Development's Division of Science, Technology and Innovation (originally known as NYSTAR). This division funds Centers for Advanced Technology (CATs) around the state. At RPI, for example, is the Center for Advanced Technologies and Systems. NYSTAR also funds 10 Regional Development Technology Centers that work with SMEs. It also supports high-performance computing at RPI's Computational Center for Nanotechnology Innovation, a joint $100 million investment by the state, RPI, and IBM.

Dr. John Wen of Center for Automation Technologies and Systems at RPI acknowledges that there is always a debate on "how best to balance applied research, which usually has a company-specific focus, with the basic research we know is the driver for innovation and long-term discovery. The key is that industry tells us what's important. That is like gold for researchers," because it allows them to focus their energies on what is most relevant.

The Center for Economic Growth (CEG), a private regional economic development organization works with these and other partners "to advance the ability of the region and its assets to succeed in the global marketplace."[17] In his conference remarks, CEG President Michael Tucker said that he found a decade ago that there was wide support among businesses for cluster-based growth and has been promoting it ever since. "Clusters increase the productivity of companies," he said, "and enable them to be more competitive locally, nationally, and globally. They do this by capturing the important knowledge linkages among technology, skills information, marketing, and customer needs." The CEG offers a suite of services in sales, marketing, family business advice, startup assistance, business acceleration, productivity, and new market expansion.

Implementing Strategic Plans and Multiple Partnerships

Some version of Governor Cuomo's Regional Economic Development Council is found in most states, but the one in New York has developed a new way of doing business from the ground up. Each of the state's 10 economic

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[16]Frank Murray, "New York's Nanotechnology Model," April 4, 2013, symposium presentation.
[17]The Center for Economic Growth website notes that "CEG receives funding and resources from Empire State Development's Division of Science, Technology and Innovation, which works to facilitate the integration of innovation and technology throughout New York's economic development efforts, the National Institute of Standards and Technology (NIST) / Manufacturing Extension Partnership (MEP) and National Grid." Access at <*http://www.ceg.org/*>.

Box D
Partnering to Market the Region

A broad-based effort to market the region around the world, titled *NY Loves Nanotech* was developed in the late 1990s by the Center for Economic Growth (CEG) with support from the National Grid, many local economic development organizations, universities like the University at Albany and later CNSE, RPI, and many regional businesses in the nanoelectronics field. The goal of this effort is to advertise the region's growing industrial capacity and to position to support semiconductor manufacturing as well as leading-edge research and development and thus attract more firms to invest and relocate in the Albany Capital Region.

The initiative involves targeted sales calls to key industry leading companies, comprehensive electronic marketing, public relations, trade show and industry conference participation, and the hosting of key industry events in the region, such as the World Semiconductor Council's Annual Meeting in 2012 in Saratoga Springs.

Through *NY Loves Nanotech*, the region and the state have developed key industry relationships and have raised global awareness about New York's commitment to growing a vibrant nanotechnology cluster and ecosystem that could and would compete globally for investment. *NY Loves Nanotech* now involves participation from academic, industry and economic development partners and regions across Upstate New York, consistent with Governor Andrew Cuomo's strategy of leveraging key state investments to bring technology-driven companies and employment across the entire Interstate 90 corridor in New York State.

regions develops its own strategic plan; the state then looks at each and decides how best to support it. "This stimulated a tremendous dialogue among stakeholders," said Mr. Tucker, "that otherwise might not have taken place."

SUNY's Dr. Killeen has also seen advantages in the public-private partnerships entered by the state, such as the Micro-Electro-Mechanical Systems (MEMS) center in Rochester; the Smart Systems Technology and Commercialization Center in Canandaigua; and SUNYIT, the Institute of Technology at Utica. "All of this," he said, "is the innovation system that is rooted in academic institutions with entrepreneurial flair, with early career scientists and students involved, high school students, strong major partnerships with big-time industry, and open doors to other components of the industrial spectrum."

The state has further taken steps to directly assist technology companies. It has created 10 innovation "hot spots" as well as support for existing incubators through a competitive funding process; these allow

companies to receive tax benefits for up to five years if the stay in the state. It is also creating a $50 million innovation venture capital fund to address the shortage of VC firms in the region.[18] Finally, it supports the Innovation New York Networks, groups of seasoned professionals who volunteer their time to serve as mentors to startup companies.

The new $300 million photovoltaic manufacturing plant in Halfmoon, said Dr. Haldar, is also attracting many private-sector participants. The challenge, he said, is to help the industry make the major transition from crystalline silicates to indium-gallium-arsenide materials. Nearly 20 industry partners have signed membership agreements, and some plan to move to New York to participate. "The focus is less on basic research than on technology development and the translation to manufacturing," he said. "We'll work at the scale where industry needs to be."

THE ROLE OF THE PRIVATE SECTOR

Along with academia and government, the private sector has been a key leg of New York's partnership "stool," as described by Dr. Jackson. As noted above, speakers such as Gary Patton of IBM, Dan Armbrust of SEMATECH and Mike Russo of GLOBALFOUNDRIES described the scope of the private sector contributions to the economic revival of the New York Capital District.

IBM Corp.

New York State has long been a site for "captive" production of semiconductors for internal use by IBM, which has operated production sites at East Fishkill, NY since the 1960s. As Dr. Patton said, although IBM's capabilities in microelectronics were typically state of the art, the company recognized that as the costs and risks associated with microelectronics escalated, even a firm with IBM's resources and scale would be required to rely to an increasing extent on external sources of supply and collaborative arrangements to ensure a stable source of state-of-the-art components for its information technology products and systems.

For IBM, locational factors also favored New York's Capital District. IBM's Senior Vice President and Director for Research, John E. Kelly, a driving force behind the emerging nanotechnology and semiconductor cluster, had local roots, having earned a bachelor's degree from Union College in Schenectady, and a master's degree in physics and a Ph.D. in materials engineering from RPI in Troy. In addition, IBM already had a considerable history working with SUNY at Albany on a variety of research projects and had hired numerous graduates from the institution.

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[18]Ken Adams, "New York's Nanotechnology Model," April 3, 2013, symposium presentation.

Building on these foundations, IBM and SUNY-Albany in the early 2000s cooperated to create the world's only site of a 300-mm wafer fabrication plant and nanoelectronics R&D and prototyping complex.[19] The state provided $85 million and IBM provided $100 million of a total public/private commitment of $185 million to create the Center of Excellence in Nanoelectronics and Nanotechnology (CENN).[20]

In his conference remarks, IBM's Gary Patton said such collocation and collaboration is essential from a design perspective as well. "This is very complex stuff," he said. "Why has IBM not gone the route of a fabless company, just buying the technology it needs? For one thing, the technology we develop for IBM isn't available anywhere in the world. Second, this 14 nm and 10 nm technology becomes so complex you have to look at co-optimizing the entire stack, from the atoms to the devices, to the circuits, to the Watson system. Many of our fabless partners come to us and want to engage with Albany. They can't just wait for us to deliver a technology; they need to get in early, give us their requirements, and work with us hand in hand."

Building on IBM's momentum, a series of new investments by microelectronics companies have been made in the Capital Region. In 2005, ASML, one of the world's largest makers of semiconductor manufacturing equipment, announced a $325 million investment in Albany. IBM, Advanced Micro Devices, Micron Technology and Infineon joined in a $600 million consortium (with $180 million provided by the state) to integrate the technical capabilities of the companies to develop lithography, a project dubbed INVENT. In September 2005, IBM and Applied Materials committed to joint new investments of $300 million in nanotechnology research in the Albany area.[21] GLOBALFOUNDRIES announced plans to build a $3.2 billion semiconductor wafer fabrication plant in Malta, NY in 2006, the culmination of over eight years of talks between the company and state economic development officials.[22] In 2008, IBM concluded a $1.6 billion deal with New York State that included establishment of a 120,000 square foot, 675-employee, and an R&D center

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[19]Significantly, the state's funding of nanotechnology research at the University at Albany enjoyed bipartisan support. Key players were Republican Governor George Pataki, Republican Senate Majority Joseph Bruno, and Democrat Assembly Speaker Sheldon Silver.

[20]"IBM Executive Shares Vision of High Tech Future," *The Times Union* February 23, 2003. IBM "pledged in April 2001 to pay $100 million over three years to help construct the nation's only university-based facilities that support research in the design and manufacture of ultrathin silicon wafers with a 300-milimeter diameter." "How SUNY Albany Shocked the Research World and Reaped a Bonanza Worth $850 Million (and Counting)," *The Chronicle of Higher Education* February 7, 2003. College of Nanoscale Science & Engineering, University at Albany, "Center of Excellence in Nanoelectronics and Nanotechnology (CENN)," <cnse.albany.edu/LeadingEdgeResearchandDevelopment2/CenterofExcleence.aspx>

[21]"U Albany Ready to Organize Itself in Nanotech Research," *The Daily Gazette*, op. cit.

[22]"For Planning Growth, the Future is Now—Changes that AMD Could Bring to the Region Must Be Anticipated, Executive Warns," *The Times Union* March 25, 2007.

dedicated to semiconductor packaging technology that would be owned and operated by the CNSE.[23] And SEMATECH is moving most of its remaining workers from its base in Austin, Texas, to Albany, New York.[24]

According to CNSE's Michael Liehr, IBM's early and steadfast role as a champion has been absolutely critical for the emergence of the Capital Region as a global center for the research and production of nanotechnologies. "Without its presence, and its collaborative nature, CNSE would not be what it is, and Global Foundries would not be here. This, sustained advantage has enabled us to be what we are."

SEMATECH

One model for the collaborative activities and structures in Albany is SEMATECH. Formed in 1987 with headquarters in Austin, Texas, SEMATECH united the competing U.S. semiconductor manufacturers in the face of intense competition from Japanese chipmakers. As its share of world market share dipped below 50 percent, the industry was sufficiently alarmed that it agreed to cooperate together and work with the government on product quality and trade.

As Dan Armbrust noted in his presentation, SEMATECH was part of a multi-pronged response, coordinating pre-competitive research through Semiconductor Research Corporation, manufacturing through SEMATECH, and cooperating on an innovative trade policy with the U.S. Government.[25] Designed as a public-private partnership and funded jointly by the Department of Defense and the semiconductor industry, SEMATECH is widely credited with helping the U.S. semiconductor industry regain its world leadership.

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[23]"Region Wins $1.6 Billion IBM Pact," *The Times Union*, op. cit.

[24]"Key SEMATECH Program, Jobs Moving to New York," *Austin American-Statesman*, op. cit.

[25]"While many believe that SEMATECH contributed to the resurgence of the U.S. semiconductor industry in the early 1990s, it was by no means the only element in this unprecedented recovery. For example, time [and the necessary earnings] for the industry to reposition itself was provided by the 1986 Semiconductor Trade Agreement, [which stopped Japanese dumping in United States and third markets.] The U.S. industry also repositioned itself, profiting from shifts in demand, i.e., away from DRAMS (where Japanese skill in precision clean manufacturing gave significant advantage) towards microprocessor design and production (where U.S. strengths in software systems and logic design aided in their recovery.) Arguments about which of these elements were most decisive probably miss the point. The recovery of the U.S. industry is thus like a three-legged stool. It is unlikely that any one factor would have proved sufficient independently. Trade policy, no matter how innovative, could not have met the requirement to improve U.S. product quality. On the other hand, by their long-term nature, even effective industry-government partnerships can be rendered useless in a market unprotected against dumping by foreign rivals. Most important, neither trade nor technology policy can succeed in the absence of adaptable, adequately capitalized, effectively managed, technologically innovative companies. In the end, it was the American companies that restored U.S. market share." National Research Council, *Securing the Future: Regional and National Programs to Support the Semiconductor Industry*, C. Wessner, ed., Washington, DC: The National Academies Press, 2003, page 81.

Some of the most important transitions for SEMATECH came in 1994 when it withdrew from federal support; in 1995, when it decided to form and orchestrate a subsidiary for 300mm wafer conversion; and in 2000, when it voted to expand the membership to international companies.

By 2001, Albany was eager to offer SEMATECH its own 300mm facility if it would move its headquarters from Austin. On the day before the September 11 attacks, Governor Pataki began discussions directly with Robert Helms, then the president of SEMATECH, about such a plan. The talks, often complex and contentious, continued for the following 10 months, involving the governor and his higher-education staff, SUNY's Karen Hitchcock, CNSE's Alain Kaloyeros, and half a dozen representatives of SEMATECH.

After dozens of meetings, an issue emerged that brought the negotiations into strong focus: the oncoming need for a full-scale research program on EUV, the next-generation lithography technology using extremely short-wavelength ultraviolet radiation. Such a program would tax the ability of any single SEMATECH member, but would be a good fit for a consortium using Albany's 300mm wafer facility, its expertise in interconnections of microchips, IBM's strength in lithographic research, and most important, Albany's desire to support the collaborative working style that would allow many companies to benefit and share the costs. On July 18, 2002, the 12 leading chipmakers pledged $193 million to develop EUV in Albany, and the state contributed $210 million.

Upon arrival in Albany, SEMATECH created a new manufacturing subsidiary to focus on manufacturing collaboration. It then expanded its membership further to include supply chain companies. Most recently it has entered into a partnership with CNSE to demonstrate the 450 mm platform, and to launch PVMC, the Photovoltaic Manufacturing Consortium.

"[SEMATECH's] mission now is no longer confined to research," said Dr. Armbrust, "although it does research. Instead, it specializes in bridging research, development, and manufacturing. We emphasize technology that our members prioritize. They say we believe that this is going to go into manufacturing, but we have gaps in the infrastructure, and we help with that. That mission differentiates us from everybody else."[26]

GLOBALFOUNDRIES

The new GLOBALFOUNDRIES fab in Malta, located some 30 miles from Albany, is the most recent addition to the Albany cluster. After breaking ground in 2009, production began eighteen months later; there are plans for a further expansion of the facility. At the conference, Mike Russo described the

[26]Dan Armbrust, "New York's Nanotechnology Model," April 4, 2013, symposium presentation.

presence of the "world's most advanced" fabrication facility as the "anchor tenant" of the Albany technology cluster.[27]

It also comes with an unusual pedigree, said Mr. Russo, having emerged from a deal in 2009 between Advanced Micro Devices (AMD) and an investment fund owned by the government of Abu Dhabi called Advanced Technology Investment Co. (ATIC). Until then, Abu Dhabi had depended on petroleum reserves for some 70 percent of its revenue, and this agreement grew out its desire to diversify its economy, especially into technology. AMD agreed to transfer its manufacturing operations to ATIC in phases through the creation of GLOBALFOUNDRIES, which would operate as a pure-play foundry, while AMD continued as a "fabless" semiconductor producer.

The fab itself has developed rapidly. "Semiconductors are seen as a key component of the future economy," said Mr. Russo "And we are at the leading edge of this in our collaborations in the 450mm-wafer transition, 3D stacking, and extreme ultraviolet technology. The fab in Malta is right now producing chips at 28- and 14-nanometer sizes, and will soon reach 10-nanometer size."[28]

He said that it takes three to four months to make each wafer, and yet Fab 8, as the facility is known, has already reached 60,000 wafer starts per month; the goal is 80,000 starts. He emphasized the flexibility of Fab 8, which easily re-formatted in response to changing development needs or market conditions. Already it has been modified to increased production for the mobile phone and tablet markets. In addition, GLOBALFOUNDRIES has decided to make a $2.2 billion addition to the facility with a new Technology Development Center adjacent to the foundry itself. Mr. Russo emphasized the importance of this "lab-to-fab" arrangement, with engineers, technicians, and researchers able to confer easily and the allowing manufacturing feedback to inform development. The activities of Fab 8 have already strengthened the company's revenues, which expanded by 31 percent in 2012.

Mr. Russo noted that the benefits of joining the Albany cluster the arrangement are already apparent. It has allowed the company to become the "first truly global foundry," referring to its distributed worldwide presence. GLOBALFOUNDRIES now includes not only the new Malta facility in North America, but also Chartered Semiconductor Manufacturing, a pure-play foundry in Singapore; a 300mm fab in Dresden, Germany; and a planned facility in Abu Dhabi, giving the company proximity to customers in most regions of the world.

This geographic dispersal reduces the vulnerability of semiconductor production facilities to disruptions caused by natural disasters. This is especially true for semiconductors, most of which have been produced in the "ring of fire,"

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[27]Mike Russo, "New York's Nanotechnology Model," April 4, 2013, symposium presentation.
[28]Mr. Russo said he had calculated that 10 nanometers is "about the distance a fingernail grows in five seconds."

the perimeter of the Pacific Ocean where earthquakes are common.[29] A wide manufacturing footprint is also beneficial in regard to issues of trade, control, security, and intellectual property.

GLOBALFOUNDRIES' location in Malta offer physical advantages as well. The site rests on a 120-foot thick cushion of glacial sand which reduces the potential threat of tremors caused by earthquakes or other shocks. This is critical for a modern fab, where even mild vibrations can disrupt delicate operations at the nanoscale. Other basic but important advantages include access to reliable resources of water, natural gas, and electricity, all upgraded to satisfy foundry requirements.

Mr. Russo described the broader impact of the fab on the region's development potential. "To meet its own needs, the company had to bring in natural gas, a 30-mile water line, and electricity upgrades," he said. "It's very costly to bring in big infrastructure, but once it's here, it helps economic development throughout the region. The same effect is being seen for the educational system and the innovation ecosystem as a whole."

Among the region's advantages, he said, were the rich talent pool at RPI, CNSE and SUNY-Albany; the fiscal support of the state government; the support of the broader community; and the partnership with IBM and other leaders of the industry. In return, he said, the region benefits from some 2,000 direct jobs on the site, soon to grow to 3,000, with an average salary of $87,000; more than 200 companies that have grown or located in the region; and the rapid growth of partners and other members of the supply chain. "A decade ago," he said, "CNSE was beginning to grow, but we had few companies besides IBM. Today a great many of the world's leading firms are here."

Mr. Russo expressed particular pride in GLOBALFOUNDRIES' relationship with the building trades in a region known for strong labor unions. "The trades have been very progressive," he said. "We've laid our cards on the table with them from the beginning and began working with them to develop training curricula for the fab environment. We had to teach them what a clean space it. It's a totally different animal, building these large fabs. And we have to make sure the labor is available when we need it. We're very proud that we've been able to reach an agreement on the original project which has amounted to the largest private labor agreement in the history of this country."

STRENGTHENING EDUCATION AND WORKFORCE TRAINING

Several speakers noted that strengthening the Capital Region's high-technology labor force is essential to sustain the development of the Albany

[29]For example, the Tohoku earthquake and tsunami disrupted Japanese semiconductor production in 2010.

Box E
The New Fab Model and the Benefits of Clustering

Traditionally, the semiconductor business has been dominated by integrated device manufacturers (IDM), such as Intel, Samsung, Texas Instruments, Micron Devices, and AMD. Initially, many of these firms competed at every point of the business: systems, design, assembly, packaging, chip technology, automation tools. In the 1990s, however, the IDMs began to fragment when it became too expensive for them to undertake every step of the supply process. Today, with a new fab costing as much as $10 billion, a new industry structure has emerged that features many more fab-less semiconductor firms and "fab-lite" firms, which focus on design and stand-alone fabs, or foundries, which focus on manufacturing and other links in supply chain.

In his conference presentation, SEMATECH's Dan Armbrust noted that this fab-lite structure answers the challenge of production, but renders other functions along the supply chain too costly for many firms. These fab-lite firms, along with fab-less and stand-alone fabs can benefit from clustering with other each other to capture their complementary strengths. This clustering accelerates the movement of new products through pre-proprietary development stages, allowing firms to expect revenues earlier and to move ahead more quickly and cheaply to the proprietary stage, rather than going it alone at great expense. The development of such a cluster in the Albany area is attracting and anchoring a range of semiconductor related firms, thereby strengthening the local economy.

innovation cluster. According to Darren Suarez of the Business Council of New York, the region faces a skills crisis. He pointed to New York State Department of Labor projection of a 135 percent increase in STEM-related computer electronics manufacturing jobs in the Albany area between 2008 and 2018, which is "driven by the growth in this sector." A key concern, said Mr. Suarez, is that "We are not educating our kids to be college or career-ready." He showed a chart indicating that only 34.7 percent of graduates are "calculated college and career ready and said that more than 50 percent of students in two-year institutions of higher education must take at least one remedial course. At the same time, Mr. Suarez noted that the "perception that the U.S. has fallen so far behind that we don't have the ability to close the gap. We don't believe that. Models like [Albany] can help us to radically change, bringing innovative ideas directly into our classroom and helping strengthen the next generation."

Building the Technical Workforce

Andrew Matonak, the president of Hudson Valley Community College (HVCC), expressed confidence in the region's ability to "open a path toward

these emerging fields" through a host of ongoing programs and fulfillment of the HVCC mission to be "a powerful provider of on-demand workforce training." As an example, he cited the Northeast Advanced Technological Education Center (NEATEC), which is funded by the National Science Foundation to train people in semiconductor manufacturing. "We want to make sure we meet the need for a skilled workforce, and we work very hard at that. The community colleges can do this only by working with the school districts, business and industry, with support from the state and federal governments."

Dr. Matonak's comments were welcomed by Ajit Manocha, CEO of GLOBALFOUNDRIES, who called HVCC "a great partner and ally of Global Foundries" and praised it for "bringing the education, infrastructure, and research to prepare people for the countless jobs that Global Foundries is creating." GLOBALFOUNDRIES' Mike Russo also drew attention to a significant new worker retraining program, the Tech Valley Connection for Education and Job. The program, which helps train and retrain workers through the community colleges in a 13-county area, was initiated by the Center for Economic Growth, in partnership with SUNY. Mr. Russo, GLOBALFOUNDRIES' representative in the program, called it "the largest education initiative of its kind in the country." He called it "basically a very large-scale laboratory to try out the most innovative practices, and to identify roadblocks, and eliminate them."

For its part, SUNY has involved leading educators in the Tech Valley Connection. They have developed a credential for teachers at several levels: those going through certification; furloughed teachers who want to upgrade their skills; and tenured teachers who want to add skills. "For kids who don't have the benefits of shop courses anymore," said Mr. Russo, "we started work on an advanced manufacturing pathway for students on an early college high school path. This leverages the trade schools and high school math and science courses."

Dr. Matonak added that HVCC created a program called TEC-SMART, Training and Education Center for Semiconductor Manufacturing and Alternative and Renewable Technologies. This is situated on the Malta site to take direct advantage of GLOBALFOUNDRIES' expertise. TEC-SMART includes high schools in 12 New York school districts.

Current Education and Training Initiatives

Conference participants also highlighted a number of other education and training initiatives underway in the region:

- Darren Suarez described P-TECH, Pathways to Technology and Early College High School, as a partnership among New York City's Department of Education, the City University of New York, the New York College of Technology, and IBM Corporation. Participating industries and businesses partner with high schools to improve the

effectiveness of education and raise the number of individuals who meet job market requirements.

- Pradeep Haldar drew attention to Tech Valley High School, a new, state-funded initiative to bring high school students to the CNSE campus.
- Robert Blackman of the Center for Economic Growth made note of other CNSE outreach programs, such as Nano High and Nano Career Days, which bring students from Albany city school districts.
- Don Siegel, Dean of the University at Albany School of Business, referred to his school's annual statewide business plan competition. "This is designed for students for the purpose of trying to build an entrepreneurial culture."

"It's all a pipeline," said U.S. Rep. Paul Tonko, "to make sure we're educating the next generation of people who are going to be needed. Our workforce, our schools, and our colleges, especially our community colleges, are key ingredients to the success that we now taste."

SUSTAINING THE ALBANY MODEL

If there is an "Albany model" for building an innovation cluster, one key feature might be the strength of each of the three legs of its three-legged stool as referred to by RPI President Shirley Ann Jackson. Another would be the large number of participants. Neither of these features is unique, but taken together these features stand out.

Industry Leadership

Other regions might be able to profit from this strategy as well. But some features of the Albany model are not easy to replicate. In his keynote remarks, Representative Tonko noted that the region has benefited from the long-time presence and leadership of corporate champions like IBM as well as a sustained and bipartisan flow of political support. These advantages have been reinforced, he said, with the arrival of GLOBALFOUNDRIES, which brought to the region thousands of jobs and billions of dollars in investment.

Key Challenges

While highlighting the unique collaboration that distinguishes the Albany Model, several conference participants also identified some of the challenges ahead in sustaining its success.

GLOBALFOUNDRIES' Mike Russo noted that global competition in nanotechnology is fierce even as the semiconductor business continues to face significant technical and financial challenges. Charles Wessner noted that many

countries around the world have targeted the semiconductor industry as a part of their national development strategy. "You have gone around the first lap in the race really well. But it is just the first lap. You also have to make sure you have the support from Washington that you need as you go forward, because you are now playing in the tall grass with the big animals."

RPI's John Wen identified four major challenges for effective industry-academia collaboration. Number one is control of intellectual property. Number two is maintaining continuity, which he called "extremely challenging." He emphasized that the State of New York needs to sustain its substantial investments over the long term. Number three, he added, is the difficulty of reconciling the different timelines of academia and industry. The final challenge, he said, is learning how build effective multidisciplinary teams. RPI's Jonathan Dordick, further warned that the industry's dominant presence in and around Albany NanoTech may give industry too much power in determining the curricular and research agendas of academic institutions, and may skew activities toward short-term needs instead of the long-term basic knowledge that must guide the industry in the future.

Other participants, including CEG's Michael Tucker and Empire State Development Corporation's Ken Adams, noted the relatively small number of start-ups that have so far been generated around Albany, the insufficient pool of workers trained for high-technology jobs, and the scarcity of venture capital.[30]

Supporting Start-ups

Even so, a number of conference participants spoke with optimism about the future of the Capital Region. CNSE's Dr. Haldar drew attention to the growing number of start-ups in the area, and "a network of close to 100 VC firms that are interested in investing in this area." He also saw value in the business incubator on the CNSE site, supported by NYSERDA, and predicted that the larger companies around CNSE will perform a natural and effective nurturing function for startups. "In the past," he said, "the successful start-ups would move out of our state and be bought by larger companies on the West Coast or around Boston. Having the entire technology ecosystem here means that our companies can capture that technology."

Building the Value Network

Several participants described the Capital District as part of a "new paradigm" of partnerships and collaborations, one that is not only effective but

[30]New York companies attract only about 4 percent of the total venture capital, while nearly half of all U.S. VC is invested in California. "Cuomo's $50M Venture Fund Seeds Startups," Albany, *The Times Union* January 23, 2013.

also essential. The most detailed picture is offered by long-time resident Gary Patton of IBM. "This is something we recognized all the way back in 1990," he said, "when we started our first technology alliance with Siemens in East Fishkill. Eventually Toshiba joined us, and the partnership migrated into our logic alliance and then our partnerships in Albany, where it has spawned other collaborations. We came to the conclusion that it's not only about collaboration between process companies, like Global Foundries and IBM; it's collaboration with the equipment suppliers. And we see all of them now moving to Albany NanoTech. They are finding the benefits of shared investment, shared learning, and the ability to accelerate their process, versus going it alone."

The model for collaboration, he continued, is SEMATECH, which was "unthinkable at the time" it began in 1987 given the independent mindset and often fierce competition among its members. Today the model is extended to include not only the process firms and equipment makers, but also materials suppliers, all of which are needed to advance the industry roadmap.[31] "These technologies are becoming extremely complex," said Dr. Patton, "and we have to come together to make them work. The equipment suppliers used to do their research back in their own labs, but they've concluded that they can't make these tools function without a close partnership with the manufacturers and access to leading-edge technology. And that's what Albany provides."

Developing New Models of Collaboration

Collaboration is essential from a design perspective as well, Dr. Patton said, which explains why IBM is not a fabless company that simply buys the technology it needs. The technology IBM develops for its own needs is not available anywhere, he said. Second, the 14-nanometer and 10-nanometer technology is so complex "you have to look at co-optimizing the entire stack, from the atoms to the devices, to the circuits, to the Watson system." Many of IBM's fabless partners want to engage with IBM in Albany, he said. "They can't just wait for us to deliver a technology. They need to get in early, give us their requirements, and work with us hand in hand. I think we're at the beginning of a new paradigm in how to do this."

CNSE, as well, sees great benefits from collaboration. "Our approach," said Dr. Haldar, "is to sit down across the table from our industry partners and ask them how we can work with you on your short, medium, and long-term goals. The time frame of this industry is not the same as a typical academic institution, so we have to be very responsive. The buildings that go up on our

[31]For a review of the history and future strategies of the International Technology Roadmap for Semiconductors, see Bernd Hoefflinger, "ITRS: The International Technology Roadmap for Semiconductors" in *Chips 2020: The Frontiers Collection,* Berlin: Springer Verlag, 2012, pp. 161-174.

campus and the research we're doing are all timed to meet industry goals and standards. Otherwise industry will leave us in the dust."

Building Shared Infrastructure

Dr. Armbrust of SEMATECH agreed with the need for collaboration and the value of the cluster. "In Texas," he said, "SEMATECH pretty much worked on its own. Here the community is pooling its assets to do much more. There's no way to create what we have here except through shared infrastructure." New York State's support for CNSE, he emphasized, has built the infrastructure needed by both academic and industrial researchers. This helps anchor new instrumentation in the region, avoiding the losses that would occur if companies go bankrupt or leave the region. And the private sector has largely accepted this practice, seeing the advantages of so many partners. "By next year, said Dr. Armbrust, "every materials supplier of consequence, most of them from abroad, will be doing significant work in Albany. They choose to invest here to share the infrastructure."

The concentration of research facilities can, in turn, attract manufacturing. Stephan Biller of General Electric remarked that even legacy

Box F
Investing in the Global 450 Consortium

Housed at CNSE's NanoTech Complex in Albany, NY, the Global 450 Consortium is a $4.8 billion collaboration is made up of five member companies: IBM, Intel, GLOBALFOUNDRIES, Samsung and TSMC. "The goal of the Global 450 Consortium is to support the industry transition from 300mm wafer to 450mm wafer production. The consortium will leverage industry and government investments, and the state-of-the-art infrastructure at CNSE's NanoTech Complex to demonstrate and deploy 450mm wafer tools and process capabilities."[a]

Describing New York State's participation in this consortium, Darren Suarez noted that grants are provided directly to CNSE to build the needed infrastructure. "In a way," he said, "the state is investing in itself. This is a strategy that provides stability. If the state gave that money directly to a company, and the company did not exist here in a couple of years, the investment would be lost. This way, we know the infrastructure will be here and we can offer it to all companies."

[a]CNSE website, <*http://cnse.albany.edu/*>.

companies with traditional products like GE find strong advantages in co-locating their R&D with manufacturing.[32] By facilitating information sharing, smart manufacturing can complement smart economic development,

EXPANDING NANO TO THE PHYSICAL AND LIFE SCIENCES

Industrial variety in a region, based on different but complementary technological fields, promotes greater innovation activity and cluster development.[33] While early discussions in the conference underscored nanotechnology's role in semiconductor research, later discussions followed the scope for nanotechnologies to address challenges in biomedical and pharmaceutical research.

The Crisis in Pharmaceutical Research

The pharmaceutical industry, several speakers noted, is severely squeezed between the twin stresses of rising research costs and declining drug approvals.[34] RPI's Jonathan Dordick, for example, suggested that the industry is facing a developmental crisis. At the same time, he and others speculated that the dangers may be sufficiently dire to spark the kinds of "crisis-driven" efforts at collaboration seen among semiconductor firms.

Others voiced agreement with Dr. Dordick's tone of urgency. Michael Fanter of the CNSE's Center for Advanced Technology agreed that "pharma is an industry that is screaming for a new public-private partnership. They're where the semiconductor industry was in the mid-1980s, when those companies came together and said, 'You know this is nuts. There are too many paths to pursue, and we can't each do it on our own.' The industry came together and formed a vision and a roadmap of shared challenges. Many industries are still at the early stage of that, but they have the SEMATECH example to give confidence."

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[32]GE recently decided to pull its appliance manufacturing back to Louisville, Kentucky to re-join its research, engineering, and marketing activities. "We can produce appliance products better and cheaper in Louisville than in China," said Dr. Biller, "because we can discuss manufacturing principles and market research all in the same room."

[33]Michael Fritsch and Viktor Slavtchev, "How does industry specialization affect the efficiency of regional innovation systems?" *The Annals of Regional Science* 45(1):87-108, 2010.

[34]According to Dordick, between the years 1996 and 2006, a steep upward slope of R&D spending is mirrored almost exactly by the steep decline of new drug approvals over the same period. From 2009 to 2011, he said, fewer than 60 drugs were approved by the FDA, and the cost of approval is now close to $2 billion per drug.

The Need for Convergence

Larry Nagahara of the National Cancer Institute spoke about his own institute's attempt to promote collaboration between the physical and life sciences. He reminded the audience of the famous partnership between Salvador Luria, a microbiologist, and Max Delbruck, a physicist, in the 1940s, whose combined perspectives produced new understandings of bacterial mutations and led to their 1969 Nobel Prize in Physiology or Medicine.

More recently, the concept of "convergence" between the physical and life sciences has been articulated in a white paper by Phillip Sharp and others at MIT, who described a new generation of discoveries in biomedical science. Their suggestion is based partly on the assertions that "advances in information technology, materials, imaging, nanotechnology, optics, and quantum physics, coupled with advances in computing, modeling, and simulation, have already transformed physical science. They are now beginning to transform life science as well."[35]

Dr. Dordick of RPI suggested that the time may be ripe for more efforts to explore convergence. For example, RPI already makes a chip that mimics how the body deals with a drug, and calculates how much to apply. "We need to combine big data with nanotechnology and biotechnology for three areas," he said: "R&D combinations to improve understanding of therapeutic molecules; new visualization tools for not only the brain-computer interface but also the whole body-computer interface; and networks of sensors that are linked hospital to hospital." He offered a specific example to show how investments in microelectronics can help to develop new, collaborative biotechnology. "The expertise exists. You go to the doctor where your genetic makeup is known; the data will tell you the nature of your disease. We know how to put the molecules together, how they fit into proteins of your body. We make a drug specifically for you; maybe it's made by bacteria. You'll have your own drug within a day."

Adapting the Semiconductor Research Model for Pharma

Brian Toohey of the Semiconductor Industry Association addressed the same question: Can a collaborative research model be built for the pharma industry that is similar to those emerging in nanotech, semiconductors, and biotechnology? "The short answer," he said, "is yes." Evidence emerges from recent activities, he said, "such as the use of semiconductors in non-invasive instruments or small inserted devices." He cited breakthroughs already achieved through collaborations, including the first chemical synthesis of polio virus, chip-based high-throughput DNA synthesis, MEMS DNA synthesis, DNA

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[35]Phillip A. Sharp et al, *The Third Revolution: The Convergence of the Life Sciences, Physical Sciences, and Engineering*, Cambridge, MA: Massachusetts Institute of Technology, 2011.

"origami,"[36] the first synthesis of a bacterial genome, and DNA information storage. He also described hybrid semiconductor/biological circuits in which cellular material provides the intelligent components for electronic circuits. "The crisis," he said, "may help motivate companies to sit down and have this discussion."

Dr. Dordick agreed in principle, although warning of several "barriers" to such discussions, including the need to secure intellectual property. "We don't yet have a model for biotech like the one used by the semiconductor industry," he said. Mr. Russo of GLOBALFOUNDRIES also saw potential difficulties, but urged both sides to make the effort. "In order to move forward and innovate," he said, "it's more than risk taking, it's sometimes getting out of your comfort zone and your vested interest. Medical devices, pharma, and semiconductors can all look at possible collaboration and the benefits they can find."

Even amid signs of progress in semiconductor partnerships, however, several voices cautioned against complacency and emphasized the need to sustain the current high level of investment. Dr. Armbrust, reflecting on his long experiences with IBM in East Fishkill and with SEMATECH in Texas, pointed to likely struggles ahead. "I would caution you about complacency," he said. "We are where we are, and many people are trying to copy us and get ahead of us. It's time to double down. We have strengths, but we need to continue to invest in those strengths, so that in 10 years you'll read every day about a new startup, a new spinoff, more venture capital, and jobs. That can be our future."

IN CLOSING

This conference report provides a first-hand account of New York state's two-decade long effort to transform its Capital Region into a leading center of nanotechnology research and production. It highlights the large-scale investments in university research infrastructure and the collaborative arrangements with the private sector and regional development organizations that have altered the competitive landscape in the semiconductor industry and built a sustainable basis for the region's economic growth. This overview has highlighted many of the key issues discussed at the conference. The proceedings of the conference, summarized in the next chapter, provides rich detail of speakers' descriptions and perspectives on the policies, institutions, and initiatives underway in New York State.

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[36]The folding of DNA to create arbitrary two and three dimensional shapes at the nanoscale. Resulting models are used to explore such phenomena as self-assembly and self-destruction of drug delivery vessels. Paul W. K. Rothemund, "Folding DNA to create nanoscale shapes and patterns," *Nature* 440(7082):297-302, 2006.

II

PROCEEDINGS

DAY 1: APRIL 3, 2013

Welcome

Drew Matonak
President
Hudson Valley Community College (HVCC)

Dr. Matonak greeted the attendees to Hudson Valley Community College (HVCC), in Troy, New York, and expressed his pleasure at hosting a symposium on nanotechnology, a topic "of such significance to the Capital District and surrounding communities and businesses." He pointed out that the rapid development of nanoscience and nanotechnology in the region was a function of successful partnerships among business, education, and government, which "need to work together to make things happen. And we have great evidence that things are happening here in the capital region."

First, he said, the New York higher educational system, and particularly its community colleges, have been "workforce development assets and economic engines" for the state, and HVCC itself had been a "powerful provider of on-demand workforce training" since its creation 60 years ago. "We've partnered with local, regional, state, and international companies to learn what is required by each of them, and how we can help those companies grow. At the same time, we identify specifically what our students need to be valuable employees." He defined the mission of HVCC as working in partnership with organizations in other sectors, especially businesses, to help them meet their workforce needs.

In pursuing that mission, HVCC relies on a diverse group of advisory committee members who offer council on making sure the curriculum is relevant and current. "What is important for us," he said, "is to be able to change as the demands in our region change. To be flexible is a huge part of our mission."

Among the examples Dr. Matonak offered was the development of a semiconductor manufacturing program a dozen years ago, "before a lot of this effort we're seeing today came about." More recently, he said, the college sent several faculty members to Dresden, Germany, to learn more about the workforce needs of GLOBALFOUNDRIES, a large chip maker then owned by Advanced Micro Devices (AMD) and soon to be part of the

GLOBALFOUNDRIES company that has recently arrived in the Albany region. "What we learned by working with the folks in Dresden," he said, "was that we had some skill gaps between our program designed for the global workforce needs in our area and the specific workforce needs of GLOBALFOUNDRIES. We brought that back and our school of engineering and industrial technologies developed a specific gap certificate that ensures that students at the point of graduation are well matched with the specific workforce needs of GLOBALFOUNDRIES."

Other programs, he said, such as the advanced manufacturing program, reach for similar goals by working closely with business and industry. As a result, many students receive job offers and accept employment even before finishing their programs. Other examples are the allied health and industrial technology programs.

In 2010, HVCC applied for a National Science foundation grant to train students in biomanufacturing and biotechnology "to open a path toward these emerging fields." The school has also opened a new facility called Tech Smart to train students in the GLOBALFOUNDRIES semiconductor manufacturing program, photovoltaics, geothermal energy, and wind technology. For each of these fields the school works closely with General Electric, GLOBALFOUNDRIES, IBM, and other companies to determine and meet their workforce needs.

Dr. Matonak repeated his welcome to all attendees, and invited them to tour the HVCC campus to see school programs in action. "The real magic happens in our classrooms," he said, adding that the school was finishing construction of a new science center just to the south of the meeting site that would provide "state-of-the-art facilities."

He then introduced the Hon. Paul Tonko, Representative for the 20th Congressional District, whom he characterized as "a strong and vocal advocate for higher education, especially in fields of science and technology that are vital to the continued growth and economic development of our region."

Introductory Remarks

The Honorable Paul Tonko
U.S. House of Representatives

Representative Tonko repeated Dr. Matonak's welcome of the participants and thanked them "for recognizing this region" as a place he characterized as "one of the hottest hubs in the country, if not in the world, for clean energy, innovation, and job growth." He said that the region is "truly a collaborative at work," and said that his service on the House Energy and Commerce Committee was a "perfect fit" for the district, with its rapidly growing reputation as an innovation leader. "It's important for us to tailor public policy with the work we are doing here and the challenges that present themselves in a very welcoming fashion." He noted that *Forbes* magazine in 2012 had ranked the Capital District of New York fourth on its list of best cities for jobs, praised its commitment to a green economy, and stated that no other region had more workers employed in "fields with environmental benefits."[1] He also said that a Brookings Institution report had ranked the Albany metro region first in the nation in its share of clean-economy jobs.[2] "These accolades should not come as a surprise to those of us who have lived here for many years and understand that our workforce, our schools, and colleges, especially our community colleges, are key ingredients to the success that we now taste."

He also noted that President Obama had visited the region three times since September 2009, and said that the Administration "recognizes the incredible clustering and collaboration here resulting from unique partnerships between the private sector, New York State government, and the higher education community. Nowhere else in the country and perhaps in the world," he continued, "have we seen such seamless integration between cutting-edge research, private investment, and government-inspired job creation." The President discussed those themes at HVCC in September, 2009, at General

[1]Daniel Fisher, "Washington, Des Moines best cities for Jobs," *Forbes* February 27, 2012.
[2]Mark Muro, Jonathan Rothwell, and Devashree Saha, *Sizing the Clean Economy: A National and Regional Green Jobs Assessment,* Washington, DC: The Brookings Institution, 2010.

Electric in Schenectady in February, 2011, and at SUNY's College of Nanoscale Science and Engineering in May 2012.

ATTRACTING MORE JOBS, EQUIPPING MORE PEOPLE WITH SKILLS

Rep. Tonko also quoted the State of the Union message of 2013, when the President said, "A growing economy that creates good middle-class jobs: that must be the North Star that guides our efforts. Every day we should ask ourselves three questions as a nation: How do we attract more jobs to our shores, how do we equip our people with the skills needed to do these jobs, and how do we make sure that hard work leads to a decent living." He also discussed the country's new initiatives in advanced manufacturing, biomedical research, clean energy, and updating the aging infrastructure. Rep. Tonko said that the Albany region "will be a contender in any of these fields," and that the region had a track record of success through a new model of collaboration "that is second to none." The challenge, he said, was to "continue to leverage our assets and to maintain our competitive edge over the next 10, 25, and 50 years."

This record of success had been built on a few key elements, he said, including "our people, and our workforce, as well as our educational institutions." These were "the best foundation for which we could ask." From that foundation, he said, the region had developed a model for building upon clusters of industry and research, which included a shared vision and open dialogue across industry, government, and higher education. He attributed much of the credit to the Center for Economic Growth (CEG), and its director Michael Tucker, "for serving as facilitator of that dialogue." He also extended praise to "dozens of individuals who work tirelessly toward achieving a common vision, many times sacrificing their own success or recognition for that greater effort." To maintain our competitive edge for the long term, he added, "we must keep that sense of humility. Our achievements cannot be sustained or built upon without these co-equal partnerships. Success inevitably brings competition, and we must confront this with a continued laser-sharp focus on preparing our region for the opportunities of tomorrow."

He said that the success of the region "did not happen overnight or in a vacuum," but was the result of many years of careful planning and investment by the private sector, higher education, and state government—led by the administrations of three different Governors and the State Assembly—which promoted the initial investments in a then-little-known field of nanotechnology. Having served in the state assembly for nearly 25 years, he praised Speaker Sheldon Silver's large role in promoting technological development.

"Having this high level of investment and potential for great growth is a great feeling," he said, "and I do want to credit the State Assembly for the role it played. New York State led the way in promoting and encouraging grass-roots technology investments, versus a more traditional, trickle-down approach of depending on the federal government."

Rep. Tonko also saw parallels between President Obama's "laser-sharp focus" on strengthening technological innovation in the country and President Kennedy's response to the "embarrassing Sputnik moment" of the 1950s. "We dusted off our backsides and said never again. And through the leadership of a president, this country came together with passionate resolve. We need to have that passion again today. The President is calling upon us to enter in with a sort of reverence for training so we can win this race and stay a kingpin of the international economy. As a region, we can't afford to be complacent. If we are to retain our competitive edge in this international sweepstakes for jobs, innovation, and investment, we have to win, not simply be listed as a participant. And having a competitive edge means research."

He recalled the role of his region even farther back in history, when New York was a "donor state to the westward movement, the Industrial Revolution of ages past." New Yorkers then were proud participants in that movement, he said, inspiring great progress, academic prowess, and creative ingenuity. He recalled the blue-collar workers of the Erie Canal, the capacity for work as "part of our DNA," the evolution of a "little town, New York City," that became a huge metropolitan area, just as the banks of the canal gave birth to a "necklace of communities, dubbed mill towns," that became the epicenters of invention and innovation.

"So we know what research, investment, and worker strength mean to success," he said, "and the growth that is tethered to reality. So let's make it happen with a competitive design that embraces research, that inspires additional sophistication, solutions, and good-paying jobs. A sophisticated society such as ours is challenged with this moment not to fall back but look forward to the sense of product discovery and product delivery that only a sophisticated nation can accomplish."

WORLD LEADERSHIP BEGINS WITH INVESTMENT

To be world leaders, he said, begins with investment. "I don't want to hear about cuts to research, cuts to innovation. It is deplorable how that environment grips our nation's capital. This President is calling for a plan of action; this country deserves nothing less." This plan requires a workforce that can attract and sustain the industries of the future, he said. "And we must remember that we do not compensate our workforce by a race to the bottom, but by competitive wages." He said that international companies no longer make labor costs the driving factor in locating their business. Much more important, he said, is proximity to higher education and research institutions, especially in the form of a technology cluster like the Capital District.

In terms of workforce development, he said, a sound education must begin at an early age. He said that he had helped to create the region's Tech Valley High School to provide opportunities for science- and technology-minded students, and that the legislation was supported by both Houses, working with the governor. He also commended GLOBALFOUNDRIES for its

efforts in local workforce development. This included the Tech Valley Connection for Education and Jobs, led by GLOBALFOUNDRIES and CEG to develop "the workforce of tomorrow through government, industry, and educational collaboration." The CEO of GLOBALFOUNDRIES, Ajit Manocha, he said, was "someone who recognizes the value of the local workforce and who has worked hard to not only hire local workers but to encourage the Tech Valley Connection to develop a pipeline of talent."

Rep. Tonko closed by noting that his colleagues in Washington are envious of the President's three visits to the Capital District, and of its "growing sophistication in this competitive sweepstakes." He predicted "tremendous opportunities for Tech Valley to embrace exciting initiatives that lie just around the corner," and urged continued participation "from top to bottom." The achievements so far, he emphasized, "belonged to the people of Tech Valley, New York," including New York's state and local governments.

"Our state government recognized the value of this cluster of business and research, and invested in higher education in Tech Valley." He singled out the research universities, including Rensselaer Polytechnic Institute (RPI), the nation's oldest technological research university, the State University of New York (SUNY), and the College of Nanoscale Science and Engineering, which had "broken new ground in what an institution of higher education could do," as well as the strong network of Hudson Valley, Schenectady, and Fulton-Montgomery Community Colleges. The academic sector was complemented by a growing technological private sector, led by both international-scale organizations, including IBM, GLOBALFOUNDRIES, SEMATECH, and GE, and scores of small startups, such as Ecovative Designs.

Most importantly, he concluded, "our people are Tech Valley. We are Tech Valley, and we will continue to be, and this is why it will continue to grow stronger from top to bottom."

DISCUSSION

Dr. Wessner thanked the Congressman for his inspiring talk, Dr. Matonak for hosting the symposium, Mr. Russo of GLOBALFOUNDRIES for co-organizing the conference, and all the participants. He introduced the keynote speaker, Ajit Manocha of GLOBALFOUNDRIES, by reviewing the purpose of the symposium. In part, he said, it was an effort to understand not only what other countries are doing by way of innovation, but also various regions of the country. One survey of the innovation strategy, he said, had just been released by the National Academies: *Rising to the Challenge: U.S. Innovation Policy for the 21st Century.* The report described innovation activities in many countries, including China, Germany, Singapore, and Belgium, as well as those in more than half a dozen regions of the United States. The Capital District of New York was chosen to conclude the series of regional studies, he said, because of both its success and its lessons for other regions.

He characterized Dr. Manocha as one driver of that success, and "one of leading CEOs in the U.S." who had been named by *EE Times* to its Top 40 Innovators list.[3] Dr. Manocha, he said, had successfully navigated the challenges of growing a major company "despite incredibly fierce competitors" who often have significant government support. The success of GLOBALFOUNDRIES, he said, had significant implications not only for the region's economic development but also for U.S. economic competitiveness and national security.

[3] <*http://www.eetimes.com/*>.

Keynote Address

Ajit Manocha
CEO
GLOBALFOUNDRIES

In his introduction, Dr. Manocha thanked Dr. Matonak of Hudson Valley Community College for being a "great partner and ally of GLOBALFOUNDRIES" and for "bringing the education, infrastructure, and research to prepare people for the countless jobs that GLOBALFOUNDRIES is creating. Without this kind of flexible program we would not be starting all this."

He also thanked Gov. Andrew Cuomo for his consistent leadership in supporting the public-private partnership and for "driving the state agenda for high-tech manufacturing and innovation."

He began with an update on Fab 8, the GLOBALFOUNDRIES building where ground was broken in 2009. "We have come from basically forest land to the most advanced wafer fab in the world today."[4] He said that an indication of the fab's importance is that he is often recognized by cab drivers when returning from the airport.

Dr. Manocha said that while "building a fab is easy if you have money," the real key to a state-of-the-art fab is leadership in technology, and that GLOBALFOUNDRIES had become the "champion of the most advanced technology." The company had begun operation in December 2011 by producing 32 nanometer (nm) [5]silicon-on-insulator technology for IBM, with which it has a close working relationship. Within a year it had launched 48 nm, 40 nm, and 14 nm technology as well. He noted that chip features as small as 14

[4]GLOBALFOUNDRIES, since breaking ground for Fab 8 in 2009, has quickly climbed into a leadership position among the top dozen semiconductor manufacturers in the world. It is now second only to industry leader Taiwan Semiconductor Manufacturing Company. Source: Gartner Group, 2013.

[5]A nanometer is a billionth of a meter, from the Greek *nanos,* dwarf, and *metron,* unit of measurement.

nm are very difficult to realize, comparing it for illustration with the width of an average human hair, which is about 75,000 nanometers.

This ability, he continued, is a result of not only GLOBALFOUNDRIES' expertise, but also its close relationships with IBM, CNSE, RPI, the community colleges, and other partners. "This is called a true partnership," he said, "and because of it we have been extremely successful."

He also said that Tech Valley itself is effectively a partnership for promoting economic growth, as is the Tech Valley Connection for Education and Jobs, launched by GLOBALFOUNDRIES. "Tech Valley Connection," he said, "is driving President Obama's agenda about developing the workforce and skill sets of people, and driving advanced manufacturing in this country."

Dr. Manocha reviewed current plans for expanding the GLOBALFOUNDRIES facility in Malta. Two months previously the company had announced plans for a new research facility called the Technology Development Center on the Fab 8 campus adjacent to the fab itself. The purpose of this $2 billion investment, he said, was to drive the specific research and development programs relevant to the work of the fab. "That's the proof point for us to drive innovation," he said, "and the proof point that we are committed to this business for a long time to come." To audience applause, he said that "$2 billion is not a small amount," and that the new investment is expected by the end of next year to create an additional 1,000 jobs inside the Fab 8 campus, along with 5,000 more indirect jobs in the region.

CREATING NEW JOBS IN MALTA, NEW YORK

Creating these new jobs in Malta, he argued, both "stresses" the education system and enhances it at all levels, from K-12 to continuing ed. The Tech Valley Connection for Education and Jobs (TVCEJ) connects all training levels, developing and improving the skills to support the "high-level, high-quality manufacturing jobs we need in this country."

A benefit of this strategy, he said, "is that we are now awake. Thirty years ago, I don't know how it happened, we started shipping all those jobs to overseas. The time has come that we are reversing that trend. We're bringing the pride back into this nation. The pride of advanced manufacturing and innovation." We know that research and innovation fuels GDP growth, he continued, but that growth has faded in recent years.[6] He expressed confidence that GDP growth would return. GLOBALFOUNDRIES itself, he said, is "driving GDP growth by supporting advanced manufacturing," producing products not only for the semiconductor industry, but for many sectors, including mobility, automotive, medical science, consumer products, and industrial applications.

[6]For the first time, exports of high-technology exports began to decline more than a decade ago, and have not yet recovered.

At the same time, he said, the State of New York is becoming a role model for other states in demonstrating the economic impact of manufacturing. The 2,000 jobs in Fab 8, he said, supported an annual payroll of about $300 million, or, assuming a total of five indirect jobs for every one direct job, a total payroll of over $1 billion. The new Technology Development Center (TDC), estimated to cost about $2.2 billion, is schedule to raise those totals to 3,000 direct jobs and 15,000 total jobs for a payroll of "a couple of billion dollars, great for the State of New York." Also, he said, new techniques of stacking chips vertically using through-silicon vias, or TSVs, is likely to lead to new technologies that drive mobile and consumer applications. [7]

The purpose of locating the TDC next to Fab 8, he said, is to make possible a true "lab-to-fab" relationship, with new technologies from the lab immediately testable in the fab, and new observations from the fab easily researched in the lab. This close relationship is not possible for a fab that is located in a different country state from the research facilities. "Having the TDC right there," he said, "helps with time to market and time to value. That's another way of driving competitiveness in this country, and competing with countries that got the benefit when we shipped jobs overseas. We're bringing that back."

GLOBALFOUNDRIES AND THE STRATEGIC AGENDA

Dr. Manocha emphasized the close linkage between the mission of GLOBALFOUNDRIES and the strategic agenda of the United States. "Ever since I became CEO of this company," he said, "and had the opportunity to meet President Obama and visit the White House, I have listened very carefully to the national agenda. When I come back and talk to my team, I can tell them that everything we are doing supports that, whether through creating jobs, growth, innovation, economic security, or national security. I can give example after example where we are doing that."

He emphasized the importance of the silicon industry itself to the national agenda. It has "changed our lives," he said, in sector after sector. To illustrate, he asked his audience if anyone in the room did not have a smart phone with them, and saw no hands. "You feel weird without your phone," he said. "When I was at Bell Labs, I would carry hundreds of pages of paper home in my briefcase every night, stuffed full. Now people carry just an iPad or maybe smart phone. Productivity has gone up. Silicon has changed the way we live and work, the way we interact with others. In my opinion this is the most strategic industry on the planet," he said, "and we are fortunate to be part of it."

[7] A 3-D package stacks various chips vertically and connects them by deploying through-silicon vias (TSVs). The aim is to shorten the interconnections between the chips, reduce die sizes, and boost device bandwidths. TSV chips are expected to extend Moore's law and bring out a new wave of products that are smaller, more energy-efficient, and more powerful. Mark Lepedus, "What's the cost of 3-D stacking?" *ee times* December 2010.

He thanked members of the audience who helped "provide all the innovation required to grow this industry," and promised his commitment to help grow GLOBALFOUNDRIES in Malta, New York, and to support public-private partnerships that include community colleges, universities, IBM, CNSE, GE, and others. "And for the next two days," he concluded, "I'm counting on everyone here to work together, because what we learn from one another will further enhance our program and serve this nation."

Panel I

INNOVATION AND GROWTH: REGIONAL, NATIONAL, AND INTERNATIONAL DIMENSIONS

Moderator:
Jason Miller
Special Assistant to the President for Manufacturing Policy
National Economic Council
The White House

Mr. Miller introduced the panel by saying the "the game is changing, there are new models, and the one in this region is incredibly exciting. It is involving companies, the higher education system, and local and state government in a compelling way. You may be driving something that is unique around the world."

He said that while dialogue in Washington is often dominated by budgets, "we forget that the purpose of those discussions should be to set priorities and direct investments in productive directions. Those priorities in many ways establish the long-term foundation for our growth and competitiveness."

Within the White House, he said, discussion at the National Economic Council often includes three topics that should be occurring simultaneously. While some consider them to be in conflict, he said, this is "absolutely not true." The first is "doing everything we can to strengthen the recovery. We've seen a lot of positive momentum over the last several years, but there's more that needs to be done." The second is to address long-term debt "in a balanced way." A number of important steps have already been taken, he said, but the approach needs to be more balanced and cannot take away from public investments in long-term growth. The third is to invest for the future—in education, research and development, and physical infrastructure. "These are the building blocks for our economic growth."

Investments in such public goods, he said, do not take place in a vacuum, and the White House National Economic Council increasingly discusses the connection between public funding and promoting more private

investments that stick and "self-reinforce." A key component in investing in public goods is active collaboration of the kind that has occurred in the Albany region.

During such discussions, he continued, the President has put special emphasis on manufacturing and the role it plays in an innovation economy. Among the reasons for this, said Mr. Miller, is that our ability to make things is closely linked to our ability to innovate. "If we lose the ability to make things," he said, "we should be afraid that we will lose that ability to innovate."

Mr. Miller cited several reasons why the President had visited the Albany region. They included the region's ability to make meaningful investments in education and technology, and the vibrant role of both state and local governments in doing so. One result, he said, was the massive installation of GLOBALFOUNDRIES just north of the city. "This really is an important hub for innovation," he said. "We in the Administration want to learn from this kind of success, and identify appropriate roles for the federal government as a partner. We've put forward proposals for ways it can spur regional economic development."

In closing, Mr. Miller noted that what is most important in building a technology cluster such as Albany's is that multiple actors join in solving challenges. "I am talking about government at all levels, the private sector, the academic institutions, and the non-profit organizations. This will be important in shaping our discussion over the next two days."

THE GLOBAL INNOVATION IMPERATIVE

Charles Wessner
Director, Technology, Innovation, and Entrepreneurship
The National Academies

Dr. Wessner began by expressing his gratitude to those who had gathered to participate in this symposium. He said he would place his talk in the context of several "current global mega-challenges, most of which were being addressed in the Albany region." The first is to foster economic growth through innovation, which is a driver of domestic growth and employment. The second is to develop new sources of energy, including the commercialization of renewable alternatives to oil and increasing the capacity to meet the rapidly growing global demand for electricity. The third calls for a greener economy based on nanotechnologies and other advanced technologies to address the challenge of climate change. The fourth challenge is to improve global health, which requires the transformation of large investments in research into affordable and personalized care. Finally, strengthening national security calls for new technologies, some of which are likely to grow in parallel to innovations developed for the preceding challenges.

He emphasized the unexpected outcomes of many new technologies, including the recently tapped potential for shale gas extraction. While the United

States has been criticized for not signing the Kyoto Protocol on climate, the increased use of shale gas could mean that the United States can reduce carbon emissions more rapidly than many signatory nations, while drawing on more secure domestic supplies of energy.

Tilting the Playing Field

"What you are doing in Albany," he said, "requires innovative policies and institutions, and we need to learn how to innovate better across the country. We often hear that on a level playing field, American workers can out-compete their counterparts, but there are two things wrong with that message. First, there is no level playing field; the rest of the world is tilting it in their favor as far as they can. And second, not all American workers are getting the training they need to prepare themselves for high technology manufacturing jobs. We are proud that BMW is making cars in South Carolina, but not proud that they have to make special efforts to train American workers."

By contrast, other countries are investing directly in the innovation challenge. They are providing abundant and sustained support in five key areas:

- A high-level policy focus on growth and strength.
- Sustained support for universities.
- Rapidly growing funding for research.
- Support for innovative small business.
- Government-industry partnerships to bring new products and services to market.

In addition to spurring new startups, he said, many countries invest substantial resources to create, attract, and retain industries of today as well as of tomorrow. To compete globally, the United States must continue to support semiconductor research and investment. It is not a "legacy" technology as some think, but one with huge new opportunities. At the same time, these investments build support for the new technologies with new applications, such as in medicine, where the National Cancer Institute is doing very promising work.

He cited China as both a challenge and a lesson. The government has publically set the goal of becoming an "innovation-driven economy" by 2020. China's strategy includes boosting R&D investments, with a doubling of basic research expenditures between 2004 and 2008 and tax incentives for R&D enterprises; building R&D infrastructure and facilities; developing more world-class universities; building innovation clusters through the development of large S&T parks; and acquiring technologies and talent from abroad.

Singapore, a tiny nation, has also become a global innovation leader, following its goal of becoming Asia's pre-eminent financial and high-tech hub. The government is investing $12.8 billion under the Research, Innovation, and Enterprise 2015 plan. The task of its Agency for Science, Technology, and

Research, A*STAR, which has some $5 billion in funding, is to attract a skilled R&D workforce, draw major investments in pharmaceuticals and medical technology production, invest in S&T parks—notably Biopolis and Fusionopolis—and focus on funding for early-stage firms. For a nation whose per capita GDP in the 1960s was about $350 per year, these achievements and bold planning are remarkable.

For Germany, High-wage But Competitive

The good examples, Dr. Wessner noted, are not all in East Asia. Germany, for example, is a high-wage, highly regulated, highly unionized economy that nonetheless competes well with China and other low-wage countries in a variety of high value products. It does so with its own version of an innovation ecosystem, investing substantial amounts in education and research through both federal and state governments. Its new High-Tech Strategy 2020 seeks to create lead markets in Germany, intensify cooperation between science and industry, improve the framework conditions for innovations, and maintain the country's well-established focus on manufacturing.

Among the factors behind Germany's manufacturing success are government support for traditional industries, especially automobiles, machines, and chemicals; a focus on niche markets for high-value products; continuous vocational training for workers; stable access to finance for manufacturing firms, often through local banks; support for applied research in cooperation with both large and small companies; and well-funded export promotion programs.[8]

Institutionally, Germany's best-known force for innovation is the Fraunhofer Institutes, a stable and well-organized system of 60 research institutions employing some 18,000 scientists, engineers, and technicians. The Fraunhofers benefit from sustained and substantial investment of $2.5 billion per year, consisting of state and federal contributions (about 80 percent in aggregate) and industry fees for contract research projects. They focus on the practical steps of applied research, making incremental improvements to products with a market orientation. The Institutes also help build the country's skilled workforce by closely engaging with industry and allowing students to absorb practical as well as theoretical skills.

One result of German strategies and programs is its leadership in exports. The growth of Germany's exports to China—considered to be a global

[8]Susan Helper et al, "Why Does Manufacturing Matter?" Washington, DC: The Brookings Institution, 2012.

leader in exports itself—has soared in the past decade, far exceeding exports to any other market.[9]

Numerous U.S. Strengths

Dr. Wessner acknowledged numerous U.S. strengths, calling them "very real." A traditional pillar of the innovation system continues to be the U.S. research universities, with some having a culture of innovation and commercialization, and many strengthened by top-flight talent attracted from the United States and around the world. He also praised strong private-sector R&D activity, which he called "the envy of the world," and the "sustained and substantial" federal support for basic research. The country also benefits from technology-based entrepreneurship, which is nourished both by public-private partnerships, a strong venture capital industry, and a legal climate that encourages small-firm formation.

U.S. leadership in innovation is supported by investments in R&D estimated at $1,496 billion in 2013that make up more than a quarter of total global spending on R&D.[10] However, by far the largest portion of this spending is allocated to the Department of Defense, which receives about 50 percent, or $72 billion; the National Institutes of Health receives $31.4 billion, which accounts for nearly a quarter of the total; and the Department of Energy, which receives $11.9 billion. The rest is divided in much smaller amounts among all the other agencies.[11]

While the DoD share of R&D spending does support important basic and applied research, that portion has fallen in recent years. One consequence of this trend is that about 90 percent of the DoD's R&D budget is used to support weapons systems development.[12] The result is that the nation spends far less on basic and applied research than the overall spending total would suggest.[13]

In addition, he said, the growth in R&D spending in the United States is low compared to that of competing nations. The United States' national R&D intensity grew about 10.4 percent between 1995 and 2008, compared with 20.5 percent in Germany, 26.2 percent in Japan, 42.2 percent in Korea, 135.1 percent in Singapore, and 170.2 percent in China.[14] He also noted a steadily declining

[9]According to *Financial Times* (April 20, 2012), "Germany's economic fortunes have become linked to China's; exports to the country were worth E65 billion last year, more than double the 2007 level."
[10]Battelle and R&D Magazine, *2013 Global R&D Funding Forecast*, December 2012.
[11]Sources: OMB R&D data, agency budget justifications, and other agency documents. R&D includes conduct of R&D and R&D facilities. AAAS 2012.
[12]Sources: OMB R&D data, agency budget justifications, and agency budget documents; Defense R&D = DoD + DoE defense. AAAS 2011.
[13]By one estimate, DoD spends only about $10 billion on basic and applied research, most of it for information and communications technology. Anthony J. Tether, Director of Defense Advanced Research Projects Agency, 2001-2009; personal communication.
[14]Gregory Tassey (2011) and OECD S&T Indicators 2010.

ratio of federal R&D spending to gross domestic product from the mid-1960s to the present.[15]

Risks to Future Growth

"A major risk we have, looking at this low growth," said Dr. Wessner, "is complacency at the national level." He also suggested there is "real danger of complacency" in the Albany region as well. "You have gone around the first lap in the race really well. But it is just the first lap. You also have to make sure you have the support from Washington that you need as you go forward, because you are now playing in the tall grass with the big animals," meaning that many countries seek to host semiconductor production and research and are willing to spend heavily to attract it. He, like several others at the conference, emphasized that the fortunes of even the most successful industries can decline quickly in response to unfavorable public policies and emphasized the ongoing competition for semiconductor share from major technological firms in Taiwan, China, Germany, Singapore, and Korea. And he reminded his audience how quickly even a country as advanced as Japan could—and has—fallen behind in its share of the industry after many years of leadership.

Dr. Wessner continued with a warning about the U.S. focus on current consumption rather than investment for the future. "We are investing less in the front end," he said. "We are no longer investing in R&D on the scale of our fathers—or our competitors. Per-student funding for major public research universities has dropped by 20 percent during the past decade.[16] At the same time, U.S. research universities face a growing regulatory burden.[17] These developments are jeopardizing the health of the nation's research universities, a principal pillar of the U.S. innovation system."

He remarked on the impact of the budget sequester ordered by Congress, whose first-year impacts are estimated by the American Association for the Advancement of Science as a $12.1 billion reduction in federal FY2013 R&D funding. This includes about $1.6 billion the NIH expects to lose, and a reduction of about 1,000 of the 11,000 grants usually awarded by the NSF. Also, some universities are admitting fewer graduate students this year because of the fiscal uncertainty.[18]

He cited the judgment of Gordon Moore, co-founder of Intel, about times of uncertainty. "When the market is down," he said, "you don't have

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[15]National Science Board, *Science and Engineering Indicators 2012*, Arlington, VA: National Science Foundation, 2012.
[16]National Science Board, *Trends and Challenges for Public Research Universities,* Arlington, VA: National Science Foundation, 2012.
[17]National Research Council, *Research Universities and the Future of America: Ten Breakthrough Actions Vital to Our Nation's Prosperity and Security,* Washington, DC: The National Academies Press, 2012.
[18]"Sequester Cuts University Research Funds," *Washington Post* March 17, 2013.

revenue, stockholders are upset, and the board is uncertain. That's the time you have to invest in new technologies. You never get healthy on the old technologies; you have to invest your way out of a downturn." The primary concern about the sequester, he said, is that it will cause a "long-term resetting of federal funding at a lower baseline," which will have a negative impact on U.S. competitiveness.

Invented Here, But Manufactured There

Dr. Wessner turned to the state of manufacturing. As the manufacturing sector shrinks, the nation has less ability to capture the value of its investments in research. Manufacturing supports an estimated 18.6 million jobs in the United States, about one in six private-sector jobs. It also dominates the U.S innovation system, accounting for 70 percent of industrial R&D, 80 percent of patents, and 64 percent of employed scientists and engineers.[19] "In years past," he said, "if we invented it here, we usually produced it here. But we have seen a whole set of technologies, such as liquid crystal displays, that were invented and developed here, but then moved offshore lock, stock, and barrel."

He said he often heard that the importance of manufacturing to the country had decreased with the rise of service-sector jobs, but he argued that manufacturing is an essential element in U.S. national security, promoting growth, competitiveness and trade. The manufacturing sector fosters economic growth by producing some $1.7 trillion in value annually. It improves competitiveness and expands trade by providing goods for export, and the currency earnings to maintain national economic independence.

He reviewed several causes for the flight of manufacturing overseas. The first is the decline of vertically integrated industries. Many of the great new American companies of the past 30 years, such as Dell, Cisco, Apple, and Qualcomm, perform little or no manufacturing in-house. A second is the increased focus on "core competence," as the stock market assigns higher value to leaner, "asset-light" companies. This encourages outsourcing and offshore manufacturing.[20] Finally, the rapid growth of skills, R&D, and government support in countries overseas has created substantial manufacturing capabilities in other countries.[21] Results include declines in the U.S. trade balance for all manufactured products over the past decade, with steep declines for all manufactured products and, for the first time, over the last few years, we see a decline in export of advanced technology products.

[19]National Association of Manufacturers, 2009.
[20]Suzanne Berger et al, *Production in the Innovation Economy,* Cambridge, MA: Massachusetts Institute of Technology, 2013.
[21]National Research Council, *Rising to the Challenge: U.S. Innovation Policy for the Global Economy,* C. Wessner and A. Wm. Wolff, eds, 2012.

The Close Link Between Innovation and Manufacturing

What makes this an issue, he said, for both the country and the Albany region, is that manufacturing is closely linked to innovation. Anchoring more production onshore brings more high-paying jobs, more applied research geared to industrial needs, local production and local learning, a healthy and reliable supply chain, and synergies for further innovation. Thus research, training, expertise, supply chain, and tax revenues are all linked to a dynamic manufacturing base. In the view of Suzanne Berger of MIT, "The loss of companies that can make things will end up in the loss of research that can invent them."[22]

The same issues apply to New York at the state and regional levels, he said, turning to "some of the huge accomplishments you've made, including the public-private partnerships, new institutions, and state-of-the-art research labs." He assigned much of the credit to "inspired leadership at multiple levels, including an enthusiastic governor, state assembly, and community." He praised the shared investments in facilities, including the joint investment by the state and IBM in the world's only university-based 300mm semiconductor wafer fabrication facilities and clean room, which has attracted both SEMATECH and other microelectronics firms to Albany. He also recognized the unique College of Nanoscale Sciences and Engineering (CNSE), founded in 2004 as part of SUNY to train a nanotechnology workforce at bachelor's, master's, and PhD levels. He also noted the bipartisan support that provided essential funding, entrepreneurial leadership, inward investments for the supply chain, and the major effort to attract GLOBALFOUNDRIES, with its massive investments.

In return for this leadership and investment, New York already benefits from several kinds of payoffs. It is already recognized as a center in the key enabling industry of semiconductors. Its growing innovation cluster has drawn billions of dollars' worth of investments from large companies, including IBM, GLOBALFOUNDRIES, Samsung, and Tokyo Electron. And economic activity and high-value jobs are moving to New York State, including some 2,500 at SUNY Albany, 2,000 at GLOBALFOUNDRIES, and new economic activities in downtown Albany, Schenectady, and Troy.

Dr. Wessner applauded in particular the ability of the cluster to attract an entire supply chain. Equipment and materials suppliers, he pointed out, are moving to New York because they need to be in close proximity to the design, research, and manufacturing activities already there.

At the same time, he said that the future health of this and other innovation clusters would depend on addressing key public priorities. The first is to raise and sustain federal support for R&D, reversing the long-term downward trend of federal spending on basic research as a percentage of GDP. The second is to reverse the severe cutbacks in university support by state governments.

[22]Susanne Berger et al, *op cit*.

These cuts risk placing the United States at a severe disadvantage to international competitors, who are expanding and upgrading their own university systems. Third, all actors in the innovation ecosystem must support public-private collaboration to capture greater value from investments in research. This includes strengthening university links to industry, more partnerships to facilitate learning, developing clusters, and expanding support for innovations in manufacturing to help overcome low-wage competition. Fourth, both state and federal governments must improve the competitiveness of the tax and regulatory environments, ensuring that both support corporate investment and maximize competitive advantage.

Finally, he said, he is concerned that the United States does not pay enough attention to what the rest of the world is doing. "I can't imagine any high school football team going out to play on a Friday night without having seen films of the other team playing. We don't really understand how Singapore, or Korea, or China plays this game, and they are playing to win."

Dr. Wessner closed by extending this challenge into future. "We need to know what the world is doing, and we need to cooperate with both our friends and our competitors out there at the same time we are competing ferociously. What's at stake is not only jobs and security for today, but also the future of our children. Can they find rewarding employment, can they have a better life than we have, and can they be safe in their homes? This is more than a casual conversation, it is a discussion of the future of the region and the country."

THE U.S. INNOVATION STRATEGY: THE NIST CONTRIBUTION

Phillip Singerman
Associate Director for Innovation and Industry Services
National Institute of Standards and Technology (NIST)

Dr. Singerman said that he had worked for 30 years work in public economic development, state and local organizations, and two previous assignments in the federal government. "What I want to share," he said, "is my sense of how the administration's policy on manufacturing has evolved over the last four years. I think that can be instructive because it gives some coherence to what we're seeing and perhaps some optimism about the federal response."

He laid out four major themes: innovation as a driver of economic activity, manufacturing as a key enabler of innovation, the recognition that geography matters, and the recognition that cooperation matters at both the federal and regional levels.

A Direct Connection Between Basic Science and Future Value

Innovation, he began, has been a consistent theme of the administration since 2009. Early policy statements of the National Economic Council, Office of Management and Budget, and Office of Science and Technology Policy—

oversight agencies that address science and technology policy—revealed a common theme of collaboration. For example, these agencies issued joint papers, which was rarely done by turf-conscious organizations. "That is something I don't recall during my first tenure in the federal government [during the Clinton Administration]," he said. "Those statements set forth the argument that R&D is a driver of economic development, that there is a direct connection between basic science and new inventions that might yield something valuable in the future. This insight was reflected in strong and consistent administration support for increases in budgets for science and technology, and these were supported by Congress." The America Competes Act of 2007, for example, proposed doubling the budget for the physical sciences and engineering agencies, including the Department of Energy's Office of Science, NIST, and the National Science Foundation. This was part of an effort to rebalance federal investments in R&D, which had strongly emphasized biotechnology, life science, and defense electronics while neglecting the "hard" sciences. "Part of the Act was an attempt to put more money into activities that support manufacturing," he said. "There was strong recognition that innovation matters and is driven by R&D."

Why Manufacturing Matters

This realization, Dr. Singerman said, was followed by a second one in the last several years that "manufacturing matters"—because of its connections to innovation, jobs, the defense industrial base, and the need to restore our trade balance through revived exports of advanced technology products. "The driver that connected this recognition to our innovation agenda," he said, "was the notion that without a strong manufacturing base, you cannot have a strong innovation ecosystem."

The recognition of the importance of manufacturing in the innovation ecosystem has been reflected in high-level administration policy. Manufacturing was the major theme of the State of the Union message in 2012, he said, where it was mentioned more than a dozen times. "That was quite unprecedented," he said. Start with "Manufacturing is both a lagging and a leading indicator—lagging because it reflected the high-level policy consensus within the administration and agencies, and leading because it predicted new programs that would be rolled out over the succeeding three years. One of these, he said, was a billion-dollar program announced in 2012 to create a National Network of Manufacturing Innovation (NNMI) Institutes. "That is a reflection of its importance," he said. "A billion dollars is a reasonable amount of new money for a new concept."

Technology, he added, is just one aspect of the government's multi-layered approach toward manufacturing policy and competitiveness. Trade issues, tax and regulatory policies, and workforce development are also "crucially important." Important lessons were learned in all these areas during the semiconductor industry's resurgence in the early 1990s. "The approach by

both government and industry was not solely a technology approach. It included strong enforcement of trade policy, as well as tax policies that facilitated research in the semiconductor industry."

Dr. Singerman referred to Dr. Wessner's admonition that policy makers need to be informed by what competitors are doing worldwide. "The NNMI is helping us do that," he said. "We were strongly influenced by the Fraunhofer institutes in Germany, as well as other models, especially in Southeast Asia. These are conscious, strategic, systematic investments in networks of research institutes that are rooted in local communities but have a national capability."

There are also domestic models, he said, beginning with the former Bell Laboratories. He said that Patrick Gallagher, director of NIST, describes a "missing Bell Labs problem, a 'missing middle,'" a free-ranging R&D component of vertically integrated organizations that were broken up 30 years ago because they were deemed monopolistic. "We lost that spectrum of R&D, and we're trying to put it back together through public-private partnerships, leveraging private investments with simulative public investments."

Why Geography Matters

Dr. Singerman turned to his third theme, that "geography matters, the recognition that where you build a manufacturing facility is significant. For a long time we had the notion that you could design a product here and build it there. That confused the notion of invention with innovation. Innovation is the full spectrum of development, from the very early stages to product development and commoditization of products. Invention is the very early stage, and we've come to realize that invention by itself is not enough."

The framework developed for the NNMI programs, he said, includes the understanding that innovation is a function of a complex ecosystem. The country has many research institutes, for example, but they must be embedded in regional clusters that have complementary assets in workforce training by community colleges; access to small and mid-sized manufacturing firms, assisted by the Manufacturing Extension Program; and regional and state programs that stimulate seed funding. Without this ecosystem, he said, "we're unable to capture the full value of our R&D investment. The investment needs to be deployed worldwide through corporations able to take advantage of it. This is how we can level the playing field to capture the full value of our technological assets."

Why Collaboration Matters

The fourth concept, he said, is collaboration, generated at both federal and regional levels. When the President announced the NNMI in 2012, he said he would launch a pilot program in "additive manufacturing" as a model for the NNMI institutes. In August 2012, the DoD awarded $30 million for additive manufacturing to a tri-state consortium consisting of Ohio, Pennsylvania, and

West Virginia, which included 3D printing. It was supported by three agencies—DoD, NASA, and NIST—and centered in Youngstown, Ohio, an area which has been struggling to recover its economic vitality for two decades. The locale is the Youngstown business incubator, which creates new businesses "almost out of whole cloth." A former auto showcase, for example, now invites graduates of Youngstown University and others to develop companies. A second example is the DoE Energy-Efficient Building Innovation Hub, won by a consortium led by Penn State, in Philadelphia. Five agencies, led by the DoE, have received $130 million for five years to support small business manufacturing and training.

Last fall nine communities won more modest awards of $2 to $3 million from the Advanced Manufacturing Jobs and Innovation Accelerator program. Upstate New York won two of the nine, one led by Syracuse University and the other led jointly by the University of Rochester and Rochester Institute of Technology.

Dr. Singerman noted two features these programs will need in order to succeed. One, the geographic location of a technology cluster needs to include national research assets. Two, organizations at both the federal and regional levels need to leverage their assets and provide seamless support for research activities. Many such organizations have been isolated in programmatic silos, he said, and these need to be opened to cooperation within the region.

He concluded with a note about process. The administration's strategy is to offer policy guidance and mentoring whenever possible. One mechanism is the Advanced Manufacturing Partnership (AMP) consisting of a dozen equipment manufacturers and six engineering research universities. The AMP issued a report in July 2012 offering guidance in 16 specific areas on national policy, including not only descriptions of federal programs, but also guidance for industries, universities, and state and local governments. Other bodies included a NIST Visiting Committee on Advanced Technology, the President's Council of Advisors for Science and Technology, the President's Job Council, and the Department of Commerce's National Advisory Council on Innovation and Entrepreneurship, all of which are populated by leaders from the business, nonprofits, and universities to provide specific guidance to the administration.

"A substantive focus on manufacturing collaboration does not happen by itself," he said. "It's hard for any large bureaucracy to move in a single direction. My observation is that it's a consequence of persistent, consistent, high-level coordination. The coordination among the NEC, OSTP, and OMB has continued, and has led to the development and coordination of programs I've mentioned." He noted that Jason Miller of the NEC has been an effective leader in this effort, drawing together the agencies and helping overcome their cultural differences and bureaucracies.

Dr. Singerman closed with an operational note about NIST, which is the host agency of the Advanced Manufacturing Program. A white paper issued in January 2013 is available on the website manufacturing.gov, he said, along

with many other documents that "give a clear picture of the Administration's thinking and how its programs will be rolled out."

CHALLENGES AND OPPORTUNITIES FOR THE NEW YORK INNOVATION ECONOMY

Darren Suarez
Director of Government Affairs
Business Council of New York

Mr. Suarez welcomed the "impressive gathering" of attendees to Albany, and said that the discussion is an important one, especially in an area of great historic importance that has changed radically in recent decades. The Business Council of the State of New York, he said, was formed in the 1980s in a collaboration between the Chambers of Commerce and manufacturers and has since been a force in guiding the direction of this change. It has more than 2,500 members, and represents the full spectrum of business activity, from single entrepreneurs to small companies to multinational organizations. The symposium would be an opportunity for others, he said, "to take a look at New York's model."

The topic on most people's minds today, he continued, and the focal point of the meeting, is nanotechnology, specifically the application of advanced manufacturing by GLOBALFOUNDRIES at the Luther Forest Technology Campus just north of Albany. His own history overlapped with this development, he said, because he once worked for state Senator Joseph Bruno, who represented the district where Luther Forest is located. Focusing on economic development initiatives, he was assigned to begin the development of the 1,400-acre technology campus, including the clearing of land, establishment of infrastructure, and search for a tenant. "I am often asked," he said, "whether the investment was worth it, and I think unequivocally the answer has to be yes."

One reason, he said, is that so much of the activity in the Capital District is centered around research and development, which complements the advanced manufacturing at GLOBALFOUNDRIES. "But really we'd have to say it was successful because it built on the history we already had in the area." In this he included the long-time work of IBM and its leadership in creating the College of Nanoscale Science and Engineering, as well as its sustained investments in education. He also highlighted the activities of General Electric, which recently began a major new battery technology program at the GE Global Research center in Niskayuna and announced in 2012 that it would invest $70 million to expand its advanced manufacturing plant in Schenectady, adding 450

new workers.[23] These major initiatives, he said, have made the community as a whole more willing to support additional investments in R&D.

Addressing the Skills Crisis

At the same time, he cautioned, the region faces "a skills crisis" in meeting the personnel demands of their new projects. New investments in R&D, he said, "would depend on the presence of individuals skilled enough to fill those positions." He said that the New York State Department of Labor has projected a 135 percent increase in STEM-related computer electronics manufacturing jobs in the Albany area between 2008 and 2018, which is "driven by the growth in this sector." STEM manufacturing employees earn a median salary of $76,000, he said, which has an important ripple effect through the economy. The Business Council projected 47 million job openings between 2009 and 2018, nearly two-thirds of which will require workers with at least some post-secondary education. Fourteen million jobs will await employees with an associate's degree or occupational certificate, and these jobs will pay a significant premium over jobs open to those holding only a high school degree.

As a result, said Mr. Suarez, the Business Council, in partnership with member companies, decided to improve the opportunities for advanced STEM learning and training. "Our economic future will be defined by our ability to educate those individuals. Right now we're not meeting that requirement, and the children in America's schools are competing against peers in Finland and Singapore who are better prepared."

In reviewing current statistics on school achievement in New York, he said that the four-year high school graduating rate is 74 percent, which is reasonably good. On the other hand, only 34.7 percent of New York State's high school graduates are calculated to be "college and career ready."[24] "When we look at what they are bringing to the table," he said, "we find that it's not what is needed."

Also, he said, more than 50 percent of students in two-year institutions of higher education take at least one remedial course. "So higher institutions are forced to re-teach our kids something they should be learning at lower levels, and that puts us behind. We're having to make investments in higher education to make up for deficiencies at the other end."

One might expect these deficiencies to occur primarily in urban areas, he said, rather than suburban communities. In fact, even the students of educated parents are lagging. "We ask whether our kids will be better off than their parents," he said. "Unfortunately, in many situations, we're not educating them

[23]GE's new Durathon sodium batteries contain no lead acid materials, reducing end-of-life disposal costs, and they store more energy and charge more quickly than traditional batteries.

[24]"Calculated college and career ready" indicates students graduating with a score of at least 75 on Regents English and 80 on Math Regents, which correlate with success in first-year college courses. Source: NYSED Office of Information and Reporting Services.

as well as we were educated, and we're certainly not doing as well as other nations." He said that the percentage of 15-year-olds proficient in math is 42 percent in the United States, 50 percent in Canada, and 75 percent in Shanghai.[25]

The Model of P-TECH

New York has adopted a number of initiatives to improve STEM learning, he said. One is P-TECH, Pathways to Technology and Early College High School, a collaboration among New York City's Department of Education, the City University of New York, the New York College of Technology, and IBM Corporation. In P-TECH, industries and businesses partner directly with high schools to help improve the effectiveness of education and raise number of individuals who meet job market requirements. IBM was a leader in creating this program, and brought it to the business council as an opportunity for other companies to join. The current governor's budget contains funding for additional P-TECH schools, championed by the Business Council in hopes of seeing this program emulated in other districts of the state.

At the Paul Robeson Educational Complex in Brooklyn, where P-TECH is based, each student is paired with a mentor from a company. In the case of IBM, students are treated to a visit to the IMB facility in East Fishkill, New York, to see how chips are made. The company also helps train their teachers, and provides a full-time industry liaison person who helps develop the curriculum. The students participate from grades 9 through 14, so that they can graduate with an associate's degree, "breaking the bounds of what we had thought could be covered in traditional high school."

The P-TECH program was highlighted by President Obama in the State of the Union message, in which he praised the model "for the way it prepares students for a 21st- century economy and enhances American competitiveness." Many participating students are from low-income families; 88 percent of them qualify for free lunch. "But the students are succeeding because of the overall commitment and investment. They've built an effective partnership, and led with clear vision and shared decision making, fostering community engagement. The family is engaged at a level that is not traditionally seen."

Mr. Suarez praised the program further. "When we talk about education, a perception is that the United States has fallen so far behind that we don't have the ability to close the gap. We don't believe that. Models like this can help us to radically change, bringing innovative ideas directly into our classroom and helping strengthen the next generation." He emphasized that the program is designed to encourage more girls and minority students to enter STEM fields.

Finally, he said, the state is making a strong effort to offer a consistent and favorable business environment. It has begun with the "legacy companies,"

[25] Arthur Levine, "The Suburban Education Gap," *The Wall Street Journal* 2012.

especially GE, IBM, and Corning, to "make sure we're not abandoning the companies that brought us where we are in the first place. Part of that is making sure our environment is supportive of business. In the past, there has been a regulatory environment that made it uncomfortable for them to be here, but we've see a change at the state level. The Cuomo administration has made a commitment to streamlining processes so companies know what compliance is required, or how to find their own pathways to compliance. And we are taking more steps to ensure that they continue operation here in the State of New York, which will ultimately mean a better reputation and business climate."

DISCUSSION

Mr. Miller began the discussion with a question about the level and targeting of federal spending on R&D. "In the focus on budgets in Washington," he said, "what gets lost is discretionary spending. This is a small proportion of federal expenditures, but it is the part of the budget we keep cutting, and it is where we make our investments in technology, education, and physical infrastructure. Discretionary non-defense spending has sunk to its lowest level in over 50 years. What's also important is how we spend it, particularly in allocating R&D resources to science agencies. We've made some progress on advanced manufacturing R&D, and our focus there is on enabling technologies, which can have a broader impact. The question I have is whether there are good models for how to keep R&D spending up and spend most effectively in supporting development."

Dr. Wessner said that the government does invest in basic research, and much of this spending spills over to many users. He said that one sector that should be increased is "the ICT space for defense." He also said that the United States needs to learn from the rest of the world how better to capture the value of the research. "I strongly believe that this administration has it right," he said, "and that they actually have some time to get this done. No one's opposed to having better manufacturing, and defense, but we need to put more money in both applied and basic research." He added that China spends little on basic research in favor of applied programs that lead quickly to products. "They are using our basic research and capturing its value to their advantage."

A questioner asked whether the largest threat might in fact be losing the 24- to 35-year-old cohort of early career investigators whose funding had been reduced. "It makes a big difference if a researcher has a 10 percent chance of getting their first proposal funded or a 30 percent chance, and now we're much closer to 10 percent. I think we could lose brilliant young people who can be the next inventors unless we fix that problem."

Dr. Singerman agreed, saying he wished he could write a large enough check to cover that problem. The dollars involved restore competitive awards to traditional levels "are not significant, but the losses can be huge. This is of course compounded by cuts in state support for major public universities, especially for infrastructure." Dr. Wessner agreed that this issue was important

and troubling, and urged the states to "step up," perhaps by supporting young investigators programs. "It's not just an issue of intergenerational equity. The young people are those that come up with new ideas."

Can There Be a Manufacturing Renaissance?

A questioner asked whether manufacturing is the "right investment," given the possibility that its decline was part of a larger and perhaps systemic decline, resembling the steady drop in the number of people involved in food production. Mr. Miller described two streams of debate around this question. One, which was popular during the middle of the last decade, was that manufacturing was indeed going the way of agriculture, and that this is a natural consequence of the nation's evolution into a high-value service economy. The second debate, he said, concerns recent signs of improvement in manufacturing employment: How much of that improvement is the result of the economic recovery, and how much is caused by a restructuring of manufacturing which may signal a manufacturing renaissance?

Regarding the first debate, he agreed that manufacturing has lost employment share over time, dropping from just under 30 percent in the early 1960s to a little below 10 percent today. What that fails to recognize, he said, is that from about 1965 to about 2000 the number of people working in manufacturing held steady at 17.5 million. We were increasing output at about 3.5 percent a year, but this was caused by rising productivity. "So generally speaking the level of employment was flat while the share of the population directly employed in manufacturing was going down. And if you think about the long term, in both advanced and emerging economies, this is what you'd expect over time."

Over the last decade, however, the behavior of the economy did not follow that pattern. The country lost some 6 million manufacturing jobs, or about one-third of the manufacturing workforce. "That wasn't because we were becoming more productive," he said. "Our productivity gain, according to the Brookings Institution, was 3.9 percent per annum in the last decade. It was because we stopped making stuff. Between 2000 and 2010 our growth in production was flat. If we keep getting more productive and stop making stuff, we're going to have many fewer people in manufacturing."

The High Spillover Value of Manufacturing

There is some justification, he continued, in accepting that manufacturing as a share of population will go down over the long term because of productivity gains. But using that view to explain current trends misses two things, he said. One, the decline in the last decade was much greater than normal. And two, accepting a weakened manufacturing sector is to accept a weaker economy. "There is a much broader impact in having a strong manufacturing sector than the jobs we count within the four walls of a

traditional factory," he said. "Those jobs have broad spillover effects into the service economy that go beyond whether we have 17 million or 15 million manufacturing jobs. So long term, having a strong manufacturing sector is critical. And in fact there are a lot of reasons to be optimistic in the near and medium terms. But we need to take advantage of this moment in promising regions such as Albany."

Dr. Singerman added that the change in production in the United States is largely a function of public policy. "Over the last 30 years we have shifted our support from physical engineering to financial engineering, largely through deregulation and tax policy. This has been very conscious, so that the vast proportion of our growth over the last decade has been in financial services, not in manufacturing. We can choose to reverse this by adopting new public policies. Other countries have adopted policies to grow their manufacturing, and we can do exactly the same. We know what these policies are, in terms of trade, taxation, regulation, technology, and workforce development. One could shift those parameters and create a very different story."

A questioner asked Dr. Wessner what could be done at the local level to "win the second lap," as he had urged. Dr. Wessner said, "Don't stop. Spend more on infrastructure and education, evaluate what is working, and nurture the cooperation that is critical. City-states in Italy fell apart because they stopped cooperating, they fought each other, and eventually external enemies took over. I'm optimistic, and I share Jason's view that what has happened here is really good. But complacency is your enemy."

Keynote Address

The Honorable Shirley Ann Jackson, Ph.D.
President
Rensselaer Polytechnic Institute

Introduced by
Mike Russo
Director of Government Affairs
GLOBALFOUNDRIES

Mr. Russo introduced Dr. Jackson, the keynote speaker, as a "truly remarkable individual" who has held senior leadership positions in government, industry, research, and academia. Since her arrival at Rensselaer Polytechnic Institute 14 years ago, he said, "she has led a remarkable transformation of the oldest technological research university in the U.S." He noted that Rensselaer founder Stephen Van Rensselaer established the university for the purpose of "instructing persons in the application of science to the common purposes of life," and that Dr. Jackson has "ensured that the university has remained aligned with the vision of its founder."

He also noted that more of GLOBALFOUNDRIES' engineers, technicians and new college graduates have come from Rensselaer than any other institution. "From my perspective, having lived here all my life, it is remarkable to see the continued excellence of Rensselaer since Dr. Jackson took the helm in 1999. I believe the true measure of a person's worth is the degree to which they are able to make a difference in others' lives. With that as a measure, Dr. Jackson, you surely have made your mark."

Dr. Jackson began by thanking Mr. Russo, the National Academies, and Rensselaer's co-hosts for the symposium: Hudson Valley Community College, GLOBALFOUNDRIES, and the Center for Economic Growth. "We all understand that the success and economic well-being of our citizens are critically dependent on the development and nurturing of an innovation ecosystem," she said. "Indeed, our national security, our competitiveness, and our future prospects rely on our ability to excel in the understanding, advancement, and application of science, engineering, and mathematics."

Scientific discoveries and technological innovations, she continued, rest on strong collaborations among business, government, and academia. Over the

years, especially since the end of World War II, this three-way partnership has created an innovation ecosystem that has long driven the U.S. economy.

Keys to a Strong Innovation Ecosystem

A strong innovation ecosystem requires four more specific elements, she said: (1) strategic focus, (2) game-changing idea generation, (3) translational pathways to bring discoveries into commercial or societal use, and (4) capital, including financial, infrastructural, and human capital. She said she would offer examples of research and commercial successes that were dependent on game-changing ideas from Rensselaer's students and faculty, and emphasized that such outcomes were possible "only when academia, government, and the private sector each play their respective roles."

She pointed out that, as a university, Rensselaer's core mission is the education and training of students. "Economic benefits derive in the end," she said, "from our graduates' productive lives and from the research and innovation of our faculty and students." She said that Rensselaer has a long history of partnering with New York State, regional organizations, and global corporations such as IBM, Corning, and GE. "We have collaborated with them to build intellectual and physical platforms that have led to fundamental discoveries, attracted large-scale federal research investments, commercialized technologies, and created start-up companies."

One visible result of this collaboration, she said, is the Computational Center for Nanotechnology Innovations (CCNI), established as a $100 million partnership with IBM and New York State—with each partner contributing one-third of the cost of creating CCNI, which hosts one of the world's most powerful university-based supercomputers. "CCNI," Dr. Jackson said, "has allowed companies of all sizes to improve their products and processes by tapping the expertise of Rensselaer scientists and engineers and the power of high-performance computing for simulation, modeling, and the manipulation of big data." CCNI has had 800 discrete users and 25 corporate partners.

She cited ITT Goulds Pumps as an example of CCNI's value and pointed out that the company has been making pumps so long, "its first material for making pumps was wood." The company used computational fluid dynamics programs at CCNI to model its pumps and design more competitive products. Similarly, Ames Goldsmith Corp. (AG), a New York company that supplies silver-based products for printed electronics, came to CCNI with a concern about the particle size distribution of silver during production. A Rensselaer simulation model demonstrated how the process could be improved by controlling the nucleation and growth phases of the particles independently. As a result, AG stands to increase the quality of its product and to be able to tailor that product to individual customers.

CCNI-affiliated faculty are working also on a range of challenges in health care, energy, and other fields, while engaging both graduate and undergraduate students at Rensselaer and preparing them to be digital leaders.

"These are the kinds of tools and partnerships," said Dr. Jackson, "that make our region—and Rensselaer—attractive to talented individuals, entrepreneurs, and high-tech businesses."

A Virtuous Circle Formed by Expertise in Nanotechnology Combined with Human Capital, Entrepreneurship, a World-Class Infrastructure, and Government Support

Dr. Jackson pointed out that while nanotechnology's role in semiconductors and computers may be top of mind, the field includes work in biotechnology, pollution control, materials for buildings, and energy. She offered an example that links nanotechnology and the life sciences: Engineering researchers at Rensselaer, led by Vice-President for Research Jonathan Dordick, Professor Ravi Kane, and Professor Linda Schadler, have developed a new method of killing the deadly pathogenic bacteria, such as *Listeria,* that are sometimes found in food handling and packing facilities. It is a food-safe, nano-fabricated gel that destroys *Listeria* on contact, even at high concentrations, within a few minutes, without affecting other bacteria. This represents an important alternative to antibiotics and chemical decontamination in food supply chains, the security of which is an important issue around the globe.

Dr. Jackson explained that for 10 years, beginning in 2001, the Rensselaer Nanotechnology Center, which discovers and develops ways to assemble nanoscale building blocks with unique properties, hosted the National Science Foundation (NSF) Nanoscale Science and Engineering Center for Directed Assembly of Nanostructures. Directed assembly is a fundamental gateway, because it allows the control of the functional properties of nanomaterials and their ultimate applications in electronics, medicine, and consumer products.

The Nanotechnology Center also integrates innovative educational outreach activities into its work, including the Molecularium Project,[26] which educates students from kindergarten through college in the fundamentals of physics, chemistry, and biology. The Molecularium offers a planetarium-like exhibit that does not turn outward to the universe but inward to the smallest units of matter.

She added that Rensselaer's Nanoscale Science and Engineering Center was one of the six original NSF-funded nanotechnology centers, which also included Cornell and Columbia Universities in New York State. New York matched the Rensselaer funding with half-million-dollar grants through the New

[26]The project's website states, "The Molecularium® Project's mission is to expand science literacy and awareness. We aim to excite audiences of all ages to explore and understand the molecular nature of the world around them. We do so through compelling stories, experiential learning and unprecedented visualizations in immersive and interactive media." <*http://www.molecularium.com*>.

York State Office of Science, Technology, and Academic Research (NYSTAR) for 10 years.

She then turned to a local company called ThermoAura, a Troy startup founded in 2011 by Rensselaer graduate student Rutvik Mehta and several Rensselaer professors to produce a high-efficiency material that creates electricity from waste heat. "This start-up is on the verge of scaling up for commercialization," she said. "The essence of this success is taking Rensselaer research into new nanomaterials and processes to convert heat into electrical energy in new ways, adding entrepreneurial capabilities, and finding support in the form of a business partnership and seed money—in this case, help from the New York State Energy Research and Development Authority (NYSERDA)." She offered this as a model for the National Academies to consider in its recommendations for regional development. She also emphasized the importance of the collaboration with NYSERDA in helping to guide Rensselaer innovators towards success—and to create jobs in the region.

She offered Precision Valve and Automation, or PVA, as example of nanotechnology innovation that created jobs—over 70 since 2010. Rensselaer's association with PVA, a global supplier of coatings and fluid dispensing equipment, began in 1992, when the company moved into Rensselaer's incubator, a leading-edge facility that gave PVA the space and the access to expertise it needed to grow. As it continued to expand, it moved into a new site that was granted Empire Zone designation by the State of New York. This allowed the firm to take advantage of tax incentives to expand its business and to invest in human capital, including graduates from Rensselaer, Siena College, and Union College. "PVA has become an important part of our community," she said, "providing opportunities for internships and shadowing by local high school students."

This example, she said, demonstrates the kind of "virtuous circle provided when high-level expertise, world-class infrastructure, human capital, entrepreneurship, and government come together."

Maximizing the Effects of State Funding

Rensselaer has maximized the value of state funding to drive innovation, discovery, and ultimately economic growth, she said, through a range of other partnerships. These include Rensselaer's two state-funded Centers for Advanced Technology—the Center for Automation Technologies and Systems (CATS) and the Center for Future Energy Systems (CFES)—both of which receive funding from the Empire State Development Division of Science, Technology, and Innovation. This office, the successor to NYSTAR, works to strengthen the region's manufacturing base. She offered Rensselaer's Center for Biotechnology and Interdisciplinary Studies (CBIS) as another example of collaboration with the state. Rensselaer built CBIS with funding from New York's Generating Employment Through New York Science Program (Gen*NY*Sis), the Empire State Development Division of Science, Technology

and Innovation (NYSTAR), the New York State Department of Health, and New York State Stem Cell Science (NYSTEM). Finally, she said, the Rensselaer Interconnect Focus Center, also supported by NYSTAR, works collaboratively with universities and businesses globally to increase the power and speed of computer chips that are at the heart of the nanoelectronics revolution.

"As proud as we are of these achievements," Dr. Jackson said, "we recognize the work is incomplete. We need to continue helping to grow the local economy and to catalyze growth more broadly. We need to sustain—even expand—investments in our innovation ecosystem by preparing students to participate—that is, developing our human capital—and building the financial capital and physical infrastructures that are needed for the opportunities and challenges we face. We need to continue to encourage partnerships that share knowledge, resources, and talent more effectively."

Now is not the time to pull back, she emphasized, when the health, prosperity, and security of our region and country depend on our strength in science and technology. "The innovation ecosystem—and a vibrant 21st century economy—rests on three legs: academia, the private sector, and the public sector. All three," Dr. Jackson concluded, "must play their essential roles, working in partnership."

Panel II

The New York Nanotechnology Cluster

Moderator:
Rex Smith
Editor
Albany Times Union

Mr. Smith said that participants should not be surprised to learn about the upswing in innovation, business formation, and high-tech growth around Albany, since "this was the cradle of the industrial revolution, and is home still to extraordinary universities, great private companies, and a lot of capital. So for all the talk of the decline of the industrial Northeast, it's worth bearing in mind that this is after all the Empire State and empires tend to last a long time."

He encouraged the panelists to highlight the growth of the nanotechnology cluster in the greater capital region, exploring "how it has come about, what may lie ahead, and whether this experience can be replicated in other areas and disciplines."

Before introducing Dr. Killeen, he recalled his own experience in the history of the region that is now referred to as "Tech Valley." One afternoon about a dozen years ago, he said, "we were discussing what to put on the front page of the next day's newspaper. We had a story that made reference to the new name of 'Tech Valley,' and some of the economic development people were hoping for. Should it be on the front page? Would it be credible? Giving something front-page treatment is something you do only if you believe in it. Once you give it that position, it tends to take on a life of its own. I'm pleased to say that the doubters in that discussion have largely been proven wrong. Those who felt there was something special happening here have been shown to be right—thanks in no small part to many of the people in this room today."

THE NEW YORK INNOVATION ECONOMY AND THE NANOTECHNOLOGY CLUSTER: THE ROLE OF SUNY

Timothy Killeen
Vice-Chancellor for Research, SUNY
President, Research Foundation for SUNY

Dr. Killeen said that his role was to "get into the nuts and bolts about what has happened around Albany," adding that his perspective as a newcomer might be helpful. He had arrived in Albany nine months previously, from the National Science Foundation, "where the innovation ecosystem was very much on everyone's mind, and how to do that at scale with that three-legged stool" described by Dr. Jackson. He also referred to topics raised by Rep. Tonko earlier: co-equal partnerships; seamless integration of knowledge, science, and capability; human capital; "success breeds competition, so don't get complacent;" "the role of the community colleges in this transformational activity; how research inspires solutions that society needs; and the importance of product discovery and product delivery.

He said he wanted to examine how "this nanotechnology revolution" had happened, beginning with the role of SUNY. He reminded his audience "what an asset the state university system is for New York State and innovation in general," with outputs of nearly a billion dollars' worth of sponsored research each year, some 3.6 million alumni, students and employees, an estimated $19.8 billion impact on the local and regional economies, some 7,000 degree and certificate programs, and "a lot of square footage where startups, grad students, postdocs, and early career faculty come together and generate good ideas."

Physical Assets of SUNY

The physical assets of SUNY, Dr. Killeen said, include some 88,000 faculty members and enormous infrastructure: the campuses; six centers for advanced technology, one of which is CNSE; eight centers of excellence, and 17 incubators around the state that employ more than 2,000 high-tech employees. The system is responsible for more than 1,000 patents, 700 active licenses, and 72 active startups. "I'll be the first to say that that's not enough," he said. "Given the volume and scope and scale, we need to do more, in particular to transform career excitement into commercial pursuits."

He said that the nanotechnology college, CNSE, which is part of SUNY at Albany, did take 10 years to develop. But it has now gained strength, including more than 17,000 graduate and undergraduate students from more than 100 nations. As part of SUNY-Albany, it both "brings the world within reach" and "enriches everything that goes on" in the district.

The college itself, he said, is all about driving innovation and an economic renaissance in New York State. It has hundreds of industry partners,

over $10 billion in direct investments, and thousands of jobs. Propelled by "a major solar program, he said, CNSE is projects to create and retain as many as 25,000 jobs through 2015."

SUNY, largely through its research foundation, plays a significant role in the development of public-private partnerships at CNSE. More than 50 PIs at the college get grants and contracts from agencies, and the foundation provides pre-award and post-award services. It also provides innovation support services for startups, as well as for licenses, disclosures, and patents. It sets up the affiliated corporations, notably one that supports real estate development at CNSE. This corporation helps companies by developing infrastructure, leasing space, assuming risks of long-term leases, managing licenses, and guaranteeing loans for key instrumentation.

The Value of Affiliated Corporations

Dr. Killeen differentiated between SUNY research centers and affiliated corporations that strengthen the environment for research. The research centers, including those at CNSE, were launched and funded by the state as core centers of excellence. Key functions were to leverage existing research, upgrade facilities, and provide long-term research funding. The affiliated corporations were designed to achieve goals for CNSE beyond the reach of SUNY or its research foundation. These corporations are able to increase flexibility of CNSE in ways that academia is not equipped to do. In particular, they provide a dedicated corporate structure that can ensure alignment with SUNY's not-for-profit mission of research and education. One of them is the Fuller Road Management Corporation, which manages a land lease with SUNY, designs and constructs facilities, provides financing for construction, and issues debt for facility construction, with the research foundation as the credit tenant—an important backstop. It also provides access to research programs and facilities and owns and operates the facility, leasing office space to industry.

He referred to earlier cautions about complacency, asserting that he had seen no such tendency over the past two decades, and none at present. Fuller Road was incorporated in 1993, he said, and its first project—to develop a center for environmental science and technology management—was completed in 1997. This was followed by a large public-private partnership (PPP), the International Center for Nanolithography, established in 2002. Then came SEMATECH, which arrived in the North Building in 2003. The NanoFab South facility was completed 2004, and the Center for Semiconductor Research, another large PPP, in 2005. "You can see an oscillation between facility enlargement, world class capability development, and major PPPs continuing to this day," he said.

Fuller Road completed the Institute for Nanoelectronics Discovery and Exploration in 2006, and the Computer Chip Hybrid Integration Partnership in 2009. After that came NanoFab East and then NanoFab Central, both also

completed in 2009. "Very significantly for the future is the NanoFab Xtension, a consortium established in 2011 that will house the world's first 450mm wafer production facility. So the Albany Capital District will be the hub of the next generation technology of these larger wafers."

Benefits of Partners in Many Locations

In launching CNSE, Dr. Killeen said, the cluster effect and diversification is central to the overall story. "It's not just what's going on in this location," he said. "It's the connections across the state through affiliated corporations that are leveraging technological developments at other sites." Another partnership has been formed at the former Infotonics Center of Excellence in Rochester, focused on microelectromechanical devices, or MEMS, "which are little cantilevered beams etched into tiny silicon substrate. If you do that well you can create all kinds of miniature electromechanical devices that allow for, ultimately, mass spectrometers in lapel chips and things of that sort." Again, this advance was assisted by a commercialization center called Smart Systems Technology and Commercialization Center (SRT), located in Canandaigua, near Utica. Smart Systems now has DoD funding and is located in a secure facility.

Fort Schuyler has also formed a new partnership with the local community in Rome and Utica called SUNYIT, SUNY Institute of Technology at Utica/Rome. It has launched a center for advanced technology and a computer chip commercialization center. "This is another industry partnership rooted in academic excellence and expertise," he said.

Finally, he said, the Photovoltaic Manufacturing Consortium (PVMC) will be developing industry standards for the solar industry, helping make the major transition from crystal silicates to indium-gallium-arsenide, improving industrial efficiency and providing a vehicle for property interest by the Department of Energy. "All of this is the innovation system that is rooted in academic institutions with entrepreneurial flair, with early career scientists and students involved, high school students, strong major partnerships with big-time industry, and open doors to other components of the industrial spectrum."

The innovation ecosystem, Dr. Killeen agreed with Dr. Jackson, is a virtuous cycle. "It starts with research and discovery, leads through commercialization, licenses, and patenting. There has to be pre-seed and seed funding; state economic agencies need to get involved in development and then in IP licensing. This is a system that is as weak as its weakest component, so it's important to keep all those component parts well-tuned up. The story is a rich one, but really comes down to people and vision and leadership, and the ability to bring teams together at scale, with focus and energy and commitment."

NEW YORK'S NANOTECHNOLOGY MODEL: BUILDING THE INNOVATION ECONOMY

Ken Adams
President and CEO
Empire State Development Corporation

Mr. Adams thanked Dr. Jackson for her service on the Governor's Regional Council, which she led for several years, as well as on the Governor's Economic Development Council for the Albany area. He said he would talk about "our part of the three-legged stool," the state government, and the "incredible impact of this industry outside New York." He reminded his audience of the continuing importance of the semiconductor industry to North America. In 2010, the industry shipped over $110 billion worth of products and employed almost 200,000 people. It was the largest net exporter in U.S. manufacturing, outside the aerospace industry. Between 2010 and 2011 the workforce in semiconductors grew by 3.7 percent, compared to a general growth rate or 1.2 percent.[27]

More locally, he said, the New York State region has become the global headquarters of semiconductor industry, for a variety of reasons. The region, he said, has a skilled workforce, state-of-the-art infrastructure, the support of business, and vital natural resources, including abundant water, power, and natural gas.

The State Government as a Prime Mover

The state government has been a prime mover in support the nanotechnology sector, he said. Over the years it has invested approximately $1.3 billion in this sector, beginning with $150 million in the Nanotechnology Center of Excellence, $100M to specific companies several years ago, help for Tokyo Electron's their R&D program, $75 million for the state-of-the-art 300mm wafer clean room, and $20 million to help relocate SEMATECH from Austin, "which was huge news in 2011. When you bring the leading industry trade association here, with its 100 or so high-tech jobs, it says something about our global position."

The Empire State Development Corporation, he said, had found that state incentives could not only attract private industry to the region, but also that they could incentivize multiple investments after they arrived. "If you think about that $1.3 billion in investments, this has had a leverage effect in attracting or supporting over $20 billion from world leaders in the industry."

Drawing on state data, he said that about 20 percent of state's nanotechnology workforce, or about 12,000 jobs, were now located in Tech

[27]Bureau of Labor Statistics.

Valley, including various partnerships.[28] One example was IBM's $2.5 billion fab in East Fishkill, New York. The latest investment, GLOBALFOUNDRIES' $6.6 billion fab in Malta, New York, "showed the tremendous power of leveraging the parts of this three-legged stool."

Rapid Development for the Albany Cluster

Mr. Adams emphasized that in comparison to other well-known clusters, the Albany partnerships developed relatively quickly. For example, he said, the Research Triangle Park in North Carolina had celebrated its 50th anniversary in 1999. "It didn't just start one day," he said. "It's an incredible asset now, but it was a commitment not over years, but over decades. We need to think ahead here on that scale and visualize how transformational this will be for the region."

In reviewing the origin of the Global 450 consortium, "Governor Cuomo's most significant announcement of our ongoing state commitment to the semiconductor industry," he said that a "phenomenal investment of $400 million by the state" had triggered a $4.4 billion response from IBM and "a host of companies." One remarkable aspect of this, he said, was that the governor "twisted the three-legged stool a little, or put wheels under it, in the sense that the $400 million investment did not go directly to companies, but to CNSE." In other words, he said, government was investing in the research capacity the companies said they needed, rather than giving in more direct form. "This further cements the collaboration," he said. "The companies are working together in a unique way to do research together, unlike other sectors. Here, it was forced by the fact that the government placed CNSE, SUNY, RPI, and higher education generally in a leadership role by driving the funding there."

He added that while other sectors have not done this, the New York cluster could still be a model for others. New York has about 250 colleges and universities, more than other states, including 64 SUNY campuses, with 29 in New York City alone under the City University of New York (CUNY) system; many community colleges; and more than 150 private and independent colleges and universities. "I think that is a unique asset for development."

Mr. Adams summarized some of the highlights of recent investment New York, beginning with GLOBALFOUNDRIES, whose "investment is so phenomenal, including the recent announcement of $2 billion more for an additional clean room—without any request for state support. You don't get up every day and hear that a private company will make a $2 billion investment on top of an even larger investment already made."

As an aside, he said that Empire State Development had just had its busiest year ever in terms of project volume, largely because regional councils requested "more work that we would normally get." Empire did 243 incentive

[28]New York State Department of Labor.

deals, for which it committed $520 million, mostly through tax credits across the state. These activities leveraged $6.2 billion in private industry investment, creating or retaining about 64,000 jobs. "We're always seeking high leverage to make sure investments produce quantifiable, testable job retention and creation. And we want those jobs to be in industries that will be sustainable, not continual reinvestment to become competitive."

Outcomes of Investment in R&D

In summary, he said, the total effort in and around Albany has led to leadership in semiconductors and nanotechnology, high average wages, good transferability of skills, and very large, though difficult to document, ecosystem and supply chain growth. On the technical side, these major investments have had a huge impact, he said, along with the multiplier effect economists cite for nanoscale science- and engineering-related businesses. "As we seek to deploy taxpayer resources carefully to attract new industries to the state, we now have a critical mass here. It has led us to third position in the nation in high-tech employment, third in high-tech payroll, and fourth in the number of high-tech establishments.

The Workforce as a Competitive Advantage

Workforce is a critical issue, "and thankfully we have the institutions of higher education to prepare that workforce." In a global economy where so much activity is technologically based, and no one can rely on selling knock-off consumer items at low cost, "our competitive advantage is our workforce. No number of Excelsior tax credits or generous NYSTAR grants will attract a technology company to New York if there isn't a qualified workforce available to the company. States that think they can simply spend taxpayer dollars as incentives without regard to investments in their education system will not have sustainable economies."

Mr. Adams praised the many public and private pioneers in this effort for taking the risks they did. The state, for its part, is continuing to be a reliable partner, with sustained support in its latest budget. "This means we can continue to support these companies through new initiatives such as the creation of 10 innovation hot spots and support for existing incubators through a competitive funding process; this allows companies to get up to five years of tax benefits as long as they stay in the state. Also, a $50 million innovation venture capital fund is being created to make seed investments in early-stage companies." This will not be for "easy in-and-out investments with low risk," he said, but carefully deployed to help small companies coming out of RPI or SUNY at Albany, such as Ecovative, that need to get over the valley of death.

Finally, he described the Innovation New York Network, a group of seasoned professionals who work as volunteers to mentor startups, helping them emerge from the laboratory, raise money, grow, and "create jobs and prosperity across the state."

Mr. Adams closed with a brief summary, describing his group's mission as a broad, enabling one: "We're here to learn, listen and try to provide some of the glue for this process. We'll play an active role, under the Governor's leadership, in advancing all of this."

PIONEERING INNOVATION TO DRIVE AN EDUCATIONAL AND ECONOMIC RENAISSANCE IN NEW YORK STATE

Pradeep Haldar
Head of Nanoeconomics Constellation
College of Nanoscale Science & Engineering
The State University of New York at Albany

Dr. Haldar said that he had moved to Albany from Boston 25 years ago, when Albany was so remote he had to drive all the way back to Boston on weekends to find "a good ethnic restaurant." A decade later, when Alain Kaloyeros sought his help in a bold plan "to build the Capital District into a nanotechnology and semiconductor powerhouse," he thought there must be some mistake. "At that time there was no activity in nanotechnology," he said; "none. But it takes positive people to make things happen. The vision of bringing groups together is critical, and Alain had that vision. The fact is that I stayed here and I'm *still* here, and enjoying every day at the college."

From nothing about 15 years ago, he said, CNSE began to grow steadily and today encompasses more than 1.5 million square feet of state-of-the-art facilities. It was propelled by the vision that "there was going to be a big need for these types of scientists and engineers. Our approach was to partner with industry, as opposed to doing it ourselves. When President Obama visited last year and saw that partnership was happening, he said he'd like to see this in other parts of the country as well."

It should not be surprising that nanotechnology has become so prevalent, said Dr. Haldar, because it supports virtually every discipline that studies or manipulates matter of any kind. Dr. Haldar defined it as technology that "images, measures, models, or manipulates matter at the nanoscale, and the atomic level," he said. "When you do that, you get properties of matter that are truly exceptional, that you can't achieve in bulk matter." These properties are caused by both quantum effects and increased surface-to-volume ratio so that manipulating matter at the atomic scale is expected bring many new abilities and structures.

"This has implications across many disciplines and industry sectors," he said. "Our focus has been in semiconductors, which can have an impact on everything: transportation, environment, energy, consumer products. We need to

have strategic focus to leverage our resources, so we concentrate on three or four of these areas."

CNSE and its Strong Role in Development

Dr. Haldar reviewed the history of the college, which was officially created in fall 2003 with four or five faculty and about three dozen students in one building. Today more than 300 students are studying for bachelor's, master's, or Ph.D. degrees in nanoscale science or engineering, he said, "which is the first time this kind of major has been offered in any college." Other concentrations are nanoeconomics and nanobioscience. "The way we approach it is truly interdisciplinary," he said. "Typical academic institutions tend to be organized by silos: engineering guys don't talk to the science guys; within engineering the chemical engineering guy will not talk to the electrical engineering guy. They have nothing in common. We have mixed it all up to make sure the students get the cross-collaboration they need to understand the field."

In addition to graduate level education, he said, the college reaches out to students from K-12 "through engagement, enrichment, and finally education." The NanoCollege hosts Nano Career Days and Nano High brings students form Albany city school districts for summer courses. The new Tech Valley High School will soon be located on the campus. "It's all a pipeline," he said, "to make sure we're educating the next generation of people who are going to be needed."

Moving Research into the Development Phase

Another unusual feature of CNSE is its emphasis on moving research accomplishments through the development process. "Our approach is to sit down across the table from our industry partners, and ask them how we can work with you on your short-, medium-, and long-term goals. We need to understand their requirements. The time frame of industry is not the same as a typical academic institution, so we have to be very responsive. That's why the buildings that go up on our campus and the research we're doing is timed to meet industry goals and standards. Otherwise industry will leave us in the dust."

CNSE's infrastructure and resources are "very cutting edge," he said. With the latest infrastructure expansion, the college will have close to 150,000 square feet of clean rooms, which is more than "any of the other universities." And its 300mm tools will soon be joined by the advanced 450mm facility.

The story of CNSE is one of intense and rapid expansion. Including the $1.3 billion invested by the state, he said, the total investment in infrastructure over the last dozen years has been about $14 billion, and the number of people on the site has grown from about 40 to about 3,000. The economic impact has been significant, he said, as the college works with about 300 companies in a

variety of collaborations, consortia, and private proprietary developments. "We're very focused on delivering company needs."

Since the Global 450 Consortia announcement in September 2011, $4.4 billion have been pledged by IBM, Intel, TSMC, GLOBALFOUNDRIES, and Samsung, along with the $400 million from New York State. Intel announced that it would establish its East Coast headquarters in Albany to manage its 450mm development. About 2,700 more jobs are forecast, including 800 high-tech positions at CNSE and 400 in Utica, along with 1,500 construction jobs in Albany.

For the new 450 consortium, he said, the state directs its portion of funding to build infrastructure for industry to use at the CNSE facility, as indicated by Mr. Suarez. "So in a way," he said, "the state is investing in itself. This is a strategy that provides stability. If the state gave that money directly to companies, they might not exist a couple of years from now. This way, the resources are still here and we can offer them to other companies."

A New Step Toward Photovoltaics

Now CNSE is beginning to leverage its success in the semiconductor area to photovoltaics. Solar PV is very closely aligned to semiconductor research, with similar equipment, processes, and technologies. "Based on our past successes with the U.S. Department of Energy," he said, "we're currently building a $300 million PV manufacturing site in Halfmoon, New York, just to the north. For the first time the federal government is coming in, seeing that the nanotechnology at the college can leverage those capabilities and attract industry." The solar industry has "taken a beating" from overseas competitors, he said, primarily in China, much as the semiconductor industry did in the 1980s. "We would have lost that industry if the federal government hadn't put in money to establish core capabilities in the United States. In the same way, Halfmoon is expected to be the innovation center for solar, to help bring manufacturing back to this country." The program, a partnership of DoE, SEMATECH, and CNSE, is just beginning. Nearly 20 partners have signed membership agreements and some plan to move to New York to participate. "The focus is less on basic research than on technology development and the translation to manufacturing," he said. "So the scale at which we do these things is where industry needs to be, and the equipment we have can manufacture large quantities of the material."

Dr. Haldar added that the innovation ecosystem forming for PV is similar to that of the semiconductor ecosystem. "We have partners who are from research, supply chain, equipment manufacturers, and the cell and module manufacturers. In the middle we have PVMC at the college that brings all these partners together."

CNSE is also focusing a major effort on entrepreneurial activity and the innovation ecosystem. It has been working with DoE, especially its national labs, to provide support and acceleration services to industry. "We have helped

more than 200 companies," he said, "which have raised over $200 million in funding. And we've supported over 500 student-led teams, as well as some early-stage investor firms. We have a network of close to 100 VC firms that are interested in investing in this area, looking for pipeline technologies, ideas, students, and/or faculty. We also have an incubator on site, supported by NYSERDA. With the larger companies in place, we can nurture the smaller startups. In the past, the successful ones would move out of our state and be bought by larger companies on West Coast or around Boston. Having the entire technology ecosystem means that larger companies here can capture that technology."

His final example was CNSE's statewide business plan competition. This is designed for students, he said, for the purpose of trying to "build a culture." Initiated in 2010, it offers prizes of $100,000 to student teams planning to start a business. The 2013 competition, he said, drew more than 400 teams from 50 universities, and a total of more than $500,000 will be awarded for the best plans. "It's not just an award and a prize," he said. "We want them to start to build their business here in New York State. As they meet key milestones we'll be giving them the award money they won."

Dr. Haldar closed by reminding attendees that CNSE is expanding into "other areas, in addition to the startup space. He said that his message "is that our model of having everybody in one location—university researchers, industry scientists and engineers, startup businesses—is truly the right model for us."

DAY 2: APRIL 4, 2013

Panel III

Growing the Semiconductor Industry in New York: Challenges and Opportunities

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

BREAKING NEW GROUND: THE NEW YORK ADVANTAGE

Mike Russo
Director of Government Affairs
GLOBALFOUNDRIES

Mr. Russo, co-organizer of the symposium with Dr. Wessner, called GLOBALFOUNDRIES the first truly global foundry, or contract chip manufacturer. He distinguished a "pure-play" foundry such as GLOBALFOUNDRIES, which manufactures but does not design chips, from an integrated device manufacturer (IDM), such as Intel, Samsung, or Advanced Micro Devices (AMD), which designs, produces, and fabricates chips. GLOBALFOUNDRIES fabricates only the chips designed by its customers.[29]

[29]Prior to the 1980s, semiconductor firms were vertically integrated, both designing the process technology for their integrated circuits and operating their own silicon-wafer fabrication facilities. As smaller design firms began to form, they needed a way to fabricate their products but could not afford the huge expense of a fabrication plant, or fab. They found a solution in the larger integrated device manufacturers (IDMs), such as IBM, Intel, and Samsung, which usually had excess production capacity. This trend gave rise to the birth of the fabless business model, where companies make their own chips without owning a fab. When Morris Chang founded the Taiwan Semiconductor Manufacturing Corporation (TSMC) in 1987, foundries became the cornerstone of the fabless model, providing a non-competitive manufacturing partner for fabless companies. A business with a fab that makes products for fabless "design houses" is known as a pure-play foundry. TSMC is the largest of these, and Global Foundries is the second-largest.

The Formation of GLOBALFOUNDRIES

GLOBALFOUNDRIES began as a spinoff of AMD, he said, partly because it is becoming more cost-prohibitive for design houses and others to produce their own semiconductor chips. It costs as much as $10 billion to build a large fab today, he said, and hundreds of millions of dollars to retool as the technology advances. AMD was one of the original shareholders of GLOBALFOUNDRIES, but today the only shareholder is the government of Abu Dhabi, through its Advanced Technology Investment Company (ATIC). The reason for Abu Dhabi's role is its desire to diversify its economy, which depends on petroleum revenues for about 70 percent of revenues. ATIC elected to invest in technology, and GLOBALFOUNDRIES is its first investment in the technology sector.

As a high-technology acquisition, GLOBALFOUNDRIES was desirable to ATIC for both its technical and geographic reach. AMD had been an experienced integrated device manufacturer (IDM), and as the primary competitor of Intel, it was a leading-edge IDM with strengths in both design and fabrication. In 2010, AMD acquired Chartered Semiconductor Manufacturing, a pure-play foundry based in Singapore, which was the number two semiconductor foundry in the world. "Chartered allowed us to offer a full array of technology," said Mr. Russo, "from mainstream to leading edge."

GLOBALFOUNDRIES also represented good geographic reach, with existing or planned facilities on four continents. Its flagship 300mm fab was already available and operational, in Dresden, Germany. This fab served just AMD, but it was easily converted to a foundry model.[30] Chartered Semiconductor in Singapore gave access to Asian markets, and the new foundry planned for Malta, New York opened the Americas to the new entity. Finally, ATIC began to plan its own facility in Abu Dhabi, which is still in the planning stages. "What we had to do was to pull all these together to form GLOBALFOUNDRIES," said Mr. Russo, "and those two plus Malta were the main manufacturing assets. Worldwide we have more than 160 customers, over 13,000 employees, about 6,000 patents, and capital expenditures through 2012 of about $11 billion."

Mr. Russo elaborated on the importance of having a wide global footprint and diversified supply chain today. "After the tsunami in Japan, companies are much more aware of vulnerability to natural disasters. We're able to offer our customers diversity and flexibility, with our facilities in New York, Singapore, Germany, and eventually the Middle East. That wide footprint is very important when it comes to trade, export control issues, security , and IP, as well as natural disasters."

[30]In 1989, before AMD built its plant near Dresden, the city had 10 companies employing 3,300 workers. The fab opened in 1999, and in 2010, the region had 1,200 companies employing 44,000 workers, most of them employed by the semiconductor cluster.

The semiconductor products manufactured by GLOBALFOUNDRIES include everything from the "leading and bleeding edge" of high-performance applications, including satellites, microprocessors, and networks, through the wireless and mobile consumer space, to mainstream technologies, including satellites, cell phones, and light switches. "One thing we're proud of," he said, "is that the company—which is not a public company and so does not open its books—had revenue growth in 2012 of 31 percent."

The Effect of a Large Fab on the Region

Mr. Russo suggested also that the presence of such a large fab in the Albany region had encouraged rapid growth of partners and the supply chain. A decade ago, he said, CNSE was beginning to grow, but few other companies had moved there. Today, a great many of the world's leading supply chain firms were present, including manufacturers such as Samsung, M+W Group, and ST Microelectronics; equipment suppliers, including ASML, Applied Materials, Lam Research, KLA Tenco, and Tokyo Electron; and materials suppliers, including Air Liquide, Air Products, ATMI, AZ Electronic Materials, Dow, FujiFilm, JSR Micro, Matheson Tri-Gas, and ShinEtsu.

The GLOBALFOUNDRIES fab itself, based on current projects underway, represents a capital expenditure of $8.5 billion. "This is the first leading-edge fab to be constructed in the U.S in close to 20 years," he said. "The clean room is unusual in being so open, like a ballroom, and about six football fields in area. It is designed with extremely flexible space for multiple leading-edge technologies. And the company has changed its business model to accommodate the unexpected growth in the mobile market. It has been able to adjust to production of low-power advanced technology, and this fab will be the flagship of that part of the business." Another advantage to the flexible space is that if the business demands more product, the space can be adapted to production; if the business requires more R&D, the space can be converted to laboratories.

The original plan for Fab 8, as the main building is called, was to generate 60,000 wafer starts per month. Given current demand, however, the company is reconfiguring this goal toward 80,000 wafer starts. "This is challenging," he said, "but that's the goal."

The fab required about 6 million man-hours to complete, including the presence of about 10,000 construction workers on the site. Currently, operations engineers and technicians total about 2,000 jobs on the site, and because a new Technology Development Center (TDC) was announced in January 2009 to "connect the lab to the fab," this total will rise to more than 3,000 jobs by the end of 2014. Much of the mid-stage of the technology design is done in CNSE, reducing the time and risk of the work done in the fab.

Room for Further Expansion

Looking ahead, Mr. Russo said, the site would allow for even further expansion. There is space for two additional fabs, each 1.5 times as large as the present facility, which would represent another $30 billion in investment. "There are no plans for that at present," he said, "but if all the stars aligned, it could be done. And it would be unprecedented."

Most of the workforce in the fab are technicians, operators, and engineers. It is a well-paid workforce, with an average salary of about $87,000. GLOBALFOUNDRIES also has about 70 employees who work with partners in CNSE and SEMATECH, as well as about 80 employees in East Fishkill working with IBM. About 50 percent of GLOBALFOUNDRIES employees are from New York and the local region, while about 50 percent come from outside the state or country, including about 36 countries. "We're bringing in the best and the brightest," said Mr. Russo. "We're building an A team. And they don't sit still. They start their own businesses, they buy houses, they move around." About 10 percent of the workforce are veterans, a "field-to-fab" initiative developed with the state Department of Labor.

Mr. Russo said there were many reasons GLOBALFOUNDRIES chose New York State for its site. One consideration, not apparent to many people, is the surface geology of the region, which features a glacial sand deposit more than 120 feet deep. This means it is geologically stable—a critical consideration for a fab, where even mild vibrations can be disruptive at nanoscale. The vivid memories of the 2011 Tohoku earthquake and tsunami in Japan still influence plans for any new industrial installation world-wide.

The region also offered fiscal, economic, and human resource advantages. Critical was the access to a rich talent pool, most notably at both RPI, SUNY-Albany, and CNSE. "The education system all the way through is pretty solid," he said, "compared to other regions." Collaboration with university professors and students had been a major advantage, he said, as has the support of the broader community. "We have seen In New York State a real collaborative effort from top to bottom," he said. "The state made the strategic decision as long ago as the mid-1990s to invest in this sector, led by then-Governor Mario Cuomo and State Assembly Speaker Sheldon Silver." The original investments led to development of CNSE, and under Gov. George Pataki and State Senate Majority Leader Joseph Bruno, and subsequent investments grew into the "richest public-private partnership in history" to bring in a big fab. He said that the political leadership had understood the value of the project to not only the regional economy, but also to national economic security. Current Gov. Andrew Cuomo has continued that political support.

In fiscal terms, New York State provided an initial incentive of about $680 million in tax exemptions to offset the expenses of developing the GLOBALFOUNDRIES site. This was followed by the Empire Zone Benefit Program, which used a formula based on capital expenditures, number of jobs created, and other actions. Although the Empire Zone program has expired, the

incentives have continued, compensating additional investments by GLOBALFOUNDRIES with continued benefits. Additional reasons for locating the plant in the U.S. included strong IP protection and access to supply chains. The benefits of this strategy include ancillary jobs as well as direct jobs. He said that some 200 companies have either located in the region or increased their hiring since the arrival of GLOBALFOUNDRIES.

A Progressive Relationship with the Trades

On the part of GLOBALFOUNDRIES, a notable and successful initiative has been its strategy for working with the building trades and other local union organizations. Knowing that a project this large would require more workers with fab experience than were available in the region, GLOBALFOUNDRIES decided to negotiate a project labor agreement that was "mutually beneficial, addressing the needs of the business as well as the expectations of labor. We're proud of the fact that we've been able to develop what amounts to the largest private labor agreement in the history of this country. We're now in the process of negotiating a project labor agreement that would include all construction work we will do on the site.

"The trades have been very progressive," he continued. "We've laid our cards on the table and talked about how we can improve training. We're working with them to develop curricula so their workers are ready to work in the fab environment, so they know what a clean space is. It's a totally different animal, building these large fabs. We have to make sure the labor is available when we need it. For a fab, that can mean thousands of workers right away." He said the trades had also been supportive in understanding the regulatory environment, helping to move town and county policies forward, and handling safety issues. "As a result," he said, "jurisdictional issues have been almost nonexistent on the site."

In seeking to expand the labor pool, GLOBALFOUNDRIES has also established a strategy to promote minority and women-owned business enterprises. He said that the effort had been rated "exemplary" by the Empire State Development Corporation—"not because we had to do it, or we've found a cost-effective way to do it, but because we really think it is a win for the communities as well as GLOBALFOUNDRIES."

The Importance of a New Education Initiative

Another ancillary benefit of the fab, besides economic growth and the advancement of R&D-based innovation, is a new education initiative. Mr. Russo said that he was GLOBALFOUNDRIES' representative on the Tech Valley Connection for Education and Jobs (TVCEJ), which was "the nation's largest education initiative of its kind in the country." It covers 13 counties—about one-fifth the area of New York State—and extends from pre-K through higher education. "It is basically a very large-scale laboratory to try out the most

innovative practices," he said, "and to identify roadblocks and eliminate them. This is the only place we're aware of where the teachers' union has said they would be flexible in trying these innovative practices. He credited the Center for Economic Growth (CEG) with initiating that program, which had been requested by the Obama Administration in 2009.

The TVCEJ has also entered into a strategic partnership with SUNY, where it helps train and retrain workers through the community colleges using federal money. As an offshoot of the education initiative, the effort is developing a STEM credential for teachers. The lack of foundational math and science skills had been identified as a roadblock for teachers in their certification process. "When they move right into elementary schools without those skills," he said, "the students pick up the fact that their teachers are not comfortable. We know it's hard to change the certification process, so we reached out to SUNY for help." SUNY did agree to develop a credential for teachers who are going through certification; furloughed teachers who want to upgrade their skills; and tenured teachers who want to add skills. "That is a safe transitional model," he said. "And it will improve the hiring process over time because the certified teachers are the ones who will be hired."

THE TVCEJ also approached business and industry leaders about their training needs. Operations managers in manufacturing organizations all shared a need for more people with hands-on skills. Among problems they identified were fewer shop courses and other ways for "young kids working at real projects to get their hands dirty." Accordingly, the Tech Valley Connection started work on an advanced manufacturing pathway offering to students on an early college high school path, leveraging the trade schools and high schools, as well as traditional math and science high school education. This program will emphasize analytical skills, problem solving, statistics, process control, hydraulics, pneumatics, and the "soft skills" needed to hold a demanding job. "The students could continue on to a community college, and either jump off in one year with a certificate to go to work, or stay on for two years or four years for a more advanced degree and more focus. This will be offered through SUNY," he said. "People will see that and know what they're buying into."

Also underway because of GLOBALFOUNDRIES' presence is participation in the Clinton Global Initiative. GLOBALFOUNDRIES is leading a national discussion on how the supply chain can help small and mid-sized manufacturers identify opportunities to partner with larger manufacturers. "We've developed three models that we hope will merge into a national system that's user friendly," he said.

Mr. Russo reviewed the impact of the new fab, emphasizing that its importance was magnified by the importance of the semiconductor industry. The industry is responsible for over one million jobs in the country, and invested over $32 billion in R&D last year. "Semiconductors are seen as a key component of the future economy," he said. "And we are at the leading edge of this in our collaborations in the 450mm wafer transition, 3D stacking, extreme

ultraviolet technology, and advanced nodes. The fab in Malta is right now producing at 28, 14, and soon 10 nanometer sizes."[31]

He added that semiconductors are an enabling technology that drives all aspects of manufacturing, "and everything you touch today." He said that the Department of Defense depends heavily on the industry and its ability to innovate and supply the most advanced technology. "We can't afford to be second in technology development." As an illustration of this importance, he noted the intense interest of other countries in developments around Albany. In the past six weeks, he said, representatives from 11 nations had visited GLOBALFOUNDRIES, "trying to figure out why we're investing in New York."

Mr. Russo described the value of the fab by analogy to an anchor tenant in a mall. "To meet its own needs, the company had to bring in natural gas, a 30-mile water line, and electricity upgrades. It's very costly to bring in big infrastructure, but once it's here, it helps economic development throughout the region. The same was true for improvements in the educational system, he said, as well as for the innovation ecosystem. "Fabs facilitate the retention of process R&D and innovation," he said, "and the clustering effect creates the huge economic impact."

His one fear, he said, was that the policy environment could suddenly change. "With the stroke of a pen," he said, "a fab can go away. Our policy makers in Washington need to understand that if you're going to invest $10 billion or more, you need clarity on what kinds of policies to expect year to year, over the long haul." Federal policies in particular, he said, are key to an industry's survival, including EPA rules and regulations, export control reform, government research funding and technology programs, corporate tax reforms, immigration reform, education reform, and infrastructure. The semiconductor industry depends especially on a complex infrastructure and low utility rates, an area where firms in the U.S. often face a disadvantage.

"Global competition is not going away," Mr. Russo concluded. "The world is forever flat. Governments around the world are offering substantial incentives and accommodative regulatory environments to attract what they understand to be the most strategic industry on the planet. Policy makers need to understand that."

Discussion

Dr. Wessner emphasized the importance of three opportunities mentioned in the discussion: growth opportunity, export opportunity, and national security opportunity. "As I mentioned yesterday," he said, "the rest of the world wants this: the GLOBALFOUNDRIES building, the next fab, the educational benefits. And they are willing to do a lot to get it."

[31]He noted that 10 nanometers is about the distance a fingernail grows in five seconds.

He also praised GLOBALFOUNDRIES for its "enlightened" approach to the project. "I extend my compliments to Mr. Russo and the company not only for their vision, but for their positive attitude. We didn't hear him complaining about something they didn't have. We heard how the company is actively working to build what they need, connect the dots, and work on behalf of the whole community.

COLLABORATION AS A WAY FORWARD FOR SEMICONDUCTOR TECHNOLOGY: ALBANY NANOTECH

Dr. Gary Patton
Vice President, Semiconductor Research and Development Center
IBM

Dr. Patton began with a personal reflection about the importance of education, and the reasons for his own move to New York State 27 years ago when he took a job with IBM and moved his family to the Hudson Valley from California. He shared that he was motivated by the opportunity to work on cutting edge technology at IBM and the recognition that the Hudson Valley was a great place to raise a family. He praised the support of Mr. Russo and GLOBALFOUNDRIES for multiple educational initiatives, especially the Tech Valley Connection for Education and Jobs, and said that IBM shared this active approach to strengthening the workforce.

IBM and the Continuing Importance of Semiconductors

He, like several other speakers, focused on the continuing excitement and value of the semiconductor industry. "Some think of it as a recent explosion," he said, "but look at the historical perspective." He showed a graph that followed the cost of computing since the early 1980s, indicating that the amount of computing power one could buy for $1,000 had grown by 6 orders of magnitude. "I challenge you to find any industry with this type of improvement over such a brief time period."

He also said that the trend has been accelerating. For perspective, he said that in 1964, the IBM 360 system, which had "revolutionized computing," was powered by "a little module with six transistors and four resistors." Today, the IBM Watson system has 360 Power 7 chips, which his team developed. It has 1.2 billion transistors per chip, as well as embedded DRAM, "an incredible innovation in memory." Each chip has eight cores, each of which is surrounded by memory which can be accessed quickly.

The revolution in the mobile consumer space is also enabled by this explosion in technology, he said, "with an incredible growth in the number of people and devices connected to the Internet, and now the ability for cloud computing and analytics. This enables us to do some incredible things in terms of smarter cities, smarter water, smarter power."

The primary driver of this growth, he said, is economics. "If you can make smaller devices, you will have better performance and lower cost, which enables more applications and larger markets. The price of a transistor has improved since 1980 by about five orders of magnitude, while the consumption of IC transistors has gone up by about six orders of magnitude."

Recent Semiconductor History

He then offered a thumbnail sketch of recent semiconductor history. The curves of improvement, he emphasized, are not continuous. "We go through these steps when we bring in new disruptive innovations. They take us through 10 or 20 years, then we need new innovations."

In the 1980s, he said, IBM built its systems out of bipolar transistors, which were very fast but power-hungry. "So we went to complex packaging solutions to get that power out," he said, "but eventually we hit what we called the power limit. Then we went to something called planar CMOS technology, which was great. We simply bought a new lithography tool for patterning smaller features; we scaled the horizontal dimensions, the vertical dimensions, and the voltage, and included a few innovations. This brought more devices per chip, better power, and better performance. It also enabled portable computing and the whole internet revolution."

Around the year 2000, he continued, came another limit called the gate oxide limit, a key roadblock. "The limit came at about three atomic layers," he said, "and atoms don't scale. We could have said it was 'Game over,' no more scaling of technology. But we innovated and came up with a revolutionary idea. We said let's change the fundamental properties of silicon. If we can introduce strain into the wafer, we can accelerate the way electrons in the wafer move. Over the last decade that has enabled all of this personal computing and smart phone electronics. It all uses strain engineering and the material innovations that make it possible." IBM also introduced high performance embedded dynamic random-access memory (eDRAM), he said, which enabled very dense memory to be integrated with logic. This increased on-chip memory at the same area by three to four times, leading to significantly improved performance, lower chip power and better chip reliability.

Reaching a Transition Point

"We have reached another one of these transitions now," he said—"the end of planar technology. Again, we could say, 'Game over.' But no, we innovate. Let's go to 3D, such as chip stacking and finFETs.[32] Eventually,

[32]IBM's finFET device is a double-gate field-effect transistor. Its distinguishing feature is that the conducting channel is wrapped by a thin silicon "fin," which forms the body of the device. Both IBM and Global Foundries have announced plans to offer 14-nanometer process technologies featuring finFET three-dimensional transistors.

around 2020, we'll have pushed that technology to the limit. We'll hit what I call the atomic dimension limit, and we'll have to get into nanotechnology—silicon nanowires, carbon nanotubes, and photonics—to speed the transport of electrons around the computer chip. Work in all those areas is going on in our research center in Yorktown Heights, New York. These breakthroughs in nanotechnology are going to result in exciting things: wearable electronics, connectivity everywhere, cognitive computing."

He emphasized that the story of microelectronics is largely a story of materials innovation. Before 1990, only about half a dozen elements were used to make a silicon wafer. From then until 2006, another half-dozen were added. But since 2006, some three dozen more have been explored for use. "The technology is now all about materials innovation," he said. "We keep innovating and breaking the old paradigms."

The nature of innovation itself has changed, he continued. During the 1990s, advances consisted almost entirely of scaling—designing smaller and smaller components, and "sprinkling in a little innovation." Today, the economics of Moore's Law are holding true, but the path of traditional scaling is reaching its limits.

The new model has two elements, he said. The first is technical innovation, where material and process innovation must transcend the limits of traditional scaling. This requires long-term R&D to sustain the technical roadmap, and design technology that can support and leverage materials and process innovation. "All the recent breakthroughs," he said, "have been technologies that were in the research phase for well over 10 years before they were ready to be commercialized."

A New Model of Collaborative R&D

The second element is the business model, where collaborative R&D replaces independent R&D. "This is something we recognized all the way back in 1990," he said, "when we started our first technology alliance on 64-Megabit DRAM with Siemens in East Fishkill. Eventually Toshiba joined us, and the partnership migrated into our logic alliance and then our partnerships in Albany, where it has spawned other collaborations. We came to the conclusion that it is not only about collaborating between process companies, like GLOBALFOUNDRIES and IBM; it's collaboration with the equipment suppliers and materials suppliers. And all of them are now moving to the Albany NanoTech complex. The benefits of this are shared investment, shared learning, and the ability to accelerate the process, versus going it alone."

The path of an innovation, he said, is long. The fundamental research phase takes about a decade, beginning for IBM primarily at the Yorktown center, and also at Almaden and Zurich, where researchers study new materials, processes, and devices. The next phase is advanced semiconductor R&D, where those ideas are explored for feasibility and developed into prototypes at the Albany NanoTech complex with equipment and materials suppliers,

SEMATECH, and the Global 450 Consortium. This is followed by technology development, involving multi-company collaborations, "a very important element of our strategy." Process technology development is done in East Fishkill, packaging in Bromont, Quebec. Finally comes manufacturing. IBM in East Fishkill makes high-performance servers, ASICs, and games products, while GLOBALFOUNDRIES in Malta provides the foundry technology offerings.

He reviewed the research activities of IBM, for which the company was awarded 6,478 patents in 2012, the 20th consecutive year it has led the world in patents. "This is what motivated me to come east and join IBM," he said. "Now that we have this incredible high-tech corridor, it provides even more motivation for people to move to this area."

A Thinner, Wearable Wafer?

He highlighted in particular some recent breakthroughs involving carbon nanotubes, nanophotonics (chips using pulses of light), and wearable electronics and folding displays. "We've developed a technique where you can take a silicon wafer, cut it much thinner than a sheet of paper, and it can become flexible. Imagine it mounted on your arm, or folded up and shoved into your pocket. Imagine embeddable electronics that could correct your eyesight. Think about the semiconductor industry here in the Hudson Valley, and the potential to spawn many more companies and industries."

He also reviewed IBM's leadership in helping New York State realize the potential of its role in the semiconductor industry. IBM's long history of investment and innovation in the Hudson Valley created the foundation for a facility such as the Albany NanoTech complex, which is now a pathfinder for the global industry's move to 450mm wafer capability. "The investment of New York State has been critical, along with visionaries like John Kelly of IBM and Alain Kaloyeros of SUNY at Albany. In the past three years, the site has doubled in size, including a new office complex, an additional clean room, and a new facility for both the 450 Consortium and R&D expansion space, which houses the EUV Center of Excellence to explore the future of lithography. This is one of a kind." Albany NanoTech, he added, was the first site to demonstrate immersion lithography and developed the first working SRAM cell in a 22 nm manufacturing process.

Collaboration Up and Down the Supply Chain

"So today this is really about collaboration," he said, "not just IBM and GLOBALFOUNDRIES, but equipment and materials suppliers. These technologies are becoming extremely complex, and we have to work together to figure out how to make them work. The equipment suppliers used to do their research back in their own labs at headquarters, but they've concluded that they can't make these tools work without a close partnership with the semiconductor

manufacturers and access to leading-edge technology. And that's what Albany provides."

He said that collaboration was essential from a design perspective as well. "This is very complex stuff," he said. "Why has IBM not gone the route of a fabless company, just buying the technology it needs? For one thing, the technology we develop for IBM isn't available anywhere in the world. Second, this 14 nm and 10 nm technology becomes so complex you have to look at co-optimizing the entire stack, from the atoms to the devices, to the circuits, to the Watson system. Many of our fabless partners come to us and want to engage with Albany. They can't just wait for us to deliver a technology; they need to get in early, give us their requirements, and work with us hand in hand. This is how we were able to co-optimize the next chip which has just gone into manufacturing, the Power 7+ Microprocessor Chip. This is a huge chip, with the equivalent of 5.4 billion transistors, due to eDRAM efficiency." In addition, he said, the latest developments for the mobile space, including successful low-power applications for smart phones, have been achieved by the alliance of companies in Albany.

He summarized by saying that Albany NanoTech is "a really unparalleled facility" which is key for fueling what needs to be done for innovation and "to keep this roadmap moving forward. It has some unique capabilities, it's continuing to grow, and that means more people and companies coming into this region."

"I hope I have convinced you that we will continue to advance the technology," he concluded. "But it's going to take innovation and 'disruptive' approaches to find cost-effective solutions. There are many challenges ahead from both the technological and financial perspectives, and this is where the collaborative model not only helps but is essential."

Discussion

Responding to a question by Dr. Wessner about leading competitors, Dr. Patton said that leading-edge research and development at this level on high performance logic technology is being done only by the IBM Alliance and Intel. He noted that Samsung—a potential competitor—is a significant investor in the alliance.

GROWING THE SEMICONDUCTOR INDUSTRY IN NEW YORK: CHALLENGES AND OPPORTUNITIES

Daniel Armbrust
President and CEO
SEMATECH

Mr. Armbrust began with the following advice: "It's terribly important to make wise decisions on long-term investments when you have scarce

resources. I want to talk about how that has occurred in the semiconductor industry." He said he had personal memories of "the consequence of not doing that" as he grew up in "the steel country of Pittsburgh. A lot of my motivation is to be a part of getting it right."

He began his career in materials science, he said, and worked briefly in a summer internship for Intel, and noticed that "the seminal papers were written out of ATT Bell Labs and IBM in East Fishkill. I was looking for a source of innovation, and that's what led me to IBM for 25 years." He said that he worked closely with Dr. Patton in developing IBM innovations and moving them into manufacturing, "which is a really difficult task." After that he joined SEMATECH, whose story, he said, was "relevant to the regional story and what we're to become."

The Virtuous Cycle of the Semiconductor Business

Collaboration has many benefits, he began, but ultimately it is driven by economics. Over the last 50 years, the semiconductor industry had moved through a virtuous cycle, he said. Starting at the top of the cycle was the "idea we can continuously drive cost per function downward. This has always been expressed as Moore's Law, and what you see is the doubling of the number of transistors on a single chip of silicon over a nearly 50-year period. This has led to devices that now have five or 10 billion transistors on a single chip. One of those devices is probably in your pocket, and it seems miraculous to economists that we can afford it." This trend is likely to continue, he said, most likely through the form of "stacked" 3D circuits and 3D structures of the transistor itself, which in turn will continue to drive learning.

Moving around the diagram of the cycle he came next to "expanding applications on silicon and more affordable consumer devices," which in turn lead to the next phase—increases in semiconductor revenues. Finally, those increases in revenues lead to reinvestment of revenues in additional R&D and more innovation for the industry, which brings the cycle full circle. This continuous cycle, he said, is the driver for the economics of the industry, and shows the necessity for continued innovation in affordable ways.

The world of the 1960s and early 70s, he continued, was one of integrated device manufacturers, or IDMs. These vertically integrated companies did everything: systems, design, assembly, packaging, chip technology, and electronic design automation tools. Bell Labs did this with communication systems, in partnerships with AT&T and Western Electric; IBM did this with computing systems, making their own equipment as well as developing their own materials.

These IDMs began to fragment in the 1990s, and in today's industry structure many have been replaced by fabless and "fab lite" firms focused on

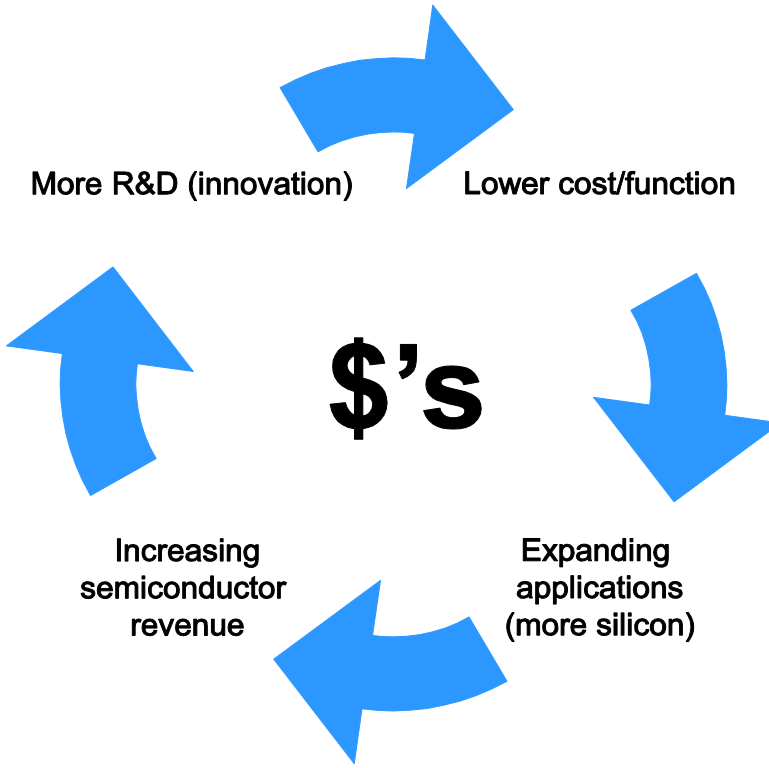

FIGURE 1 Semiconductor industry: virtuous cycle.
SOURCE: Daniel Armbrust, Presentation at the April 3-4, 2013, National Academies Symposium on "New York's Nanotechnology Model: Building the Innovation Economy."

design, and stand-alone fabs or foundries focused on manufacturing. Other companies specialized in memory logic, equipment, and packaging and materials. This industry structure evolved for reasons of focus, scale, and scope, he said, and was driven by economics. But because, as Dr. Patton said, it takes an innovation 10 or even 15 years to move through the development pipeline, different firms need to be able to see the benefit of the innovation and derive profit from it—no matter where they fit in the supply chain.

"With the advantages of this fragmented industry," he said, "comes the need to pull it all back together in order to introduce difficult new and important technologies. We have to ask, 'Who has to cooperate to get the job done?' The answer is, for most difficult problems, the industry has to find ways to work together in partnership to solve these problems. For this reason, we're quite proud that many forms of collaboration have developed in the semiconductor industry. Most of these are global in nature, although regional in presence."

Evolution of SEMATECH

Turning to SEMATECH, he said he would review the reasons for its formation in 1987 and how it has evolved. The formation of SEMATECH, he said, was a response to crisis. At that time the U.S. market share in semiconductors had dipped below 50 percent, and the trend line was "ominous." SEMATECH was part of a multi-pronged effort, coordinating research through Semiconductor Research Corporation, manufacturing through SEMATECH, and trade policy through industry and government.

"Looking back," he said, "I would say it was quite a success." For SEMATECH some of the most important transitions were to form a subsidiary in 1995 for 300 mm wafer conversion, which SEMATECH orchestrated, and to expand the membership to international companies in 2000. In the early 2000s it entered an alliance with the State of New York and the College of Nanoscale Science and Engineering at the University at Albany and launched a new manufacturing subsidiary to help semiconductor manufacturers increase productivity and lower costs. It then expanded its membership to include supply chain companies. Most recently it has entered into a partnership with CNSE to form PVMC, the U.S. Photovoltaic Manufacturing Consortium, an industry-led consortium created as part of the U.S. Department of Energy's (DOE) SunShot Initiative.

"The historians would say we're on SEMATECH 6.0 now," he said. "It's not what it used to be, and that's a good thing." Its mission now is no longer confined to research, although it does research. Instead, it specializes in bridging key industry infrastructure gaps through its research, development, and manufacturing programs. "We emphasize technology that our members prioritize. They say, we believe that this is going to go into manufacturing, but we have gaps in the infrastructure, and we help with that. That mission differentiates us from everybody else. It happens to be relatively non-sexy, and it's hard work. But it's key, and it's so important to do it pre-competitively."

He compared this approach with the history of the automobile industry. "Imagine if 15 years ago there was a common strategy to manufacture a hybrid engine, and all the auto makers trusted a collaborative entity to share one major engine development as a base platform. It would have been more cost-effective and would have reached the market quicker at a lower cost. Instead, development took place simultaneously in many places, to no great differentiated advantage. At SEMATECH we take a collaborative approach."

Addressing Challenges on Behalf of the Industry

SEMATECH also helps with many other industry-wide challenges. For example, it addresses the need for collaborative ways to address areas of common interest, such as waste reduction, safety and health, environmental issues, and manufacturing optimization through infrastructure investments.

The structure of SEMATECH has long been dominated by a few large chip makers working in partnership, notably Globalfoundries, IBM, Intel,

Samsung, and TSMC. All work at the leading edge, and all find benefits from working together on specific challenges. They receive the results of SEMATECH's R&D work, take it back to their labs, and optimize it, usually individually.

In addition, SEMATECH today has extended more deeply into the supply chains of equipment, materials, and fabless packaging. "We are working on tough problems," he said, "and the companies enjoy the benefits of working with the major chip makers. We need all members of the ecosystem to contribute researchers, equipment, materials, and dollars to solve these problems. So the network of members of SEMATECH has grown substantially; we have gained more than 70 supply chain members in just five years."

He added that collaboration is often motivated by crisis, such as the sudden dominance of Japanese chip makers in the 1980s. "Collaboration doesn't happen just because you wake up in the morning and decide to cooperate."

In the collaborative community of Albany today, SEMATECH has a network of more than 200 researchers. "They came because of the shared investments, because we all benefit from the infrastructure that's been put here, the tooling," he said. "Here the community has invested $13 billion and counting, pooling its assets to do much more. There's no way to create what we have here except through shared infrastructure."

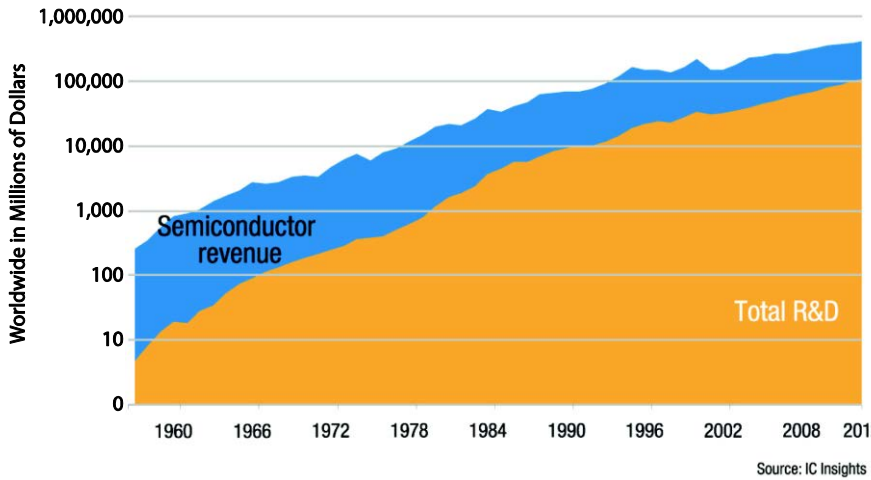

FIGURE 2 R&D costs.
SOURCE: IC Insights. Presented by Daniel Armbrust at the April 3-4, 2013, National Academies Symposium on "New York's Nanotechnology Model: Building the Innovation Economy."

The Challenge of Rising R&D Costs

Nonetheless, he said, the R&D costs of the industry are consuming a rising share of revenues—a trend that dates back to the 1950s. "If we didn't have the innovative collaborative models such as SEMATECH available to us, companies who were unable to fund R&D would have missed important opportunities for revenue growth. So while we're proud of all this collaborative work, it has to accelerate if we are to continue to drive semiconductors and nanotechnology where they need to go."

In the industry today, he said, despite the trend of escalating R&D costs, government provides less funding, presumably with the assumption that the industry is mature. "I would say this is not good policy," he said. "The semiconductor industry is critical to the global economy, enabling the technologies the world depends on. It is where investments become useful and re-used to fund other innovative industries."

In addition, he said, the supply chain is "extremely challenged" in shouldering their portion of the R&D burden. "They have less ability to do this than some of the large chip manufacturers. They are too fragmented, and while faced with difficult technology and investment choices they are continually pressured to cope with larger and larger investment choices. So we have genuine market erosion we have to address. Much of that can occur here if we play our cards correctly."

He discussed the semiconductor road map that "is now scaled into the third dimension. It does this to continue the economic proposition of Moore's law by using the vertical dimension as both logic and memory devices begin to stack." To continue this, he said, the need is to simplify the supply chain and find places in the technology pipeline where cooperation is needed. "What's needed is a holistic approach," he said. "It's not just to get the right materials, but can it be scaled to a manufacturable tool; do we understand the safety and health issues of putting interesting elements in the fab; can we get the cost down through productivity; and can we solve the yield problem. SEMATECH has programs geared toward this ongoing evolution of the silicon, and its ultimate replacement with other materials and devices."

Semiconductor Transitions: 'Hectic, Expensive, and Risky'

Another important area, he continued, is patterning the wafers. Over the last 40 years, the industry has reached transition points in developing the power source, defect-free masks, resist resolution, reticle protection, and optics quality. "Each transition is fairly hectic, expensive, and risky," he said. "And the big transition we're about to make is from a 193 nanometer wavelength to 13.5 nanometers. These things are exotic. We drop liquid tin into a chamber, shine a laser on it, and hope to get usable light out of it. We're always assessing the infrastructure—what do we need to get done. In many cases, inventions and brand-new technology all have to come together to successfully introduce the

next generation. Several billion dollars have been spent, and we've been working on these problems since the first tools came to in Albany in 2006."

What do the solutions look like? he asked. "In one case we have to actually find the defects that could fall onto masks that we fabricate. These defects can be extremely small—smaller than the images we're printing. We have to find them, determine where they come from, and resolve them. In this case, several key metrology tools were simply missing because of the risk of investment. They were obvious, but the tools cost over $100 million each, and the timing was uncertain. For any one company that is probably not a good investment, but here we could define the need, rally the chipmakers, and propose a funding model that makes sense. This was replicated in three different instances to address the infrastructure problem."

Attracting More of the Supply Chain to Albany

Similarly, he said, the industry needs to access expensive equipment to optimize the materials for imaging. By next year every materials supplier of consequence, most of them from abroad, will have done significant work in Albany. "They choose to invest here to share the infrastructure. In terms of the small defects, this issue brings to Albany a huge opportunity to claim leadership originally held in Japan. We have an opportunity to take this expertise and apply it not only to semiconductors, but to a wide range of industries where very small dimension cleaning is important."

He noted that the model of collaboration was being adapted to the solar photovoltaic industry as well. With the support of many companies in Albany, a group has been able to raise funding, partner with CNSE, and introduced a user facility at nearby Halfmoon, New York, that can be used by industry for what would be considered risky experiments in manufacturing. "This facility is up and running, and in a very challenging environment, it can be a source of stability as the industry evolves."

Thoughts on the Region's Future

He ended with several thoughts about the region's future. First, an important strategy is one that is focused on the long term, and a willingness to create opportunities for other companies to come here and lower their own costs by sharing infrastructure. "SEMATECH has benefited enormously by the consistent support of New York State, and by being a partner with many people in this room."

Second, he said, over the next five years, more of the supply chain will migrate to the region and be part of the growth story. "For me, this is all about the combination of public-private partnerships driving the ecosystem and infrastructure. There has been visionary leadership over 15 years that has taken Albany from a dot on the map to something that's recognized worldwide."

Third, he concluded, "when I talk to people across the world, they ask what's going on in Albany. They want to learn, and they want to compete. I would caution you about complacency. We are where we are, and many people are trying to copy what we are doing and get ahead of us. It's time to double down. We have strengths, but we need to continue to invest in those strengths, so that 10 years from now you'll read every day about a new startup, a new spinoff, more venture capital, and jobs. That can be our future."

Panel IV

21st Century Universities: Drivers of Regional Growth and Employment

Moderator:
Luis Proenza
President
The University of Akron

Dr. Proenza introduced the panel by recalling the passage of the Morrill Act of 1862, which allowed public universities to play an increasingly important role in economic development. "With each major transformation of technology we see their role expanding," he said, "and certainly we heard this morning about how the collaborations formed from technological opportunity, and economic pressure brings opportunity for even further innovation."

An interesting development, he said, is more collaborations not only within industry but between academic institutions and clusters of companies. Still, at present only about 5 percent of university basic research is supported by industry, so there is a "huge challenge" in bringing the two sectors more closely together. The two sectors often have disparate cultures, he said, but closer collaboration can nonetheless bring opportunities for both.

He offered an example from Northeast Ohio, where the University of Akron is increasingly regarded, in his words, "as a broad-based and yet robust platform for economic development." One objective is to integrate the university in a "relevant, connected, and productive way with the major economic clusters of our region."

In setting out toward this objective, he recalled, an early discovery was that many technologies are "stranded" when companies or industries hold them captive for fear of competitive pressure. But he found it possible to "make use of the IP rights for a particular application, and take the resulting technology into an open innovation environment." He said he had done this with the Timken Corporation, an early collaborator. "This frees the technology to be useful to other industries and fields, and to expand economic opportunity. That is a type of precedent-setting collaboration that most companies would avoid, as indeed

our colleagues did when we first presented the idea. But it is the kind of collaboration we're seeing more and more, and that we have seen in the unprecedented collaboration around SEMATECH."

He introduced the first speaker, Nancy Zimpher, as a long-time colleague with whom he worked in Ohio.

THE POWER OF SUNY

Nancy L. Zimpher
Chancellor
The State University of New York

Dr. Zimpher thanked the NAS for its leadership and for its decision to hold the series of regional conferences for the lessons and models they provide to others. She reviewed her opportunity to join SUNY as "a marvelous platform to take good ideas to scale," which she called a "critical ingredient in both economic and social development. "We have countless pockets of brilliance in this nation," she said, "but we do struggle with connectivity. So the power of SUNY has been as a vehicle to think about scale and the concept of collective impact."

She joined Dr. Proenza in praising the power of the Morrill Act, whose 150th anniversary was celebrated in 2012, and said she would propose a value proposition in honor of that legislation.

"There are anchor institutions in every geographic environment where we live, especially the state universities. They're not moveable; where we are is where we're planted. So let's make use of these anchor institutions. What Lincoln did in the middle of the Civil War, at the instigation of Justin Morrill, was nothing short of extraordinary. I would predict that if the Land-Grant Acts were authorized today, it might have different members, including urban universities and massive university systems like SUNY which play a major role in advancing education." She praised both Governors Dewey and Rockefeller for "understanding that we could connect this entire state through a network of campuses. And I have learned that the goodness of SUNY grows out of its diversity. It is community colleges, technical colleges, baccalaureate colleges, doctoral institutions, medical schools, and a host of applied medical fields."

The 'Audacious Goal' of Being an Economic Engine

Now that SUNY is in place, and has such size and diversity, how can it best be used? "You try to craft a goal," she said, "that only a large, diverse system could execute. And after months of deliberating—because after all we are a university system—we arrived at the audacious goal of being an economic engine. For the last four years this has been a defining aspiration for the system. It is also a stake in the ground: we are not only for innovation and entrepreneurship, but we can contribute to a healthier New York, an energy-

smart New York, and an educated New York, because we have campuses within 30 miles of every New Yorker. We can add to the vibrancy of every community, and attach ourselves to institutions and businesses around the world."

Next, Dr. Zimpher asked, what steps do you take when your aspiration is to be a state economic engine? "First of all you have to make friends with the state political structure. No one has been more of a friend to SUNY than Andrew Cuomo. Three years ago he started us down a path called NY SUNY 2020. He said that we need to invest in our research universities. So in each of the four doctoral institutions of SUNY we have strengthened translational research, life sciences research, entrepreneurial research, and energy research. Then two years ago he broadened NY SUNY 2020 to all 64 of our campuses. And just days ago gave us Round 3, adding CUNY to the roster. So we are all driving economic development."

The governor also divided New York into 10 economic regions. "Before that decision, one agency had 15 regions, one had five, and one had eight. We finally have a map that stands still and lets us invest where we grow." On the map is each SUNY campus, each center of advanced technology, small and medium-sized business centers, innovation clusters, and incubators, "all of which we are trying to knit together for their collective impact on the state's economy." Also on the map are innovation hubs that can radiate research, discovery, "innovation just in time," and application to drive economic development. In the Capital Region are six SUNY campuses with total enrollment of 78,000, working collaboratively, "a powerful way to approach development."

The Goal of Being a 'Thought Leader'

Dr. Zimpher said that another goal is for SUNY to be a "thought leader." Under Gov. Cuomo's plan, "the first thing we did was host a conference on the role of higher education in economic development. Most universities call economic development 'how many people you employ and how much money you spend.' We call it 'moving the dial.' What have you done to reduce your carbon footprint, to increase the number of students in the education pipeline?"

At a conference last year, she said, participants discussed the whole being greater than the sum of its parts. "We have to unpack what it means to do partnership, sharing the process when you don't care who gets the credit." She also asked each research university to define New York's unique intellectual capacities. This was difficult, she said, because "we're very competitive. We like to knock each other off. But I'm very proud that they all drew a picture that tells us what the human capacity of New York is. We also agreed we can't keep growing degree programs if they're not related to workforce demands. With a system like ours, you can reward campuses that choose to grow in high-need fields. This coordinates the degree authorizations at many campuses."

Her personal favorite plan, she said, was for every one of SUNY's 465,000 students to be offered an opportunity for an applied learning

experience. "Now we want to take this idea to scale—what will it mean for students to have a work experience and a supervised opportunity to apply their learning? Our goal is ambitious, and it's embedded in a Department of Labor grant helping us train displaced workers. My other personal favorite is that we have to work diligently to stem the leaks in the education pipeline, from early childhood through careers. We even have a partnership with the Girl Scouts called Girls Love STEM, starting with the Brownies. How are you going to get an outcome at the end of the pipeline if you don't invest early? We are entering online education so we can offer adults an online degree in a critical work area when they have some education but not a degree."

Dr. Zimpher closed with what she termed her favorite quote, from David Leonhart of *The New York Times*: "Educating more people, and educating them better, is simply the best bet any society can make."

BUILDING INNOVATION INFRASTRUCTURE: THE ROLE OF EDA

Thomas Guevara
Deputy Assistant Secretary for Regional Affairs
Economic Development Administration
U.S. Department of Commerce

Mr. Guevara began with the announcement that the Economic Development Administration (EDA) is approaching its 50th anniversary, having been founded in 1965. He noted that the EDA's mission is to "lead the federal economic development agenda by promoting innovation and competitiveness, preparing American regions for growth and success in the worldwide economy." The original focus, he said, was on "bricks and mortar. But that was old thinking—if you built appropriate infrastructure, business would soon follow. It's still important, but now we look at a new kind of infrastructure that includes human capacity, networks, and collaboration. We try to reduce the friction that prevents the efficient transfer of knowledge and solutions between economic actors, and this informs some of the grants we make."

He said that EDA makes grants exclusively to government units and not-for-profits, and each has a job creation component. Major activities are to:

- Support technology-driven ecosystems.
- Support place-based, locally driven initiatives.
- Convene stakeholders, recognizing that the economy is now global.
- Invest in infrastructure.
- Leverage cluster assets.
- Promote knowledge sharing across centers of excellence.

In promoting regional development, EDA studies the cluster assets that already exist and plans to leverage them for further economic growth. It seeks to

diversify local and regional economies, deploy human capital that is aligned with job pools, develop innovation-enabling infrastructure, increase spatial efficiency to connect people easily, and create effective public and civic cultures and institutions. "We try to promote a culture focused around innovation, capability, partnerships, and most importantly trust. In today's economy you have to learn to trust people you just met. Universities do a great job at this; we try to get them to teach communities how to do this better."

A Nonlinear Feedback Model of Innovation

He showed a chart supporting a nonlinear feedback model of innovation. It began with basic research and moved to applied research, development, and commercialization. Along the way, he said, the graph depicted unanticipated spillovers from knowledge development, and many kinds of feedback that reinforce the effectiveness of each step. "How do we refine a product; who can help us refine it, how might that lead us back to new areas of basic research?"

In addition, the ecosystem needs to focus not only on tangible assets, but on the innovators, their means of communicating, and advisors who help them. "It isn't enough for an entrepreneur and a scientist to have a good idea they can commercialize together," he said. "They need people they can go to, not just in the early stages, but through the whole life cycle, an extended group of advisors they can readily access."

He described nanotechnology as a field in which the stakes are high. According to the National Science Foundation, he said, the worldwide market for nanotechnology products in 2009 was about $254 billion. By 2020 it will be about $3.2 trillion, with the U.S. forecast to hold a little over a third. "That presumes that we do the things necessary to actually capture our market share," he said. "We see a growth rate of 25 percent annually through 2020; this will require about 6 million nanotechnology workers needed by then, or 2 million in the United States. These are big numbers, and it's work we all collectively have to accomplish."

Examples of EDA Investments

He offered several EDA investments as examples of the work to be done. One, at the University at Buffalo, SUNY, is a grant to help establish the Innovation Hub (iHUB) to accelerate commercialization, connect entrepreneurs with the university, bring public and private partners together, create community resources, and cultivate skilled talent. "Hopefully we are laying a foundation to build an ecosystem that includes the systems of groups of advisors."

Another investment supports the Battery Innovation Center at the Naval Surface Warfare Center at Crain, Indiana. The technology and research emerged from a collaboration between Indiana University, Notre Dame, and Purdue University to focus on an energy storage system using nanoscale components.

EDA is helping the project move toward commercialization, constructing an incubation space as well as "soft infrastructure" to bring together the players, a market feasibility analysis, and other strategic planning to help develop markets.

A third example is an EDA investment in California at the Cal Poly Pomona Innovation Village. "In this case," he said, "the objective is to convert agricultural land to a marketplace with different uses, attracting R&D organizations and those who want to partner with the university system. The mission is to establish a world-class R&D environment for public-private partnerships."

He concluded by reiterating his basic theme—that the mission of EDA had evolved from a "basic bricks and mortar culture" to a new objective of helping the "robust ecosystems that are necessary to drive our economy toward the jobs of tomorrow."

UNIVERSITIES AS ECONOMIC ANCHORS

Donald Siegel
Dean, School of Business
State University of New York at Albany

Dr. Siegel began by proposing two theories. The first is that universities are essential in generating "general purpose technologies" or those technologies that have widespread uses in many sectors, broad applications, transform the production process, and help create new industries. Examples of general purpose technologies are steam engine, electricity (developed in the Albany region), computers and Internet, biotechnology, laser technology, and, more recently, nanotechnology. "It's important to understand the university's role in accelerating the development of those general purpose technologies."

The second theory Dr. Siegel mentioned was proposed by William Baumol, who was seeking to explain why the American economy is so successful globally. Baumol's theory is that there are two types of innovation. The first type is routine, systematic innovation. Routine systematic innovation is primarily the domain of large companies, such as Xerox, GE, IBM, DuPont, and Motorola, and is typically conducted in an industrial laboratory. The second type of innovation is entrepreneurial innovation, which is the domain of startup companies, many of which are based in or near universities. Baumol argues that a strength of the U.S. economy is its ability to support both of these innovation types, and that this combination allows it to generate enormous wealth. Dr. Siegel noted that universities are increasingly doing more to support entrepreneurial innovation.

Commercializing Academic IP: A Review of the Literature

He offered a brief summary of the "vast academic literature on the effectiveness of the university commercialization." An important debate over

intellectual property, he said, had been whether it is better to have inventor ownership of IP or university ownership of IP. "It looks as though, based on global evidence, the U.S. has the right IP regime," he said, which was expressed in the Bayh-Dole legislation. A second topic, he said, was that while the United States is effective at conducting basic and applied research, "it needs to do more to promote commercialization and entrepreneurship on campus. Entrepreneurial education and training is critical to induce successful commercialization." A third finding is that "universities are becoming more strategic in technology transfer and academic entrepreneurship." Fourth, property-based institutions, such as incubators, accelerators, and science parks, are in fact adding value to companies. "They are making companies on their facilities more productive and effective in their commercialization, especially when they are focused on an industry or sector."

At the same time, he said, there are bottlenecks to commercialization. A problem on many campuses is insufficient rewards for faculty members who want to engage in technology transfer. "Those of us who study organizational practice on campus have found that incentives are very important. Academics, like everyone else, respond to them, so having the correct distribution formulas is needed." Also important, he said, are the culture of the university and institutional policies.

Dr. Siegel noted that a key criticism of faculty involvement in entrepreneurship and commercialization is that those who become engaged with industry are pulled away from their research. Unfortunately, the empirical evidence does not support this assertion. Several major academic studies show that faculty members are just as productive in their research after they start a company or after they become engaged in commercialization.

Immigration is an important issue in this literature, he said. Several major studies had found that foreign-born academics at universities and national laboratories tend to be more entrepreneurial. This, he said, should have implications for immigration policy.

Finally, social networks of star scientists have an enormous impact on the rate of commercialization emerging from universities. This can be so important for states and regions that some locations, such as Georgia, have a policy of trying to attract star scientists because they have a strong impact on regional economic development.

Supporting Entrepreneurship, Rather than Patenting and Licensing

Dr. Siegel noted that several recommendations emerge from these academic studies. One is that an emphasis on entrepreneurship on campus is likely to have a greater impact on regional economic development than an emphasis on patenting and licensing. This is "because our students are our greatest asset, and encouraging them to get involved in entrepreneurship is very important."

Also, universities need to provide faculty with stronger incentives to become involved in entrepreneurship. This may be done through changing promotion and tenure guidelines, as some land-grant institutions have done to reward patenting.

Third, a more open immigration policy is needed for scientists and engineers who are engaged in academic entrepreneurship. "This has an impact on the economy and I think we should promote it," he said. Similarly, it is important to increase the participation and success of women and minorities. "Women and minorities have to be engaged in commercialization, not only research."

Fourth, entrepreneurship research has to be treated seriously as a complement to education and community-based initiatives.

Fifth, "we have to develop an entrepreneurial culture at the university and in the local region."

He also emphasized the importance of connecting business schools with the scientific enterprise and engineering schools. "Business schools have to be the catalyst for the effective commercialization of IP and ideas on campus," he said. "Any kind of program that makes that happen is going to accelerate the rate of commercialization."

Steps to Refocus on Entrepreneurship and Economic Development

Dr. Siegel stated that the University at Albany School of Business has taken many steps to focus on entrepreneurship and regional economic development. The first step was the creation of an undergraduate minor in entrepreneurship, as well as separate tracks in new venture development in evening (part-time) MBA program and a new concentration in entrepreneurship in the full-time MBA program, in addition to partnerships with CNSE at the graduate level. The School of Business also organizes the New York State student business plan competition, which was is now the fifth-largest student competition in the country, awarding $500,000 in prizes to more than 50 colleges and universities in 10 separate regional events. (The four larger competitions are organized by private universities, such as MIT, Stanford, and Rice, with much larger endowments than the University at Albany. Additional steps include a student venture fund and educational partnership with the University at Albany's RNA Institute. The RNA Institute conducts world-class basic and applied research on drug discovery and is working with the School of Business to promote entrepreneurship in the life sciences. The School of Business is also promoting economic development through its new undergraduate degree in digital forensics, in partnership with eight community colleges. This partnership helps students obtain jobs in digital forensics and information security, a key application of nanotechnology.

Finally, he said, "entrepreneurship has to be treated as a credible academic field." The School of Business supports research conferences tied to major academic journals on entrepreneurial finance, several held at the SUNY

Global Center in Midtown Manhattan. It has an award-winning Small Enterprise for Economic Development (SEED) program to connect innovators to entrepreneurs, as well as a Young Entrepreneurs' Academy, which brings middle and high school students to campus to learn how to start a company. It also hosts an academic journal, the Journal of Technology Transfer, (2012 Social Science Citation Index "Impact Factor" of 1.692) and organized "the world's leading academic conference on these issues" (the 2013 Annual Conference of Technology Transfer Society) at the New York Academy of Sciences in Manhattan.

Dr. Siegel ended his talk with an invitation to hold the next workshop on regional economic development in the new $64 million School of Business building on campus. "We want to use this building to house all the entrepreneurship programs we've developed, and to truly be the catalyst for the effective commercialization of IP on campus and in the region."

TECHNICAL TRAINING FOR INNOVATION-DRIVEN EMPLOYMENT

Drew Matonak
President
Hudson Valley Community College (HVCC)

Dr. Matonak emphasized the importance of community colleges in economic development. He noted that 37 community colleges throughout the state are part of SUNY, equaling "half its institutions and half our students." In terms of the "educational pipeline," he said, and the training of human capital, community colleges are critical. "Many students are not college prepared," he said. "We have a good number dropping out between 9th grade and graduation, and that's not a pretty picture. We need to be partnering with the school districts to address that issue."

He saw the responsibility of community colleges as extending to "the entire pipeline," including pre-K and elementary school. "We need to be an active partner with them as well. SUNY has a huge investment in early childhood education, and this is a piece of it." He mentioned an initiative called Albany Promise, a "cradle to career" program that brings all levels of educators together to maximize their collective impact. "We're working collectively and individually with our school districts. Over the last couple of years, budgets have been cut. We want to make sure the curriculum stays relevant."

The community colleges have many early college high school programs, he said, many of which reach across the region to link studies with appealing careers. He cited Tec-Smart, an initiative to teach clean technology, which includes high schools in 12 school districts. "We provide students with opportunities to work on real projects so they see what the opportunities are." HVCC also offers clean-tech education in photovoltaics, geothermal, wind, semiconductor manufacturing, and biotechnology. It has a DoE grant to provide

photovoltaics training to 20 colleges across the region, so that faculty can provide infrastructure in their communities, as well as a state Department of Labor grant with other school districts in the Hudson Valley to provide opportunities in STEM education."

The region also benefits from outreach from federal agencies, he said, citing the Northeast Advanced Technological Education Center, or NEATEC, which is funded by a National Science Foundation grant to train people in semiconductor manufacturing. "We want to make sure we meet the need for a skilled workforce, and we work very hard at that. The community colleges can do this only by working with the school districts, business and industry, and collaboration and support from the state and federal governments. We need to leverage all our strengths to drive the economy in the Capital District. I think the future for our particular region is absolutely huge and I'm excited to be part of that."

Keynote Address

Michael Fancher
Vice-President for Business Development and Economic Outreach
Center for Advanced Technology (CAT)
College of Nanoscale Science and Engineering (CNSE)
The Statue University of New York at Albany

Introduced by
Bob Blackman
Chair, Center for Economic Growth

Mr. Blackman announced that the keynote speaker for the session, Alain Kaloyeros, would not be able to attend. However, he said that he wanted to be sure his audience understood the central role of Dr. Kaloyeros in developing the Albany "high-tech corridor," and specifically the College for Nanoscale Science and Engineering (CNSE). The partnership that had developed around CNSE, he said, was a model that can "give the United States a competitive edge," and provide an inspiration for other regions. It was Dr. Kaloyeros, he said—a "dynamic, rare individual"—who "hatched that egg 15 years ago, when CNSE was just a dream." For a leader to remain in such a demanding position after such a long period and to be "just as pumped up as he was on day one, is an exceptional example of leadership." A second point worth remembering, he said, was Dr. Kaloyeros' creativity in building the public-private partnerships that now characterize the region. "On the campus today," he said, "we see the results of about $14 billion of investment, and less than $1 billion of that has been public money. This is an amazing example of the ability to collaborate with industry." He suggested that Dr. Kaloyeros' true talent, and the reason for his success in Albany, was his ability to not only see what is beyond the next mountain, but "to look three mountains ahead and know exactly what's on the other side of the third mountain."

In place of Dr. Kaloyeros, he introduced Michael Fancher, who had also worked on the development of the Albany cluster since its inception.

Mr. Fancher, who works with the Center for Advanced Technology (CAT) and on CNSE faculty in nano-economics, opened his presentation opened with a picture of Gov. Andrew Cuomo "for a good reason": the CAT had started with a grant from his father, Gov. Mario Cuomo. In addition, the president of CNSE, Alain Kaloyeros, was also hired under a SUNY initiative spearheaded by Gov. Mario Cuomo to bring entrepreneurial faculty to CNSE.

He said he would like to focus his comments on the new public-private partnership in Albany, which he called "a 21st-century model of economic competitiveness." He said that Gov. Andrew Cuomo had formalized that term in September 2011 when he announced the Global 450 Consortium, referring to the next-generation semiconductor wafers planned for the CNSE facility in the near future. "With a publically organized and managed partnership," he said, "the core is usually a university. It's unusual for a college like CNSE to manage. We try not to go back and look at old models; this is a new one."

While the term nanotechnology is broad, he said, capturing much of materials science, CNSE is focused on building structures at the nanoscale. "When you can do that," he said, "you open up incredible new areas in sensors, photonics, biological systems, and fluidics. The challenge is getting more expensive, but the promise is multiple applications. The work needs to be tailored to each application, and each has unique technology and business hurdles to overcome."

GLOBAL EDUCATION AND INNOVATION RESOURCES

He said that the main emphases at CNSE are global education and innovation resources. "By leveraging its partnerships with business and government," he said, "CNSE supports the acceleration of workforce training and commercialization leading to job creation and economic growth." He noted that President Obama had announced his National Network for Manufacturing Innovation during his visit to the campus.

A primary partner of CNSE, he said, is SUNY. He repeated the words of SUNY Chancellor Zimpher from earlier in the conference: CNSE is one result of "establishing SUNY as a key engine for the revitalization of New York State's economy and a catalyst for enhancing the quality of life for the state's citizens." A key partner in allowing the college to play that role, he said, is the SUNY Research Foundation. "It has established itself as a flexible, proactive, and innovative partner that plays a critical role in CNSE's adaptive model through the provision of world-class infrastructure and facilities."

As an educational institution, he said, the primary mission of CNSE is education. "We were the first in the world to establish a college dedicated to nanotechnology, to break down the silos between not only science and engineering, but also between biology, chemistry, computational science, and even economics." It has a broad array of programs that focus on engaging the next generation of scientists and engineers. These include the summer camp program "Nano Career Days" for at-risk students; enrichment programs; Nano-

High, with Albany city schools; Girls Inc., sustained support for classes of girls. It works with trade unions to provide hands-on training, along with GLOBALFOUNDRIES. Part of the expansion planned for 2013 will include a relocation of Tech Valley High.

CNSE PARTNERSHIPS: 'A REAL STRENGTH'

CNSE has partnerships with many companies, including device companies, equipment suppliers, and materials suppliers. "This is a real strength," he said, "because it allows for consortia to exist across the ecosystem. Our competition, IMEC in Belgium, tends to have a centralized management that sets overall direction. We allow that for our consortia, such as SEMATECH and the Global 450, which determine their direction and leverage the infrastructure. But the other partners are free to have their own self-directed centers that decide how they interface with each other."

Much of what companies do at CNSE is related to commercialization, he said. A company's early activities tend to be more consortia-based; as a product moves closer to prototyping and then to the commercial product, projects become more proprietary. A key to success, he said, is quick progress from lab to fab, and fast-turnaround prototyping. "Companies gain the ability to see that research on manufacturing-scale technology is critical to the transition from long-term innovation to medium-term development to short-term commercialization." The facility operates 24/7, he said, tracking the work in process. It functions "with the same rigor as a manufacturing facility," he said, except that it operates at a research pace rather than a business pace—generating only about "900 wafer starts per month vs. 60,000 starts" produced at the GLOBALFOUNDRIES facility.

In its public-private partnerships, he said, CNSE operates as an inter-regional technology hub that provides infrastructure and consulting that would not be available to most small technology companies. It does relatively little research, which most of the companies do themselves, and instead stands ready to help with the more difficult pilot/prototype phase and especially in the manufacturing scale-up phase, often called the valley of death. "That's always been the challenge," he said. "A small company would have to borrow money to build a factory before it has a market for its product." Instead, CNSE makes available the equivalent of a factory for small firms to work on the essential proof of concept, development, and scale-up.

THE ALBANY MODEL AND COMPANY STARTUPS

The Albany model, he said, can also support other innovation demands of small-company startups. These include shortening the R&D time, sharing ever-higher capital investments, and leveraging know-how through partnerships with members of the supply chain. "The transition from research to development has always been difficult, time-consuming, and high-risk," he said. The reason is

that 90 percent of the cost and risk occur after the research work. As a result, CNSE adopted the strategy of inviting industry partners to co-locate at the campus. The college also installed unique, expensive infrastructure to enable an open innovation ecosystem. With that infrastructure the college is able to support not only short-term manufacturing challenges, but to involve the supply chain in the development phase, and to catalyze consortia-based activity that focuses on path finding for long-term research.

Institutions in upstate New York have created numerous kinds of partnerships. One is a $40 million partnership recently announced between Albany Molecular Research Inc., a drug discovery, development, and marketing company at the SUNY Albany campus, with the BN Medical Campus of Buffalo and Niagara. CNSE has a new partnership with SUNYIT, which is constructing the Quad-C Campus in Utica as a major center for nanotechnology, computer chip fabrication, and nanofabrication. CNSE is also moving into photovoltaics as a member of the consortium Solar Energy Development Center, at Halfmoon, New York, about half-way between CNSE campus and GLOBALFOUNDRIES in Malta. And most recently the Smart Systems Technology Center is being developed at CNSE to develop micro-electro-mechanical systems (MEMS), in partnership with Lockheed Martin at the Syracuse Electronics Park.

LEVERAGING THE STRENGTHS OF EACH REGION

As the CAT seeks to enable growth statewide, he said, it would try to leverage the strengths of each region on the basis of its unique assets. It would also seek to bring in funding in support of technology that can transition from one market to adjacent markets. In the past, the only funding source for many areas, such as autonomous sensing, smart systems, robotics, smart cities, and transportation grid awareness, were defense agencies. But while markets for all these technologies are present in many applications, there are barriers to commercialization, including government regulations, tax and IP concerns, and lack of knowledge of interfacing. "A university can enable technology development like this," he said. "We're a neutral site." He said that the development of the 450 mm wafer technology would enhance the ability of Albany-based enterprises to work with leading-edge companies on a variety of semiconductor and related technologies. "We want to be a one-stop shop, from the lab to the fab.

That's a cornerstone of what will continue to drive the ecosystem."

He said that the emerging market for "smart cities" expertise is a good example of how the CAT can help. This expertise involves knowledge of many systems, including transportation, water, energy, health care, sociology, and urban planning. For example, in downtown Albany, the old Union Train Station was collapsing in the early 1980s when Peter Kiernan of Northstar Bancorp invested the money to restore it. The Governor's Regional Council awarded the college $4 million to acquire and outfit it for multi-tenancy as a site to attract

companies to downtown Albany. Albany Mayor Gerald Jennings moved his agencies there "to be used as a test bed." In addition, he said, New York City is a market opportunity for smart cities technologies, "a unique opportunity to develop your device, test your systems, and build workforce training programs."[33]

In all, he concluded, the CAT works with more than 300 companies from around the world, in electronics, energy, IT, defense, and health areas. "We're at $14.5 billion in direct investments in Albany and $28 billion statewide. More than 3,100 people work on the CNSE site today; when I started there were four of us and our graduate students. I like to say it has been a nice startup. I think the vision of Governor Cuomo and President Obama is that the state and the nation are well positioned to compete in the 21st century."

DISCUSSION

Investing in Infrastructure for Companies' Use

A questioner asked whether the National Network of Manufacturing Initiatives (NNMI), which is pictured as large, self-sustaining consortia, might fit in the New York scenario. Mr. Fancher said that the New York strategy has been to invest in the infrastructure at the college. Those grants do not go to companies, but to the college to support the companies. "I would envision that New York State would replicate that model, and that the investment would be given to a public steward to manage implementation. The federal dollars might focus more on operational aspects." He recalled the discussion by Dr. Armbrust of SEMATECH about the virtuous cycle of growth, and said that this was unique to the semiconductor industry.

"What NNMI seeks to do is prime the pump on new virtuous cycles in emerging markets, like biomedical devices. There may be 'off-ramps' from the semiconductor industry that can be leveraged to bring more force to the cycle. I think New York is well positioned because of the partnerships that already exist to leverage other areas; the Rochester region, for example, is phenomenal in photonics, and also strong in flexible organic LEDs. There is a trend toward flexible, wearable technologies, so we can see an advantage there. In that marketplace you can envision bio-implants that you want to be flexible, especially at the brain computer interface.

"The key is not just to start the NNMI center—it's to feed the center. These companies are looking for emerging markets; equipment suppliers that want to build tools for markets that don't yet exist. New York has a unique position through the college to engage those companies."

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[33]The concept of "smart cities," or "city science," is driven by the likelihood that 90 percent of global population growth in coming years will be urban. Leveraging advances in data analysis, sensor technologies, and urban experiments, city science seeks new insights in creating a data-driven approach to urban design and planning. <*http://cities.media.mit.edu/about/cities*>.

Kathleen Kingscott of IBM asked whether any other states had models New York can learn from. Mr. Fancher said that the Akron, Ohio, region had done "world-class work. You can see it in the aerospace industry. I think they have an understanding that to build an ecosystem of companies you have to have focus. If you try to be all things to all people, you're nothing to no one. Also, don't be too narrow, but understand that a platform can best enable you to expand into other areas through partnerships. The college did not invent the semiconductor industry. It was thousands of companies making baby steps every day to ensure that our chips never fail when we turn on that phone. How do you harness that and focus it on emerging markets. The regions that can implement those strategies are the ones that will succeed."

Needed: A Model for Pharma

A questioner asked if there were any models in the Cambridge area, a concentration of biotech firms. Mr. Fancher said that "pharma is an industry that is screaming for a new public-private partnership. They're where the semiconductor industry was in the mid-1980s, when those companies came together and said, 'You know this is nuts.' There are too many paths to pursue. We can't each do it on our own. The industry came together and formed a vision and a roadmap of shared challenges. Many industries are still at the early stage of that, but they have the SEMATECH example to give confidence. Don't be afraid of partnerships—don't be afraid of open innovation. Gov. Cuomo has driven that to a new level. I think we're at the beginning of a new paradigm in how to do this."

Panel V

Building Advanced Manufacturing Industries in New York

Moderator:
Frank Murray
President and CEO
New York State Energy Research and Development Authority (NYSERDA)

Mr. Murray, the president and CEO of the New York State Energy Research and Development Authority (NYSERDA), said he had been "in this field of energy and environment for about 35 years, both in and out of government." He first came to Albany to work for Gov. Hugh L. Carey, when he sat in meetings with business leaders of New York State. "And these were giants—not only in New York but internationally." The meetings were very different from those with now-Gov. Andrew Cuomo, he said. Some of the firms were still represented, especially GE and IBM and Corning, but "there's a whole new universe of industry here. It would be easy enough to look backward with nostalgia about what was, but I'd rather look at what is, and the opportunities to marry some of those giants with the emerging industrial and academic sectors."

The manufacturers in New York State have been through hard times, he said, but they continue to be an important part of the overall economy, especially upstate. In the Rochester area, he said, manufacturing accounts for about 25 percent of GDP, and across New York State for about 15 percent. Even in this depressed time, computer and electronic products manufacturing continues to grow, and if its growth continues, it will be the number one product area by the end of 2013.

Similarly, there is growth in some leading-edge technology industries, especially semiconductors and nanotechnology. So there are "wonderful opportunities," he said, and "wonderful assets," including the community colleges, the Albany nanotech complex, the SUNY system, and the new corporate partners. At NYSERDA, he said, "we don't think there's anything like it in the country."

AN EXPANDED MISSION FOR NYSERDA

Like the regional economy, he said, NYSERDA has evolved. It has certain core missions, such as energy efficiency, and it still consults on traditional energy loads, including heating/cooling and ventilating. It helps identify ways of reducing the energy footprint and lowering the cost of business. It helps companies expand or locate in New York State. "But it has also become a critical part of the overall economic development team. We've moved into this space to help institutions however we can." These included a contribution of $5 million to the $50 million award received from DoE. It also includes support for HVCC and other community colleges in developing laboratories for students.

It has also moved into new areas, such as a full program with a "fascinating focus on industrial process." It contracts with engineering firms and makes them available to clients. "We find out what you need, retain consultants, and improve your industrial process." It also has a data center and works with utilities such as Con Edison and companies such as IBM. It "pushes the envelope" for the academic and private sectors by providing a half-dozen clean-tech business incubators across state, five of them affiliated with university laboratories. It has just announced establishment of three proof-of-concept centers to help deal with the valley of death. "I think we're doing a lot of cutting-edge work here in New York State."

The bottom line, he concluded, is that "none of this works unless we do it in partnership. Government has to put in the right policies and regulatory environment, and occasionally sprinkle on a little cash. We have to capitalize on the brains and intelligence at universities and private sector labs. And we have to bring in new companies, because none of this creates one single new job unless we can attract private sector investment."

ADVANCED MANUFACTURING FOR NEW ENERGY TECHNOLOGIES

Minh Le
Director, Solar Energy Technologies
U.S. Department of Energy

Dr. Le said he would talk about "the solar space, some challenges, and how to help revitalize American manufacturing competitiveness." He recalled President Obama's determination to make the nation "a magnet for new jobs in manufacturing," and discussed how that might be done.

In 2010, he said, the unsubsidized cost of solar electricity was about three to four times that of conventional sources. "Admittedly, all other sources have subsides," he said, "so it's not quite a level playing field. But if we lower the cost of a new technology to the point where it's cost competitive without subsidies, the premise is that that technology will be able to scale and people will make the economic decision to adopt it—not just to feel good about being

green, but because it makes economic sense. That's our challenge, along with promoting deployment." In doing so, he said, "we expect to manufacture in the United States and also create jobs in both manufacturing and deployment."

Costs: 'When You Look at History, You Get Optimistic'

For photovoltaic, or PV, systems, achieving this goal of unsubsidized grid parity would require a price for PV modules of about $1/watt in the field. In 2008, he said, the price of PV panels was about $3.50 to $4 a watt. "We expected them to get to 50 cents a watt, a huge lift. But when you look at history you get optimistic." The learning curve for the price of PV modules since 1976 shows that the cost goes down with the quantity manufactured. "As you learn how to make something, you learn how to make it cheaper and better. Where else have we seen this? In semiconductors; this is like Moore's Law."

It turns out, he said, that the learning curve is enabled by innovation, which has been the DoE's primary funding objective. The cost of PV has been reduced by 95 percent in 35 years, he said, and more than 50 percent in the past 1.5 years. "To achieve our goal by 2020," he said, "we still have a way to go down this curve. Through partnerships, universities, national labs, and businesses, we're able to continue. For example, the PV Manufacturing Consortium (PVMC) here in Albany is centered at SEMATECH and CNSE. This is a great public-private partnership doing exactly what SEMATECH was able to do for the integrated circuit industry by working with companies in the space, as well as universities, to integrate and push the technology forward." Of the best solar cells made in last 35 years, he said, more than half the world records were made by researchers supported by the DoE. Consistent government support for R&D has enabled the industry to make better products, which then allows it to make them cheaper.

The Challenge of Non-hardware Costs

But innovation by itself is not enough, he said. The cost for a utility-scale solar power plant in 2010 was roughly $3.80/watt. Since then, what the industry has been able to achieve in just two years is dramatic. The average cost is now about $2.25/watt. The goal is to reduce the cost to $1. "We're almost half-way toward our 10-year goal just two to three years into the program." But the challenge, he said, is no longer just in the technology; it is in the balance of systems, or non-hardware costs. "The non-hardware costs for PV are all red tape: the time it takes a home owner to apply for a permit, get their solar system onto the rooftop, connected to the grid, creating energy, and reducing their electricity bills. That's a significant time."

Red tape, he went on is "sucking up people's lives." He said that in New York City it used to take nine months to apply for an install a solar panel on a rooftop. DoE began an effort to reduce that time by one to two weeks. "Now we have a program to help cities and states streamline those processes. In

just the first year, on average, across 40,000 systems, we were able to save one week. That is the equivalent of about 790 person-lives, or 10 lives' worth of saved time."

He called HVCC a "great partner" in this effort, because many trained professionals are needed to install solar systems. "Hudson Valley is part of our solar instructor training network," he said. "This is a growing part of the nation's economy. Today, about 119,000 people work in the solar sector, and the job growth is 13 percent annually, about five to six times faster than the broader economy."

He pointed to data that documented the rapid erosion of domestic PV cell and module manufacturing in the United States. In 1997, the United States held a 42 percent share in the world market, which was then small. By last year, however, when world made 25-30 GW of solar capacity, the United States held about 2 percent market share. "That is extremely sad," he repeated.

A focus for DoE is to make up some of that loss by taking advantage of U.S. innovations. This should not be as difficult as many people think, he said. Many people assume that the United States cannot compete because of high labor costs, but the actual manufacturing cost difference is small. For solar panels and other high-tech goods, factories are automated, and the labor cost difference turns out to be about five to 10 percent of the cost of finished goods. Shipping the panels over the ocean erases all that difference. "A lot of the advantage for other countries is the way they incentivize manufacturing with policies that attract manufacturing companies.

He recounted "another sad story" about a solar manufacturer with an R&D facility in California. The manufacturer told state officials he wanted to build a plant, and asked what help they could give, such as fast permitting and training grants for workers. "The people on the other side of the table were astonished that he wanted to manufacture there," he said. "That's the wrong attitude. That CEO went next to Texas, and proposed the same project. State officials opened up their book and said, 'We can do this, this, and this.' Guess where the manufacturer put his plant?"

Innovation is Needed to Compete Internationally

At the international level, he said, innovation is necessary. "If you look at the cost difference of manufacturing in the United States or China, even with the large subsidies for Chinese firms, we can close that gap if we have factories more automated, equipment more productive, and quality higher. We could actually win here, and come back from the trough we are in."

The same is true, he concluded, for clean energy manufacturing more broadly. The week before the symposium, the DoE and the State of Tennessee had launched the Clean Energy Manufacturing Initiative at Oak Ridge's Carbon Fiber Technology Development Facility. "This is where a national lab and a local university can partner to develop new, cheaper ways to manufacture carbon fiber, two to 10 times cheaper. The goal is to increase U.S.

competitiveness in the production of clean energy products—solar panels, batteries, wind turbine blades—and also increase U.S. manufacturing competitiveness across the board through increased productivity and utilization of energy sources we have in the United States."

He closed by saying that DoE was about to join the Council on Competitiveness for a series of workshops with business leaders and state and local officials around the country. The objective was to gather ideas at the regional level about the best opportunities for the Clean Energy Manufacturing Initiative.

UNIVERSITY-INDUSTRY PARTNERSHIPS FOR NEXT GENERATION MANUFACTURING

John Wen
Director
Center for Automation Technologies and Systems
Rensselaer Polytechnic Institute

Dr. Wen said he would follow up on the themes of previous talks while emphasizing the Centers for Advanced Technology (CAT) around the state. He focused specifically on the Center for Automation Technologies and Systems (CATS), located at RPI, which has a renewable 10-year grant and receives annual baseline funding with an industrial match requirement. All the CAT centers, he said, were indebted to the funding agency NYSTAR for bringing higher education and industry together. NYSTAR also funds 10 Regional Development Technology Centers that work with SMEs, as well as high-performance computing, including RPI's Computational Center for Nanotechnology Innovation, a joint $100 million investment by the state, RPI, and IBM. All three components, he said, "should work together to help manufacturers in the state."

He said that the CAT program, started in 1983 under Gov. Mario Cuomo, worked within the university context. At that time, such industry-university collaborations were scarce even at the federal level. The program's primary activity was applied research, and its express mandate was "industrially-driven research leading to measurable economic impact."

Dr. Wen noted a question asked at the time: "Is this the right road for a university?" A number of components within the program showed foresight, he said. One was the baseline funding. It was not a large amount, but it was sustained for 10 years, allowing projects an essential degree of continuity. Also, it was not just a grant, but an industry-matched grant, and it was renewable after the 10-year period. This differed from such federal programs as the NSF's Engineering Research Centers and Science and Technology Centers, which usually end after ten years.

Measuring Success by Economic Impact

A notable feature of the centers is that their success was measured not only by papers and patents, but by economic impact. "The key is the return on investment," he said. And since 2000, the centers have been successful, documenting about $5 billion in economic impact in terms of job creation and retention and revenue generation.

He said that the CATs around the state are typically organized around disciplines, and the CATS at RPI is the only one dedicated to automation. For effective collaboration with industry, he said, there has to be research staff. Part of the funding for this is provided by the state to foster effective collaboration.

He returned to the question of whether the university is the best venue for CATs. There is "always this debate," he said, "of how best to balance applied research, usually with a company-specific focus, with the basic research we know is the driver for innovation and long-term discovery. The key is that industry tells us what's important. That is like gold for researchers," because it allows them to focus their energies on what is most relevant.

An R&D Cycle that Benefits Both University and Industry

He said that his approach is to view the work as a cycle—from basic research to development to commercialization and back to basic research. It begins when industry articulates a specific need and asks the university to provide a proof-of-concept model that can demonstrate a solution. This is followed by industry-university development to produce a product and demonstrate commercialization. "The key for us is leveraging the partnership to not only find a specific solution, but to abstract it to a more general methodology. At the same time, the industry partner is looking at the relevance, a longer-range opportunity, new tools, and new IP."

He gave several examples of this approach. The first is a fuel cell to provide clean energy. A small company came to RPI and licensed a high-temperature fuel cell membrane demonstrated by a faculty chemist. He demonstrated at table-top scale that it can be an effective membrane for fuel cells, but it was not clear how to manufacture it. "Our center's role is to reduce the risk for the company," he said. "We built a number of prototypes, and then helped them collaborate with a system integrator in New York to build a plant in Frankfurt, Germany. We continued to serve essentially as their VP for Engineering, and leveraged that to look at some challenging problems, such as bonding, which is very energy intensive; cutting; and new membrane technology. We leveraged NYSERDA, DoE, and an NSF IGERT PhD training grant, for continued research support. The company was very successful and was bought out by BASF."

A second example is a large company, Electro Scientific Industries, or ESI, a semiconductor equipment manufacturer in Portland, Oregon. The company used million-dollar machines for processing wafers, he said, but one

component was too time-consuming—a galvanometer that directs a laser beam. "We worked with them to develop a new vibration suppression algorithm. We did the prototyping in our lab, then ESI's engineer parked for a week to productize the technology. The algorithm was implemented in ESI machines, and now we have a joint patent and joint publications. Based on this work, RPI and ESI jointly obtained an NSF grant. Under this support, we developed a new microscope, and created new IP and licensed it to a different company, Thorlabs." In other words, the project started with a specific technology, and ended up with something more general, which leads to new research, new funding, and new intellectual property.

A third example involved work on composites with a large company, Northrup Grumman. RPI, with NYSERDA funding, helped them develop flexible tooling by a process called double diaphragm forming. With NYSTAR and NYSERDA support, this process was further refined and has led to the development of new efficient composites manufacturing processes, in partnership with Kintz Plastic Corp. "Again," he said, "the key was leverage for additional research support to generate new IP and support student involvement. We also have obtained additional NSF grants because of this relationship, which now leads us to a number of new companies, such as Ecovative Design and Vistex, startup companies by RPI students."

Difficult Challenges: IP, Continuity, Culture

Based on this expedience, he said he had observed a number of challenges. Number one is control of IP, and number two maintaining continuity, which he called "extremely challenging." Number three is the difficulty of reconciling the different timelines of academia and industry, and number four is how to build multidisciplinary teams.

His experience on these projects, he said, has taught him that there are two types of IP. One is company-specific, which he calls type one. Type two is more generalized, and is based on university lab research. "What we see as our role is to transform the IP from type one to type two," he said. "The company usually comes to us with type one, and we use this for the company. Then we help make a transition to type two, which is the kind that has the real value to the university."

He concluded with six lessons learned. First, for IP, he said, "we continually harp on the need to simplify the IP negotiation with companies. There needs to be a big Easy button for companies that want to work with universities. The process now still takes too long." Second, for long-term base funding, "If you have to choose between big and long, I'd rather have long. Long-term sustained funding is critical. Fraunhofer, A*STAR, and other institutions around the world succeed because they have long-term base funding. Part of that goes to research staff, which are needed as interface." Third, a quantifiable outcome is critical, especially for continuing government support and company buy-in. Fourth, there needs to be skin in the game for everyone:

companies sharing the R&D cost and universities reducing overhead. Fifth, build multidisciplinary teams both inside and outside the campus. "We need to avoid a zero-sum mentality in these projects." Finally, to close the loop or cycle, the best mechanism is "small successes. These lead to strong and sustained buy-in, and then the fulfillment of big vision."

LESSONS LEARNED TO DATE IN THE NEW 'TECH VALLEY'

F. Michael Tucker
President & CEO
Center for Economic Growth
Albany, New York

Mr. Tucker characterized the economic development of "Tech Valley"—a term designating an 11-county area adjacent to the Hudson River—as "a series of small steps and small successes." For more than 25 years, he said, the Center for Economic Growth (CEG) has been part of those successes, along with its 300-plus members in business, government, education, and the nonprofit world. "We're formed as a forum to discuss issues of regional concern, to identify opportunities for transformational change, and to work with others to bring those changes to fruition," he said.

A decade ago, CEG took "a critical look at how the region could pursue smart development that would benefit and build on its rich tradition of innovation and manufacturing, back to the industrial revolution." The group recognized that the paradigm underlying its work had changed, and that the economy "had become one of health care, government, and education." Partnering with the Rensselaer Polytechnic Institute's Lally School of Management and Technology, with grant from National Grid, CEG examined the industry clusters in the region and calculated where it should put its efforts. It identified clusters in the following areas:

- Advanced materials.
- Biotech.
- Cleantech/energy.
- IT.
- Nanotech.
- Homeland security.

Not surprisingly, CEG found a broad consensus among regional leaders that its economic development model should be cluster-based. "This did not mean isolated firms in one industry," he said, "but a geographic concentration of interconnected businesses, suppliers, R&D centers, and associated institutions in those particular fields. That's because clusters increase the productivity of companies and make them more competitive locally, nationally, and globally.

They do this by capturing the important knowledge linkages among technology, skills information, marketing, and customer needs."

Fortunately, he continued, as a result of this collaboration and forward thinking, "we have been making the smart strategic investments in our region necessary to position us as a hub for high-tech manufacturing in advanced industries. The capital region is well ahead of the game in making the adjustments necessary to connect and be successful in the global economy."

Technology-based Assets of the Region

He reviewed some of the region's technology-based assets, beginning with the supercomputing facility at RPI, in cooperation with IBM and the State of New York. The region has the highest concentration of clean-tech jobs in the nation, according to the Brookings Institution. And in the past few years, General Electric has added capacity to its Global Research Center in Niskayuna while expanding facilities in Schenectady in wind turbine service and advanced battery manufacturing. In addition, RPI has expanded its Rensselaer Technology Park to include a digital mammography imaging facility. GLOBALFOUNDRIES is ramping up production at its advanced chip fab in Malta, New York, and has announced the addition of an adjacent R&D facility. Finally, he mentioned the "tremendous opportunities and success that have been described at CNSE," notably the arrival of SEMATECH from Austin a decade ago.

Gov. Cuomo's Regional Economic Development Council, he said, has developed a new way of doing business in New York State, an up-from-the-ground process whereby each of the 10 regions around the state develops a strategic plan, and the state then looks to each of the plans to decide how to support them. This, he said, had stimulated in the capital region "a tremendous dialogue among stakeholders that might otherwise would not have taken place."

Manufacturing as a Priority

Along with R&D, the topic of manufacturing is a priority of CEG, which is a member of the NIST/Manufacturing Extension Partnership (MEP) and one of 10 NYSTAR-awarded Regional Technology Development Centers. CEG has held the NYSTAR designation for more than two decades, and its ongoing funding is predicated on impacts and outcomes from client surveys. As part of the NIST/MEP center, CEG offers a suite of services in sales, marketing, family business advice, startup assistance, business acceleration, productivity, and new market expansion.

Innovation is at the core of the MEP's mission, he said, because manufacturers that accelerate innovation are more successful and realize greater opportunities to participate in the global economy. Thus CEG provides service in innovation engineering; that is, developing a reliable, scientific system for developing and implementing profitable new ideas. CEG also markets the New

York's Capital Region nationally and globally to attract new business and investment.

Workforce Development as a Key to Clusters

Finally, he said, CEG considers workforce development to be the key to leveraging emerging technology clusters. "We believe that our education and workforce pipeline is a critical factor in building advanced manufacturing industries and preparing our region for growth. We have had tremendous public-private investment over a 15-year-plus period in this region that has put us on the world stage. I believe that it will be a "once in a generation" opportunity to leverage this investment in our region. And if we don't have the employees to fill the jobs, the employers that might locate here will go elsewhere. This includes not only large companies, but the many small and medium-sized companies. We work closely with the Chief Executive's Network for Manufacturing, a group of 75 SMEs in the region, as well as with the Manufacturing Association of New York State to provide opportunities for owners and management teams and to advocate with both the state and federal governments on opportunities for their members. We also help them reduce costs by working with NYSERDA in marketing their energy efficiency program."

In workforce development, he highlighted the Tech Valley Connection for Education and Jobs, a joint initiative of CEG and GLOBALFOUNDRIES. "Essentially," he said, "this is a 13-county laboratory in which to try the most innovative practices in education and workforce development. It connects 344 schools in 111 school districts with the assets of local business leaders, and tries to identify opportunities to overcome roadblocks in implementing an improved vision of public education. We use a scalable format that will allow us to extend this model to other regions and states."

CEG is also involved in the Federal Trade Adjustment Assistance Grant received by SUNY for the Community College system. "We will be playing a role as business intermediary to work with businesses, faculty, and curriculum developers at the community colleges to ensure that students' learning opportunities will reflect the job opportunities the businesses will have." CEG also works with two other initiatives, the Albany Promise Project and Empire STEM Learning Network.

"We think these projects are important building blocks in preparing students and existing workers for high-tech jobs," he concluded, "and in providing manufacturing with trained employees and business growth services. We need to ensure that our region is able to take advantage of the tremendous investment that's been made here over the last 15 years. At the end of the day, it's all about the quality of life and a good job."

MANUFACTURING AND INNOVATION: THE GE PERSPECTIVE

Stephan Biller
Chief Scientist for Manufacturing
General Electric

"At GE," began Dr. Biller, "we talk about market-focused R&D. We think it's important that we focus our work on the areas our businesses care about. The way we do that is to force ourselves to seek funding form the businesses for about 60 percent of our budget. About 25 percent comes from the corporation for more long-term research projects, and the remaining 15 percent comes from government contracts." He noted that this model was similar to the model employed at RPI, orienting both corporate and government funding for long-term research. "That's why we collaborate tightly with universities," he said. "The business funding is used for what the business needs to accomplish, and they drive the agenda by their time frame, which is usually much shorter than the long-term work requires."

He briefly reviewed the history of GE, which he called the first industrial laboratory. It was founded around 1900 in Schenectady, and today employs about 3,000 people. The corporate objective had not changed since 1900, he said: to improve businesses through technology. More recently, however, the importance of cost had risen, and in the last decade had become a dominant concern. "That's why you saw many jobs moving abroad," he said. "But we think that's not the case anymore. The premium is no longer so much on cost as on innovation, especially in the businesses GE is in."

To be a leader in innovation, he said, GE has to "go after the best brains in the world." For this reason it has not only the research center in Niskayuna, but six or seven centers around the world. "We look at the specific needs of those countries, and try to innovate in those spaces." For example, India develops low-cost ultrasound because they cannot afford the expensive equipment we buy in the United States. In addition, GE had just announced a new center in Oklahoma that would focus on oil and gas—"obviously driven by the shale gas explosion."

GE has a long tradition of innovation, he said, from the incandescent lamp in 1879 to the new Durathon battery recently developed at the Global Research Center. He called the battery a "sign of how innovation and manufacturing can really help a region. I think it bring us about 350 additional jobs."

Pulling Appliances Back to Louisville

The global environment is changing, he said—so much that GE today sells roughly 55 percent of its goods abroad. "GE is not U.S.-centric anymore," he said, "though it is still a U.S. company. The shortage of rare earth elements is one of many examples where we have concerns; we worry about access and

cost. We have overcapacity in many industries, and labor costs are increasing in the developed world." As labor costs rise in China, he said, the low-cost manufacturing is moving to Vietnam, the Philippines, and Indonesia. "The Chinese are worried that GE is going to pull back its manufacturing jobs from China to the United States. We're not doing that, our goal is to produce where we sell." GE has, however, pulled back is its appliance business from abroad, mostly from Mexico, and also from China, to Louisville, Kentucky. The principle reason, he said, was that the engineering, manufacturing, and marketing activities were not close enough to each other. "We can produce appliance products cheaper in Louisville than in China, because we can discuss manufacturing principles and market research all in the same room. You can imagine how powerful that is."

Because of these new forces, he said, innovation itself is changing. "We cannot afford to have these long cycles of innovation any more. We need to get from the old linear supply chain to a much more interactive circle. You can't just design something you hope will work, select the material, and throw it over the wall; this is the compartmentalized model companies have employed for a long time. You need to get to a model where everything is integrated, not sequential. We have software now that allows us to do that."

He offered a few examples of innovation, including improved carbon fiber, which has long been important in the aviation business. Recently GE has developed novel casting technologies and hybrid laser welding for greater strength. It has also developed new microwave braising and nano spray coatings for jet engines. The challenge has been that jet engines now operate close to the melting point of the titanium alloy. The new coatings raise the melting point of the alloy, increasing safety.

The Move to Additive Manufacturing

A significant innovation is techniques of additive manufacturing. "We are moving from the old subtractive manufacturing," he said, "where you take a block of something and machine stuff away. We're learning to use a kind of 3D printing, building material from the ground up. This allows us to not have such a complicated supply chain. We get a decrease in material used and a significant increase in yield."

In addition to better machines and materials, additive techniques can create more complex product geometry. "We can make air foil cooling much better because we can print more complex shapes. We can have intricate cooling channels in the air foil, and this, too, lets us operate a jet engine at a higher temperature, which translates into significant fuel savings. This is in its infancy now, but I think it has a lot of promise."

A Disruptive New Battery Technology

A major innovation for GE, he said, is the technology for advanced batteries now being manufactured in Schenectady. "This is really a disruptive technology," he said. "We originally developed it as a hybrid battery for our locomotives, but found many other opportunities. These are very different from lithium batteries. They are virtually maintenance free, will probably last 20 years, and operate at about 300 C. Our first customers are in Africa, where they have cell towers not connected to the grid. Today these are powered by diesel generators, but if you put a rather large battery next to the engine, it can run as a hybrid system, allowing significant fuel savings and lower cost."

One reason GE built the plant in Schenectady, he said, was to provide employment for the capital region, but a major reason is "to have fast learning. With the plant right there in Schenectady, about five minutes from the research center in Niskayuna, we can test things quickly and send our engineers to the plant. This is invaluable if you want to innovate, and if you're working with a new technology."

The battery manufacturing process itself is also innovative, he said. The plant is instrumented with about 10,000 sensors that measure temperature, humidity, air pressure, machine operation, and other data; it has new tablet-scale control devices where the swipe of a finger can prevent machine malfunctions and adjust numerous processes. This allows continuous improvement of efficiency and quality at a much faster rate. Also, the system makes it possible to trace the performance of a battery in the field back to the original batches of powder from which it was manufactured; every step of the production process can be reviewed and analyzed. "This allows us to have an almost perfect product genealogy," he said. "If a couple of batteries fail—which is possible with a brand-new process—you can trace which operator worked on it, which supplier gave you the powder, and so on. It is a really good tool to sleuth those quality problems you invariably have in a start-up operation, and we are quite proud of that."

'Smart Manufacturing'

Some of these innovations are elements of "smart manufacturing," which describes the communication, feedback, and self-diagnosing elements of modern IT-based systems. "You have kind of a circle," he said. "You start at the top, with the correct design and engineering, and going around to manufacturing engineering, where they design the machines and the layout of the factory; from there you go to supply chain execution where you make the stuff, and then back to services. You want to be able to trace the data all the way from design to manufacturing engineering to manufacturing execution—and back. For example, the people who actually service our jet engines are capable of giving a lot of information back to the designers. They might say this really doesn't work the way you designed it, or this part is close to failing every time I take an

engine apart. Useful data flow from design to disposal and all the way back to design."

Dr. Biller ended with a tribute which had been articulated by others as well. "For us," he said, "it's very important to support the capital region. This is where we all live. And GE tries to do that wherever it lives."

Panel VI

Nanotechnology and Biomedical Sciences

Moderator:
David Rooney
Senior Vice President
Center for Economic Growth

Mr. Rooney said that Panel VI would "shift gears" from the discussion of the collaborative model and the growth of the nanotechnology cluster to "some of the convergence points between nanotechnology and biotechnology." This would include an exploration of proposed solutions to "some of our most vexing medical and health care challenges," as well as how a collaborative, SEMATECH-like consortium model in the biomedical and pharma sectors might create a next wave of opportunity for this region.

INNOVATION IN CANCER RESEARCH: THE NANOTECHNOLOGY OPPORTUNITY

Larry Nagahara
Director, Office of Physical Sciences—Oncology
Center for Strategic Scientific Initiatives
National Cancer Institute

Dr. Nagahara said that his own career was unusual in combining experience in the fields of both semiconductors and the life sciences. He had spent a dozen years with Motorola, where he had experience with manufacturing semiconductors and with nanotechnology, and he now worked at the National Cancer Institute on a unique program that combines oncology with the physical sciences.

The reasons he was attracted to cancer research, he said, began with the costs and intractability of the disease. He suggested that virtually everyone at the symposium had been affected by cancer, either personally or through a family member or friend. In the United States, 570,000 people died of the disease in 2012, and about 1.6 million were diagnosed with some form of cancer. The costs

to the nation amounted to about $260 billion, including testing, surgery, chemotherapy, radiation, and lost productivity. "This is a staggering number that will only get larger as baby boomers go into retirement."

His other point was the slow rate of progress in curing the many kinds of cancer. Unlike other major disease killers, he said, cancer continues to take nearly the same toll as it did in 1950. He showed a chart depicting the death rate per 100,000 over the last half-century. For heart diseases, the rate has dropped from 587 in 1950 to 179 in 2010, with similar declines for cerebrovascular disease and pneumonia/influenza. But for cancer the death rate per 100,000 has dropped only from 194 to 173. "Why?" he asked. "Can we think of innovative ways to change these numbers?"

Seeking Convergence of Cancer Research and the Physical Sciences

Clearly, he suggested, new ways of thinking about cancer are needed. The one he favors is to bring new perspectives to the biomedical sciences from other fields of science.

He reminded his audience that the concept of bringing together great thinkers from both the life sciences and physical sciences was pioneered in dramatic fashion by the collaboration of Salvador Luria, a microbiologist, and Max Delbruck, a physicist, in the 1940s. Working together, they won the 1969 Nobel Prize in Physiology or Medicine, along with Alfred Hershey.[34]

The program managed by Dr. Nagahara, called Physical Science Oncology, draws much of its inspiration from the success of Luria and Delbruck. It funds 12 research teams, each led by two scientists—one from the physical sciences (physics, chemistry, engineering) and one from the biomedical sciences (in this case, oncology or cancer biology). "The idea is to try to reach new perspectives by a convergence of points of view," he said. "We do this by coupling two people, one from each sector, and establishing a center." The idea of a convergence of the biomedical and physical sciences was articulated recently by Phillip Sharp, Robert Langer, and other MIT scientists in a white paper[35] that describes a "third generation" of discoveries in biomedical science.[36] "With this revolution," said Dr. Nagahara, "we should be ready for

[34]The famous Luria-Delbruck experiment demonstrated that mutations in bacteria, like those in other organisms, occur randomly and spontaneously, rather than directed by the circumstances in which they found themselves. S. E. Luria and M. Delbrück, "Mutations of Bacteria from Virus Sensitivity to Virus Resistance," *Genetics* 28(6):491-511, 1943.

[35]Phillip A. Sharp et al, *The Third Revolution: The Convergence of the Life Sciences, Physical Sciences, and Engineering*, Cambridge, MA: Massachusetts Institute of Technology, 2011. The authors write, "We see convergence as a blueprint for innovation. Advances in information technology, materials, imaging, nanotechnology, optics, and quantum physics, coupled with advances in computing, modeling, and simulation, have already transformed physical science. They are now beginning to transform life science as well."

[36]The "first revolution," he said, occurred in the 1950s with the discovery of the structure of DNA; this led to the genomics revolution and gene sequencing.

biofuels, improved medical care, and hopefully new insights to our understanding of cancer."

An Insight from Cell Phone History

He gave an example of a new insight from his own history of working with Motorola. He pointed out that 2013 is the 40th anniversary of the cell phone. When he was doing research at Motorola, he said, the "mantra of the cell phone industry was that smaller was better, and that's all you did. People didn't want to carry around a telephone that weighed as much as a brick and cost $4,000." By the time he left, Motorola had begun selling its much smaller series of cell phones called the Razr, which became the best-selling "clamshell" design on the market.

"But what happened after that?" he asked. "The iPhone came along and changed the whole paradigm"—even though Apple did not have its roots in the phone industry. "They just made computers. They didn't know anything about phones. But they had a fresh perspective. They gave us a phone that was not smaller than the Razr, but it did all those other things. That's what we want for cancer."

Reasons for Hope from Nanotechnology

One reason for optimism, he said, is that better technologies are bringing down the costs of instrumentation and raising capabilities. For example, the cost of genomic sequencing has been dropping rapidly—"my Moore's law?"—until it is "now getting as low as $1,000 to sequence the genome of a human being." Also, he said, within the coming decade one can expect to see benefits from the use of "nanopores," extremely small holes that may be created by a pore-forming protein or as a gap in a synthetic material, such as silicon or graphene. A nanopore of about 10 nm might be made in a semiconductor-like device, allowing a single RNA or DNA strand to pass through and its base sequence identified. Developing this technology will require participation from both biology and engineering.

Beyond the goal of developing new technologies, he said, is the goal of new perspectives. For example, the cause of 90 percent of cancer deaths is not a cancer tumor, but a cancer metastasis, by which the cancer spreads via the blood or lymphatic system to new sites. "Could you use the micro- or nano-fabrication technology you have here in Albany to understand the metastatic process?"

Another challenge for trans-disciplinary thinking, he said, was the failure of some cancer treatments. "When you are diagnosed, you typically get chemotherapy of some kind. Often the disease comes back a few years later and then it is resistant to that treatment. Why does that resistance arise? Can it be prevented by interventions at the nano level?"

Nanoscale Techniques to Find Cancer Cells?

Some of his grantees are already trying to answer this question, he said. "And if they had a facility like Albany's they could advance faster. With metastasis, cancer cells float in the bloodstream, migrating from the primary tumor. The question is, can these cells be detected and captured." He said that a grantee at MIT had designed a resonator—a silicon device that vibrates up and down as blood flows through it. The goal is to distinguish cancer cells by some difference from normal cells. "He can measure differences down to picograms; but will he also ask different questions than a medical person might ask? For example, are cancer cells more squishy, or slimy? He has a restriction channel the cell has to squeeze through, and he can narrow it down to a few hundreds of nanometers. Does a cancer cell go through faster or slower because of some squishiness or sliminess factor? Maybe you can have a drop of blood drawn at your regular checkup and the doctor can tell if you have some such disease."

He cited another example from the Methodist Research Center in Houston, Texas, where researchers are interested in the transfer processes of a disease. "When you have a therapeutic," he said, "the first question is, how do you know it actually gets to the cancer, and how long does it stay there. You only know you inject it, and you assume it gets where you want it. They are trying to understand the barriers: what can prevent the therapeutic from reaching its target and remaining there long enough? They are designing multi-stage vectors, little vehicles that are pores in silicon carrying imaging agents or therapeutics to the cancer cells. This is an example of using advanced manufacturing techniques in biomedicine."

He also gave the example of a dye. "I can inject dye of different sizes into a tumor. In a primary tumor, I see something light up. Where it starts to metastasize, it does not light up. This tells me that what I injected may not have gotten there. How do I improve that? It allows drug manufacturers to design better drugs."

Finally, he said, a group at Princeton University is trying to understand the cancer ecosystem in terms of evolution—another topic that is likely to require the physical sciences. "When you get cancer, some cells develop drug resistance. In the same way, when you spray a pesticide into an ecosystem, some pests develop resistance. They're thinking it may be the same process in cancer, so they want to understand the treatment process: what is the proper dose, the diffusion gradient of the drug, the mechanism of resistance. Again, there are questions that might be answered here as he moves from research topic toward commercialization."

BUILDING THE BRAIN-COMPUTER INTERFACE: CLINICAL AND EXPERIMENTAL NEEDS

Anthony Ritaccio
Director, Epilepsy and Human Brain Mapping
Albany Medical Center

Echoing one of Dr. Nagahara's points, Dr. Ritaccio said that his own medical research on epilepsy is also likely to require physical science and engineering inputs. He said that his work is to record seizures and make maps of seizure activity in the brain in order to surgically reduce the symptoms. He also uses a multidisciplinary approach to this challenge through close partnership with colleagues in many disciplines.

He has found that people with or without disabilities can use brain signals to "communicate by intention." That is, through the use of software that detects brain signals, people can control external devices, software, or prosthetics through thought processes alone. "Just in the last decade we have begun to understand the promise of this, using an incredibly multidisciplinary partnership of electrical engineering, computer science, neuroscience, clinical neurophysiology, and perhaps, in the near future, nanobiotechnology."

"What we do," he said, "is to tune in to people's intentions and decode errors of the brain involved in simple movement and vision. We record in real time, prior to the movement, the intention to move, and in what direction. We can also predict single words or word components before they're uttered." This is done with the assistance of a general-purpose software developed by his group called BCI 2000, which is used in some 2,000 laboratories around the world.[37]

Mapping Brain Activity and Decoding Intentions

The basic technology for mapping brain activity has not changed for three decades, he said. The general technique has been to place several dozen probes on the surface of the scalp, a bulky system of individually wired electrodes. Despite the limits of this technology, the new software system can extract information from it that goes far beyond previous abilities. Using certain high (gamma) frequencies that have spatial and temporal domains, the software can produce in seconds a high-frequency buzz associated with brain function. It can be used at the bedside or anywhere to detect these functional areas.

"Being able to record and decode these spatial and temporal domains is the key to decoding the brain," he said. "It allows us to detect intended movement, intended languages, and visual recognition. We can play four or five conversations and record which one a person is actually listening to. This is the first novel mapping tool in the last quarter century, perhaps since the MRI."

[37]BCI is the brain-computer interface.

Beyond decoding intentions, he can also translate the intentions into commands. For example, he demonstrated how a patient could be taught in about 10 minutes to operate an artificial hand through the intention of moving his tongue. He also described how the software can allow patients to spell at about 30 letters a minute by recognizing each "intended" letter through the use of a flashing spelling board.

"That's great," he said, "but what am I doing here? I'm not an engineer." The problem, he said, is the outdated system of electrical probes, which are limited in spatial resolution and can only be used for a matter of days before they become sources of infection in the scalp. A new generation of sensors is being tested, he said, such as a wireless, rechargeable array with thousands of microelectrodes.

Needed: A Flexible, Thin-film, Electrical Sensing Device

"What we need is a foldable, flexible, biocompatible, thin-film, high-density electrical sensing device with microfluidic channels for drug administration, and wireless radio frequency transmission. If we can do this we can have a permanent apparatus and really begin to develop a new generation of neuroprosthetics."

In addition, he said, "epilepsy, for which the Institute of Medicine says the lifetime risk is one in 26, will be transformed instantaneously by this development. We'll have seizure alarm systems through seizure detection algorithms that can predict when seizures are going to occur. In addition to seizure detection software, we can have administration of a drug through microfluidic chambers and selective cooling of areas of the brain to stop seizures. It's all possible within a decade."

He suggested that all this can and should be done in Albany, and that the mix of abilities described during the symposium is a powerful argument in favor of that. "We're going to have some very simple outpatient operation to implant this active device. Those of us who suffer from impairments will be able to modulate their environment, communicate, or use prostheses. Those of us without impairments will have some form of augmentation or innovation, and will use the same new implant technology for functions we can only dream about."

ADVANCING NANO-BIOTECHNOLOGY

Jonathan S. Dordick
Vice President for Research
Rensselaer Polytechnic Institute

Before 2010, Dr. Dordick said, biotechnology had been an enabling discipline for both materials science as a whole, and nanotechnology as a component of that. "And we're able to do a lot more in biotechnology because

of advances in tools and equipment that come through materials science. But now this has fundamentally changed. We're at a point where we can use the tools of biotechnology to advance the non-biological world. And this brings both advantages and disadvantages."

Processing at the nanoscale is underway, he said, and could be very important. This comes about through man-made capabilities, and it is still difficult to control with high precision at scales that are small from a materials perspective. Nanoscale processing still has limited compatibility with biological systems, and in many cases it is not environmentally benign.

"But take a look at biotech," he said. "It's exquisite. The fact that we're actually alive indicates that there are systems in our bodies that provide exquisite selectivity in shape, size, and control of chemical reactions. Nature has already invested billions of years of evolution to get to where we are, so we're piggy-backing on what nature has done so well, and which is also environmentally benign and biocompatible.

Barriers to Biotech

But there are significant disadvantages, he went on. "First, nature is a lot smarter than we are, and the process of evolution is very hard to beat. We don't understand a lot about a cell. And biotech in general has been isolationist, which, for a lot of reasons, has been a significant detriment." Barriers, he said, include IP and secrecy. "So we don't have a model for biotech like the one used by the semiconductor industry. A result is that one of our most important industries, the pharmaceutical industry, is in dire straits—spending unprecedented amounts of money and time to discover new drugs. That is going to affect our ability to make the next nanotech revolution, because we have to be healthy ourselves." These can be in generating surfaces that kill bad bacteria, but not good ones, and in developing new routes to generating better and safer drugs."

Nature is the ultimate nanotechnologist, he said, coming up with unique structures that cover a wide range of different scales and unique functionalities. Half our drugs today come from a natural product or are inspired by nature. "Nature does things not for our benefit, but for its own benefit, so we need to break away from the boundaries nature has imposed and fill the gaps in our knowledge. We have to develop new kinds of materials with the properties we need."

Biotech and Nanotech to Generate Functional Materials

For example, he said, three major components are needed to bring biotech and nanotech together and generate functional materials. The first is the biomolecules themselves, which is obvious; second are nano-materials, which are enabling components; and third are polymers, the matrices or commonplace materials we use every day. These three components form what is effectively a

new "phase space" that represents the interface of biology, chemistry, and materials science. There is knowledge about the edge of this space: how the materials interact, how nanomaterials can be dispersed within polymers to generate homogeneous materials with great strength, allow sensors to function, and so on. "But we are missing the inside," he said, "and that's critical. Without it, biomanufacturing lags far behind. When we understand the inside, we'll be able to process biological-material hybrid systems and manufacture them in ways that parallel what is done in microelectronics."

This work on the missing inside has been a major focus at RPI, he said. Over the last 10 years, the NSF funded Nanoscale Science and Engineering Center has built up a better understanding of to manufacture functional materials. "Collaborations are not only critical, they're required. We can't do everything. That could be said for every university and every discipline. We need to be able to develop materials that provide form, function, and can be tailored for applications important in human health, industrial processes, consumer products, etc. We also need to discover better drugs, and bring them to market faster to make it possible to have more affordable health care technologies.

The Challenge of Infection

One of the largest challenges, he said, is infection, which is going to become even more critical. "In hospitals, the biggest problem is not what the surgeon does; it's what the bacteria do if they get into the patient. Hospital-acquired infections are the 4th or 5th leading cause of preventable death in the United States. The WHO said if we can't solve this problem we'll go back to early 20th century, when routine surgeries were so often fatal that many were simply left undone." A second problem is food supply, especially processing and packaging. "Food poisoning has a massive economic impact; a quarter of all fresh water use goes to dealing with food spoilage."

In another nanobiotechnology project in our group, he said, we have produced a paint that kills the lethal bacterium MRSA.[38] We focused on using nature to defend ourselves from nature's pathogens. We turned to viruses of bacteria, or phages, which infect specific bacteria. An interesting question that drives this work is how does the phage progeny that are being made within the bacteria get out of the cells and infect other cells? We know the answer—the phage genome codes for an enzyme that is generated in the bacterium. This enzyme effectively drills holes in the bacterial cell wall, which ultimately causes the cell to "blow up and release phage progeny, thus leading to infection of neighboring cells."

[38]Methicillin-resistant *Staphylococcus aureus.* Resistance makes MRSA infection more difficult to treat with standard types of antibiotics and thus more dangerous.

"We asked, how can we do that from the outside in, to destroy the pathogenic bacteria before they can get out of control? And we asked whether we could use our approach to protect societal infrastructure, including hospitals, from dangerous pathogens. We knew we had to stabilize the phage enzymes so they would remain viable until needed, so we put them onto materials roughly the same size as the enzymes themselves, 5 to 10 nanometers. Then we mixed them into paint. When MRSA bacteria hit the paint, they stick and die. We can do this with Listeria, too, which is a major pathogen in the food industry, and also with bacillus spores."

'The Pharmaceutical Industry Has Critical Problems'

Given the challenges faced by the pharmaceutical industry, he said, the outlook for new drug development is uncertain. He showed a chart for the years 1996-2006 depicting a steep upward slope of R&D spending that is matched almost exactly by the steep decline of new drug approvals over the same period. From 2009 to 2011, he said, fewer than 60 drugs were approved by the FDA, and the cost for approval is now close to $2 billion per drug. "This is not sustainable," he said. "Patents covering over $50 billion in drug revenue expired in 2010. The pharmaceutical industry has huge problems. Who's going to be able to develop the new drugs?"

And why is drug development so difficult to do, he asked? First, biology is complex. He said that the human cell and a Boeing 787 have basically the same number of parts. "We can design and build a 787, but we can't design and build a cell. We barely understand how some of the parts work." It is equally difficult to make drugs safe, he said. "There isn't much difference between what is effective and what is toxic. However, this is a major opportunity for personalized therapies"

Personalized Medicine Through Interdisciplinary Partnerships

He offered a vision of personalized medicine, and emphasized that this will require the kinds of interdisciplinary partnerships that were being discussed at the symposium. "We have a chip that mimics how the body deals with a drug," he said. "It has pillars or wells of enzymes, and calculates how well the drug is metabolized by the liver. It can determine whether a drug candidate is likely to be toxic, so that the candidate can be tailored to people with the appropriate genetic make-up, and perhaps one day to an individual person." He said that in the mid-2000s a public-private partnership set off on the path toward commercializing this chip.

Finally, he said, more than ever, drug development requires big data—first unstructured data. This can be coupled with systems biology and computational approaches. The high-performance and cognitive computing capabilities at RPI, he said, make possible the beginnings of a better

understanding of how an individual patient's data can be used to develop new drugs or therapeutics.

These emerging opportunities to combine big data with nanotechnology and biotechnology can be of benefit in three areas, he said. In R&D, the combinations can improve the understanding of the nature of therapeutic molecules, perhaps re-purposing drugs no longer in use. Second, they can help develop new visualization tools that, especially in clinical areas, advance understanding and make possible not only the brain-computer interface, but also the "whole body-computer interface." Such advances can lead to more personalized clinical trials. Third, the benefits can improve health care infrastructure by developing networks of sensors shared by multiple hospitals, new patient treatment regimens, and ultimately lower costs. "New York State can certainly leverage its investment in microelectronics to develop the new biotechnology, which must be highly collaborative," he said. . "The expertise exists here in nanotech, biotech, biomedical research, emerging big data, and so forth." He expressed excitement about the new venture fund described earlier by Mr. Adams of the Empire State Development Corporation, which responded to an urgent need for seed funding in the region.

Hope for a New Treatment Scenario

He concluded by sketching out his hope for a new medical treatment scenario. "Our goal is that one day soon you will be able to go to the doctor or hospital where your genetic makeup is known; this data will tell your doctor about the nature of your disease. We know enough about how to put molecules together, and how they fit into the proteins of your body, that we can imagine making a drug specifically for you, at very small scale, perhaps with the help of bacteria—just as in nature. We can do virtually all of this today, so it is not far-fetched to imagine that one day soon you will be able to have your own drug made just for you in the amounts you need and available on the day you need it."

He closed on a note of gratitude for the support his university has received from several New York State agencies. "RPI is fortunate to have such a good partnership with the state," he said. "You heard yesterday about our supercomputer, which we will expect by the end of this year will rank among the top in university-run computational facilities. Our biotech center, which is where my research resides, was supported by RPI in terms of the building, but much of the equipment was funded by New York State, and most recently our stem cell research center was supported by NYSTEM, the New York State Stem Cell Science program. So the public-private partnerships we've been discussing have real and positive outcomes at the level where they matter."

CONVERGENCE IN THE SEMICONDUCTOR, PHARMACEUTICAL, AND MEDICAL DEVICE INDUSTRIES

Brian Toohey
President & CEO, Semiconductor Industry Association (SIA)

Mr. Toohey began by observing how "impressive is what has been built here," and said it was especially encouraging to see it from the perspective of Washington. "We recently had our international SIA meeting not far from here," he said, "and after the meeting, all the international delegates wanted to talk about was what is happening in Albany. It is truly spectacular."

Can Pharma Use a Collaborative Research Model?

Mr. Toohey said that before coming to the SIA, he had spent many years in the pharmaceutical and device industry at the association, regulatory, and product development levels. Given that background, he said, he had been asked to consider whether a collaborative research model can be built for the pharmaceutical industry that is similar to those emerging in nanotechnology, semiconductors, and biotechnology.

He said that "the short answer is yes," but offered several trends that are likely to give shape to a new model. From this perspective, he said, he had seen that several strong trends were characterizing current healthcare. The first was an aging population. By 2025, he said, about 1.2 billion people will be older than age 50, twice as many as in 2006. The second is rising health care costs, which now account for more than 18 percent of GDP. Third, spending on health care is rising in emerging countries as well. In China, healthcare expenditure increased from 3.7 percent of GDP in 1995 to 5.6 percent in 2007. Finally, healthcare is becoming more personal; 33 percent of medical semiconductor revenue in 2008 went into consumer medical devices.

Semiconductors in Medical Apps

Another trend is the increasing use of semiconductors in healthcare. Just as semiconductors transformed computing and communications, he said, they are beginning to transform healthcare. For example, the value of semiconductors in medical apps is expected to rise by a factor of about 2.5 between 2008 and 2016. Among other trends increasing the demand for semiconductors is 100 percent monitoring for more patients in hospital settings, and bringing ultrasound devices to the point of care in applications such as emergency rescue, military operations, and recreation. Increasing numbers of devices are being used in clinical patient monitoring, health and chronic disease management, and vital signs monitoring.

One advantage of new technologies is convenience. For example, non-invasive devices for blood glucose monitoring are available using silicon bio-

sensors. Another is insertion into body organs with unprecedented access to conditions, such as retinal implants, deep brain stimulation, cochlear implants, gastric pacemakers, neuro-stimulators, and other implantable technologies.

Extending the Benefits of Industry-university Collaboration

One reason for optimism about extending the benefits of industry-university collaboration in pharma, he said, is the multi-decade success of the semiconductor collaborations. In that sector, industry consortia support for university basic research had led to 10-fold declines in costs every six years. He argued that a similar pattern in semiconductors and synthetic biology, or synbio, can be seen in a series of breakthroughs during the last decade. These include the first chemical synthesis of polio virus, chip-based high-throughput DNA synthesis, MEMS DNA synthesis, DNA "origami," the first synthesis of a bacterial genome, DNA-assembled carbon nanotube field effect transistors, a cytomorphic electronics concept, and DNA information storage.

Another example, he said, is semiconductor/biological circuits, in which cellular material is used as intelligent components of electronic circuits. These circuits can be used for digital, analog, and sensing functions, and interfaces between biological and semiconductor components.

He noted that "a crisis is a horrible thing to waste," and reiterated that the pharmaceutical industry is in crisis, especially with respect to new drug approvals and the cost of research and development. "That will motivate these companies to sit down and have this discussion," he said.

Two Barriers to a Semiconductor-Pharma Convergence

He said that discussions with several friends indicated the likelihood of two barriers to a semiconductor-pharmaceutical convergence. The first, he said, is a mechanism for sharing intellectual property. "The models for pharma are very different from those in the semiconductor industry. In semiconductors we have a great history of showing that it can be done, and now it needs to be solved for pharma."

The second barrier, he said, is how to merge the microelectronics technologies that already exist into pharmaceutical discovery and therapy. A big issue is the regulatory approvals—"not because the FDA or other regulators would try to be an obstacle. They simply don't have an appropriate framework from which to look at safety aspects of these types of convergent technologies." One suggestion, he said, is to bring the industries together first and try to set a framework of safety and reliability which can then be taken to the regulatory authorities.

Closing Roundtable:

New York's Innovation Future

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

Dr. Wessner moderated a roundtable discussion to conclude the symposium. He began by asking Johanna Duncan Poitier, the SUNY Vice-Chancellor for Community Colleges, for her comments.

Strengthening the Link Between Nanotech and Healthcare

Dr. Poitier said that "at end of the day, one thing we all know is that the jobs are here. Business and industry want an educated workforce. We also know that more has to be done to build the educated workforce we need. Some of us are part of the $15 million federal grant to support a consortium of all 30 community colleges in advanced manufacturing. We're building an infrastructure to make sure that more people who graduate from our colleges are prepared for the workforce, especially in advanced manufacturing. We are also going to build a consortium in health care. What I hadn't expected before today is the link between nanotechnology and health care—a huge link that can maximize resources and opportunities."

More Emphasis on Leadership

Kathleen Kingscott, Senior Director for Strategic Partnerships at IBM, said she would like to highlight the importance of leadership in building collaborations. "In my experience, visionary leaders have personal relationships with one another. Because doing technology development partnerships is very difficult and there are lots of moving parts at certain times things can get stuck. Good leaders often have the ability to work through problems and get things restarted.

She also referred to the comment by Mr. Russo that the rush of people coming from around the world to visit GLOBALFOUNDRIES made him "feel like the Department of State." This area has won the first lap and we are very pleased to see the growth the Albany area is enjoying. Yet we at IBM also see tremendous opportunities around the world; in fact in the last year we have opened our first two labs below the equator, one in Australia one in Brazil, because the market opportunities are excellent and governments often offer investment incentives. The playing field is really not level for the United States. Governments around the world see the value of the semiconductor industry, and make an effort to recruit companies.

A third point, she said, is that the role of government and its decision making are very important. She reiterated the point that "With the stroke of a pen, the environment in which business is done can be changed, for better or for worse. Tax policy, immigration policy, regulatory review, the ease of getting permits to build infrastructure; water, roads, and electricity; all these are choices government makes." Dr. Wessner agreed that "we may want to give serious emphasis in the report on the importance of infrastructure, permitting, and speed, which are often stronger in other countries."

'IBM's Role Has Been Critical'

Michael Liehr, Executive Vice-President of Innovation and Technology at CNSE, agreed that the role of federal government reached far beyond financial support to include immigration and other policies. As a takeaway, he said, he was impressed by the success of CNSE in taking advantage of all the legs of the innovation stool—not only the federal government but also state government, academia, and industry. He also affirmed, "IBM's role and the role of the Governor of New York have been absolutely critical. Without IBM's presence and without the continued support of several Governors, CNSE would not be what it is."

Dr. Wessner added that the ability of CNSE to move more quickly than most universities had also added to its success. Dr. Liehr agreed that CNSE "does move fast, because private firms have no patience in waiting for us when millions of dollars are at stake. And it's educational for the folks at the college to see what speed will be expected of them in industry. It's the speed of business, and if we as universities want to play a role, we've got to learn how to move at that speed."

Development Models Need to be Shaped by Local Circumstances

Dr. Wessner next called on Clark McFadden, Senior Counsel at Orrick, Herrington & Sutcliffe, LLP, and Member of the National Academies' Committee on State and Regional Innovation. Mr. McFadden said he was impressed by the variety of catalysts the area has had to generate "an enormous amount of economic development." But he said that the area must be prepared to

move from the support of catalysts to sustainability. He found several encouraging signs. One is the region's flexibility and adaptability in approaching economic development. "There isn't a specific formula," he said. "The models need to be derived from the circumstances you face. I have the feeling that's how you've been proceeding, and maintaining that flexibility is important.

In looking for a best practice for initiatives such as the NNMI, he suggested care in "not allowing the investment or the concept to outrun the industry and its needs. This means it is crucial to maintain local connections to what you're doing, build on your local capabilities, and make sure your infrastructure is actually co-located with your industry."

The Need to Tolerate Failures

Also, he noted that the subject of failure had not been discussed at the symposium. "Anything of this scale is very risky," he said, "If it's going to be successful in the aggregate, it has to take major risks, and you're bound to have failures. One thing government doesn't deal well with is failure. Their tendency is to shun it, and focus blame without gaining any learning. A quality of other successful areas is that they've been able to learn from things that didn't work well. You do have to have accountability and measure what you do, but you don't want to treat a failure as something you should never have tried."

Jonathan Dordick of RPI reminded his audience that "everything we've been talking about, mainly the application and transfer of technology, is built on the basic research enterprise that exists in this country, funded primarily by the federal government. This funding is being squeezed more than ever, and we will lose the sustainability of our R&D if this continues."

Dr. Wessner agreed, and added that support was needed to sustain not only basic research, but applied research and development as well. Without stronger development and commercialization, he said, U.S. innovations are likely to be developed and commercialized by other countries, which has been the case for many years. "The assumption that what's invented here gets made here has evaporated."

Mike Russo of GLOBALFOUNDRIES said that the speakers had been effective in characterizing the Albany cluster and the spirit of its activities. "I think what people have articulated is the value of innovation. While some innovation is a natural part of most research, the vast majority takes collaborative effort and funding. We're happy to have the Academies come here, and look forward to a conference report that can help us to communicate that message to policy makers."

Innovation Requires Leaving Our Comfort Zones

His take-away, he said, was that moving forward to innovate "is more than risk taking. It's getting out of your comfort zone and your vested interest."

He mentioned the example of the medical device, pharmaceutical, and semiconductor industries and their discussion of a possible collaboration. "I would argue that many entities that might not be inclined to support collaboration would actually enjoy an ancillary benefit down the road: it would not only help business, but it would advance health care and help human kind. I would encourage us to get out of our business comfort zones and contribute to those initiatives. That's kind of a takeaway, but also a challenge to the region."

Dr. Wessner concluded the symposium by agreeing that "we have some people committed to working very hard to make that happen." He thanked the participants, and "all the people who made this meeting work, and also Alexis de Tocqueville, "who wrote about the ability of Americans to self-assemble and cooperate." He complimented Mike Russo of GLOBALFOUNDRIES for not simply "identifying problems, but for working out solutions."

As for leaders of the regional effort around Albany, he suggested that their task "is not over," and that they are just "getting into the low hills of what is possible to do once you reach the mountain." But he was also effusive in his praise for the collaborators. "One thing that fascinates us at the National Academies is that you did this on your own, at the local, state, regional, and corporate levels, and that's why we're here from Washington. The problem solving you've done is truly innovative. There is a lot of electricity in the room; no one is sleeping. I congratulate you."

III

APPENDIXES

Appendix A

Agenda

New York's Nanotechnology Model: Building the Innovation Economy

A Symposium Organized by
The U.S. National Academy of Sciences
in cooperation with
Hudson Valley Community College, the Center for Economic Growth,
GlobalFoundries, and Rensselaer Polytechnic Institute

April 3-4, 2013

Bulmer Telecommunications Center
Hudson Valley Community College
80 Vandenburgh Avenue
Troy, NY

DAY 1: APRIL 3, 2013

1:00PM	**Welcome and Introductory Remarks** *Drew Matonak, President, Hudson Valley Community College (HVCC)* *The Honorable Paul Tonko, U.S. House of Representatives*
1:30PM	**Keynote Address** *Ajit Manocha, CEO, GLOBALFOUNDRIES*

2:15PM	**Panel I: Innovation and Growth: Regional, National, and International Dimensions** *Moderator: Jason Miller, Special Assistant to the President for Manufacturing Policy, National Economic Council, The White House*
	The Global Innovation Imperative *Charles Wessner, Director, Technology, Innovation, and Entrepreneurship, The National Academies*
	The U.S. Innovation Strategy: The NIST Contribution *Phillip Singerman, Associate Director for Innovation and Industry Services, National Institute of Standards and Technology (NIST)*
	Challenges and Opportunities for the New York Innovation Economy *Darren Suarez, Director of Government Affairs, Business Council of New York*
3:45 PM	**Keynote Address** *The Honorable Shirley Ann Jackson, Ph.D., President, Rensselaer Polytechnic Institute*
4:15 PM	**Panel II: The New York Nanotechnology Cluster** *Moderator: Rex Smith, Editor, Albany Times Union*
	The New York Innovation Economy and the Nanotechnology Cluster: The Role of SUNY *Timothy Killeen, Vice Chancellor for Research, SUNY, and President, Research Foundation for SUNY*
	New York's Nanotechnology Model: Building the Innovation Economy *Ken Adams, President and CEO, Empire State Development Commission*
	Pioneering Innovation to Drive an Educational and Economic Renaissance in New York State *Pradeep Haldar, Head of Nanoeconomics Constellation, College of Nanoscale Science & Engineering, The State University of New York at Albany*
5:15 PM	**Adjourn, Day 1**

DAY 2: APRIL 4, 2013

9:00 AM **Welcome and Introduction**
Drew Matonak, President, Hudson Valley Community College (HVCC)

9:15 AM **Panel III: Growing the Semiconductor Industry in New York: Challenges and Opportunities**
Moderator: Charles Wessner, Director, Technology, Innovation, and Entrepreneurship, The National Academies

Breaking New Ground: The New York Advantage
Mike Russo, Director of Government Affairs, GLOBALFOUNDRIES

Collaboration as a Way Forward for Semiconductor Technology: Albany Nanotech
Gary Patton, Vice President, Semiconductor Research and Development Center, IBM

Growing the Semiconductor Industry in New York: Challenges and Opportunities
Daniel Armbrust, President and CEO, SEMATECH

10:45 AM **Panel IV: 21st Century Universities: Drivers of Regional Growth and Employment**
Moderator: Luis Proenza, President, The University of Akron

The Power of SUNY
Nancy L. Zimpher, Chancellor, The State University of New York

Building Innovation Infrastructure: The Role of EDA
Thomas Guevara, Deputy Assistant Secretary for Regional Affairs, Economic Development Administration, U.S. Department of Commerce

Universities as Economic Anchors
Donald Siegel, Dean, School of Business, State University of New York at Albany

Technical Training for Innovation-Driven Employment
Drew Matonak, President, Hudson Valley Community College (HVCC)

1:15 PM **Keynote Address**
Michael Fancher, Vice-President for Business Development and Economic Outreach, Center for Advanced Technology (CAT), College of Nanoscale Science and Engineering (CNSE), The State University of New York at Albany

1:45 PM **Panel V: Building Advanced Manufacturing Industries in New York**
Moderator: Frank Murray, President and CEO, New York State Energy Research and Development Authority (NYSERDA)

Advanced Manufacturing for New Energy Technologies
Minh Le, Director, Solar Energy Technologies, U.S. Department of Energy

University-Industry Partnerships for Next Generation Manufacturing
John Wen, Director, Center for Automation Technologies and Systems, Rensselaer Polytechnic Institute

Lessons Learned to Date in the New "Tech Valley"
F. Michael Tucker, President & CEO, Center for Economic Growth

Manufacturing and Innovation: The GE Perspective
Stephan Biller, Chief Scientist for Manufacturing, General Electric

3:15 PM **Panel VI: Nanotechnology and Biomedical Sciences**
Moderator: David Rooney, Senior Vice President, Center for Economic Growth

Innovation in Cancer Research: The Nanotechnology Opportunity
Larry Nagahara, Director, Office of Physical Sciences—Oncology, Center for Strategic Scientific Initiatives, National Cancer Institute

Building the Brain-Computer Interface: Clinical and Experimental Needs
Anthony Ritaccio, Director, Epilepsy and Human Brain Mapping, Albany Medical Center

Advancing Nano-Biotechnology
Jonathan S. Dordick, Vice President for Research, Rensselaer Polytechnic Institute

Convergence in the Semiconductor, Pharmaceutical, and Medical Device Industries
Brian Toohey, President and CEO, Semiconductor Industry Association (SIA)

4:15 PM **Closing Roundtable: New York's Innovation Future**
Moderator: Charles Wessner, Director, Technology, Innovation, and Entrepreneurship, The National Academies

Johanna Duncan-Poitier, Senior Vice Chancellor for Community Colleges and the Education Pipeline, The State University of New York
Kathleen Kingscott, Senior Director for Strategic Partnerships, IBM
Michael Liehr, Executive Vice President of Innovation and Technology, College of Nanoscale Science and Engineering, The State University of New York at Albany
W. Clark McFadden, Senior Counsel, Orrick, Herrington & Sutcliffe LLP; Committee Member, National Academies Committee on State and Regional Innovation Initiatives
Jonathan S. Dordick, Vice President for Research, Rensselaer Polytechnic Institute
Mike Russo, Director of Government Affairs, GLOBALFOUNDRIES

5:00 PM **Adjourn**

Appendix B

Biographies of Speakers*

KEN ADAMS

Kenneth Adams was confirmed by the Legislature as Empire State Development (ESD) president & CEO and commissioner of the New York State Department of Economic Development on April 5, 2011. In these positions, Mr. Adams works to promote economic practices that attract business and create jobs throughout New York State. He also works closely with Lieutenant Governor Robert J. Duffy to implement the Regional Economic Development Councils across the state.

Mr. Adams came to ESD from The Business Council of New York State, the state's leading business association, where he served as president and CEO since 2006. He led the organization in its mission of creating "economic growth, good jobs and strong communities across New York State." The Business Council represents nearly 2,500 member businesses, chambers of commerce and professional and trade associations, employing a total of more than one million New Yorkers.

Prior to leading the Business Council, Mr. Adams was president of the Brooklyn Chamber of Commerce and director of the MetroTech Business Improvement District in Downtown Brooklyn. He was also the founding executive director of New York Cares, New York City's leading volunteer organization, from 1988 to 1994. Mr. Adams is a resident of Brooklyn, New York, where he lives with his wife and two children.

DANIEL ARMBRUST

Daniel Armbrust was named president and chief executive officer of SEMATECH in November 2009 with the responsibility to lead the consortium's advanced technology R&D programs in lithography, front end processes,

*As of April 2013. Appendix includes bios distributed at the symposium.

interconnect, and metrology, and oversee SEMATECH's subsidiary, the International SEMATECH Manufacturing Initiative (ISMI).

Armbrust previously spent 25 years at IBM Corporation, culminating in his tenure as vice president of 300 mm Semiconductor Operations for the company's Systems Technology Group where he was responsible for the operation of IBM's 300 mm fab in East Fishkill, New York, which develops leading edge technologies with IBM's alliance partners and manufactures products for IBM and OEM customers. His leadership was marked by successful efforts to improve operating efficiency, lead executive collaborations within the industry, and build strong technical teams.

Prior to his role as vice president, Armbrust served as director of 300 mm Engineering and strategic client executive for IBM's Systems and Technology Group. He began his career at IBM in 1983 and progressed through a variety of assignments in process development, manufacturing, and client engagement.

Armbrust earned a bachelor's degree in ceramic science and engineering from Pennsylvania State University as well as a Master of Science degree in manufacturing systems engineering from Rensselaer Polytechnic Institute.

ROBERT BLACKMAN

Robert (Bob) Blackman is currently the vice president of Realty USA as well as the co-founder of Blackman & DeStefano Real Estate. Bob's impressive list of board involvement includes numerous noteworthy clubs and foundations. Bob is currently board chair of Gildas Club in the Capital Region, whose mission is to create welcoming communities of free support for everyone living with cancer. He is also current vice chairman and board member of the Center for Economic Growth as well as the Executive Committee. This organization has been at the forefront of economic development initiatives and public policy discussions affecting the 1.1 million residents of New York's Capital Region and Tech Valley. He currently serves as a member of the Fuller Road Management Corporation (FRMC) which manages the facility at the College of Nanoscale Science and Engineering (CNSE). Bob is also the vice chair of the AAA Hudson Valley and a trustee of the Fort Orange Club Board.

In the past, Bob was the president of Greater Capital Association of Realtors. Bob was also a director of Camp Good Days and Special Times, as well as the March of Dimes. He served as a director on the Upstate Advisory Board of Chase Manhattan Bank, the Albany Memorial Hospital Foundation, the New York State Association of Realtors, and the Albany Country Club. Bob is also the past president of Sales and Marketing Executives Association and the vice chair of the Northeast Foundation. He served as the chair of the WMHT Great Auction in 2006.

JONATHAN DORDICK

Jonathan S. Dordick received his B.A. degree in biochemistry and chemistry from Brandeis University and his Ph.D. in biochemical engineering from the Massachusetts Institute of Technology. He has held chemical engineering faculty appointments at the University of Iowa (1987-1998), where he also served as the associate director of the Center for Biocatalysis and Bioprocessing, and Rensselaer Polytechnic Institute (1998-present) where he is the Howard P. Isermann Professor of Chemical and Biological Engineering and Professor of Biology. In 2008 he took over as director of Rensselaer's Center for Biotechnology & Interdisciplinary Studies. Prof. Dordick has received numerous awards, including the 2007 Marvin J. Johnson Award, the 2007 Elmer Gaden Award, the 2003 International Enzyme Engineering Award, the 1998 Iowa Section Award of the American Chemical Society, and an NSF Presidential Young Investigator Award in 1989. He was elected as a fellow of the American Association for the Advancement of Science in 2004 and a fellow of the American Institute of Medical and Biological Engineers in 1996. He presently serves on the Scientific Advisory Boards for several biotechnology companies and venture capital firms. Dr. Dordick was a co-founder of EnzyMed, Inc. a pharmaceutical and agrochemical discovery company acquired by Albany Molecular Research in 1999, and is a co-founder of Solidus Biosciences, Inc. a venture-stage human drug and cosmetics toxicology company. Dr. Dordick has published over 250 papers and is an inventor/co-inventor on 32 patents and patent applications.

JOHANNA DUNCAN-POITIER

Johanna Duncan-Poitier currently serves as senior vice chancellor for Community Colleges and the Education Pipeline for The State University of New York (SUNY). She provides system oversight and coordination for SUNY's 30 community colleges, which are responsible for educating over a quarter of a million students each year. In addition she provides leadership to strengthen teacher preparation and the critical connections between the State University's 64 campuses and their local PreK–12 schools, business leaders, community-based organizations, and other partners. This work focused is on maximizing student success, increasing graduation rates, improving college-readiness, and preparing a highly-qualified 21st century workforce. Prior to joining SUNY, Ms. Duncan-Poitier served as the senior deputy commissioner of Education—P-16, with responsibility for regulatory oversight of the 700 school districts, 270 colleges and universities (both public and private), and 434 proprietary schools in New York State. She also had the responsibility for the preparation policy and licensure of three quarters of a million licensed professionals in 47 health, business, and design professions.

Ms. Duncan-Poitier also serves as one of six New York State Commissioners for the Education Commission of the States, the only

nationwide, non-partisan interstate compact devoted to all levels of education. Ms. Duncan-Poitier has been recognized with numerous state and national honors and awards, including: the Governor's Outstanding Leadership Award; the President's National Award for Excellence in Administering Science, Mathematics, and Engineering Programs in New York State; the New York State Association for Women in Administration—Pathfinder Award; Doctor of Laws, *honoris causa*, Saint Joseph's College; and Doctor of Humane Letters, *honoris causa*, D'Youville College. Ms. Duncan-Poitier earned a baccalaureate degree from Queens College of The City University of New York and a master's degree in public administration from Bernard M. Baruch College of The City University of New York.

THOMAS GUEVARA

Thomas Guevara in his capacity as Deputy Assistant Secretary for Regional Affairs directs and supervises the activities of the Economic Development Administration's (EDA) Office of Regional Affairs, including the Performance and National Programs Division and all six EDA Regional Offices. EDA's Regional Offices are responsible for program delivery of investments that fulfill the agency's mission of leading the federal economic development agenda by promoting competitiveness and preparing American regions for growth and success in the worldwide economy. Mr. Guevara brings over 24 years of management experience in financial advisory services, public-private partnership finance, and local economic development consulting.

Previously Mr. Guevara worked for the state of Indiana as CIO of the largest state agency, where he was responsible for information technology projects and expenditures in excess of $140 million annually, serving over 8,500 agency users statewide, and administered by over 250 employees and contractors. Mr. Guevara also served as assistant state budget director at the Indiana State Budget Agency, where he headed the Health and Human Services division.

Mr. Guevara also has served as an adjunct professor at Indiana University, teaching finance, management, and budgeting courses to graduate and undergraduate students.

PRADEEP HALDAR

Pradeep Haldar, head of the Nanoengineering Constellation at the College of Nanoscale Science and Engineering, conducts research on advanced fuel cells, advanced photovoltaics (solar power), next generation superconductors, supercapacitors and advanced power electronics. His focus is to support energy and environmental technology deployment through accelerated commercialization by leveraging partnerships between industry, government, and the university. He is executive director of New Energy New York, a consortium of energy related organizations whose objective is to

develop and deploy clean energy technologies. He is also vice chair of the U.S. DOE's clean energy incubator alliance and has recently co-authored a report to establish a hydrogen economy in New York State. Haldar received his doctorate in materials science & engineering and solid state chemistry from Northeastern University, and holds an executive MBA from Rensselaer Polytechnic Institute.

SHIRLEY ANN JACKSON

The Honorable Shirley Ann Jackson is the 18th president of Rensselaer Polytechnic Institute, Troy, New York, and Hartford, Connecticut, the oldest technological research university in the United States. Describing her as "a national treasure," the National Science Board selected Dr. Jackson as its 2007 recipient of the prestigious Vannevar Bush Award for "a lifetime of achievements in scientific research, education, and senior statesman-like contributions to public policy."

Described by *Time Magazine* (2005) as "perhaps the ultimate role model for women in science," President Jackson has held senior leadership positions in government, industry, research, and academe. Since 1999, Rensselaer President Shirley Ann Jackson has led an extraordinary transformation of the Institute with an ambitious strategic effort known as *The Rensselaer Plan*. Guided by her vision, Rensselaer is now home to the Center for Biotechnology and Interdisciplinary Studies, the Computational Center for Nanotechnology Innovations, the Curtis R. Priem Experimental Media and Performing Arts Center, and the East Campus Athletic Village. Under her leadership, more than 275 new faculty members have been hired, research awards have nearly tripled, and scholarships have increased. Her tenure also has been marked by innovations in curriculum, expansion of undergraduate research, and new award-winning student life initiatives.

Nearly $1.25 billion has been invested in *The Rensselaer Plan*, including more than $725 million in new construction, new equipment, technology, infrastructure, and renovations. In 2001, President Jackson secured a $360 million unrestricted gift to the Institute. In 2004, she launched a $1 billion Renaissance at Rensselaer capital campaign. In 2006, the goal was expanded to $1.4 billion. The campaign closed in 2009, having surpassed the ambitious goal of $1.4 billion in gifts and gift commitments, nine months ahead of schedule, exceeding all previous fund-raising at Rensselaer.

Dr. Jackson holds a Ph.D. in theoretical elementary particle physics from MIT and a S.B. in physics from MIT. Her research specialty is in theoretical condensed matter physics, especially layered systems, and the physics of opto-electronic materials. In April, 2009, U.S. President Barack Obama appointed Dr. Jackson to serve on the President's Council of Advisors on Science and Technology. PCAST is an advisory group of the nation's leading scientists and engineers who advise the President and Vice President and formulate policy in the many areas where understanding of science, technology,

and innovation is key to strengthening the economy and forming policy that works for the American people.

Dr. Jackson is co-chair of the President's Innovation and Technology Advisory Committee (PITAC), part of the PCAST. Through PCAST, PITAC advises the President on matters involving science, technology, and innovation policy. As PITAC co-chair, in 2011 she co-authored the *Report to the President on Ensuring American Leadership in Advanced Manufacturing,* which provided an overarching strategy as well as specific recommendations for revitalizing the nation's leadership in advanced manufacturing. Prior to her leadership of Rensselaer, President Jackson was chairman of the U.S. Nuclear Regulatory Commission (NRC), a theoretical physicist conducting basic research at the former AT&T Bell Laboratories, and a professor of theoretical physics at Rutgers University.

In 1995 President William Clinton appointed Dr. Jackson to serve as chairman of the U.S. Nuclear Regulatory Commission. She was chairman of the NRC from 1995 to 1999. As chairman, she was the principal executive officer of and the official spokesman for the NRC. She had ultimate authority for all NRC functions pertaining to an emergency involving an NRC licensee. The NRC is charged with the protection of the public health and safety, the environment, and the common defense and security by licensing, regulating, and safeguarding the use of reactor byproduct material in the United States. This includes power reactors; research, test, and training reactors; fuel cycle facilities; reactor byproduct use in medicine, industry and research; the transportation, storage, and disposal of high-level and low-level radioactive waste; and the licensing of nuclear exports for peaceful uses.

While at the NRC, Dr. Jackson initiated a strategic assessment and rebaselining of the agency, leading to a new planning, budgeting, and performance management system that put the NRC on a more businesslike footing. She conceptualized and introduced risk-informed, performance-based regulation to the NRC (utilizing probabilistic risk assessment on a consistent basis), which has been infused throughout its regulatory programs. As a result, NRC Standard Review Plans and associated Regulatory Guides were changed to a risk informed approach. This also led to the American Society of Mechanical Engineers (ASME) implementing a risk-informed revision to its codes and standards for nuclear power plants and key nuclear components. Elements of risk-informed regulation also have been incorporated into the nuclear regulatory programs of other nations. She led the development of a new reactor oversight program, and created, with the Commission, a license renewal process resulting in the first renewal (in March 2000) of the license of an operating reactor in the United States.

While chairman of the U.S. Nuclear Regulatory Commission, Dr. Jackson spearheaded the formation of the International Nuclear Regulators Association (INRA) in May 1997, and was elected as the group's first chairman, a position she held from 1997 to 1999. As the first INRA chairman, Dr. Jackson guided its development as a high-level forum to examine issues, and to offer

assistance to other nations, on matters of nuclear safety. The association is made up of the most senior nuclear regulatory officials from Canada, France, Germany, Japan, Spain, Sweden, the United Kingdom, and the United States (and now South Korea, with China as an observer).

TIMOTHY KILLEEN

In June 2012 Dr. Timothy Killeen was appointed president of the RF and SUNY vice chancellor for research. As RF president, Dr. Killeen is the chief executive officer responsible for supervision and operation of the largest, most comprehensive university-connected research foundation in the country.

In his dual role, Dr. Killeen is at the center of SUNY's strategy for the growth of basic, translational, and clinical research. His interaction with campus presidents, provosts, vice presidents for research and economic development, deans, faculty, students and SUNY leadership will drive the implementation of innovative programs, initiatives, resources, policies, infrastructure, investment, and business practices that support SUNY research. Dr. Killeen leads the SUNY Research Council, an advisory body to the SUNY board of trustees, RF board of directors, SUNY provost, and campus presidents. In its advisory capacity, the council sets strategies that encourage and nurture research as one of the primary missions of SUNY, defines principles that govern research throughout the system, and examines research strengths and opportunities throughout SUNY.

He also chairs the Patent and Inventions Policy Board, which is charged with developing and interpreting SUNY's intellectual property, commercialization objectives, and policies to encourage interfaces with industry and the advanced use of SUNY research for the public benefit in furtherance of SUNY's strategic goals. He appoints, oversees, and supports the performance of RF operations managers who are charged with the management and growth of research at each of the 29 state-operated campuses and collaboratively across the SUNY system, and will report jointly to the RF board of directors and to SUNY's executive vice chancellor & provost.

Prior to joining the RF and SUNY, Dr. Killeen was the National Science Foundation's assistant director for geosciences beginning in 2008. As head of one of the scientific directorates of the NSF, he managed a funding portfolio of roughly $880 million, up from $750 million when he started. Dr. Killeen was also a Lyall Research Professor at the University of Colorado and, in 2007, was elected to the National Academy of Engineering. From 2000 to 2008, he served as director of the National Center for Atmospheric Research (NCAR), one of the premier atmospheric and climate-change research centers in the world and one of most-cited research centers in its fields.

He spent more than 20 years on the faculty and in the administration at the University of Michigan, Ann Arbor, including a term as associate vice president for research. He has been the principal investigator on numerous theoretical and experimental investigations relating to atmospheric and space science, computing and information technology, and educational innovation, and

has authored more than 150 publications in referred journals and 300 other publications, papers, and conference proceedings. Dr. Killeen has led major strategic planning processes, including the development of the 10-year strategic plan for the $2.6 billion annual, 13-agency U.S. Global Change Research Program, and has established several significant new programs including the Science, Engineering & Education for Sustainability (SEES) initiative. He has been active in promoting NSF's international programs, co-founding the Belmont Forum, which gathers representatives of leading government funding agencies worldwide (including NSF), to collaborate on global climate environmental change research. He has served on various White House Committees and Task Forces, testified frequently to Congress and the Executive branch, and is chair of IGFA, the 25 member International Group of Funding Agencies for global change research.

Dr. Killeen, a U.S. citizen, grew up in Wales and completed his undergraduate and graduate education at University College London, earning his Ph.D. in atomic and molecular physics at the age of 23.

KATHLEEN KINGSCOTT

Kathleen Kingscott is senior director of strategic partnerships for IBM Research. She is responsible for working with governments to further collaborative research partnerships, having assumed this role in July 2009. She also serves as the chair of the Semiconductor Industry Association CTO Work Group. In that capacity, she leads the policy work in support of innovative, collaborative research partnerships between semiconductor industry companies and the federal government.

Prior to this, Ms. Kingscott held the IBM Industry Chair at the Industrial College of the Armed Forces, National Defense University. She served as visiting professor, teaching classes for senior U.S. military and civilian government executives in science, technology, and innovation policy and in studies of the global electronics industry. In her final year at ICAF, her students won the Antonelli Award for the best industry study and the Commandant's Award for Outstanding Research in Support of the Director, DDRE.
Earlier roles include director of worldwide innovation policy for the IBM Corporation, responsible for worldwide public policy matters regarding innovation, science, and technology. Her global team provided political and legislative support on innovation policy matters ranging from fundamental and applied multidisciplinary research to semiconductor and supercomputing technology policy. She also focused on innovation-based regional economic growth.

Ms. Kingscott led IBM's participation in the U.S. National Innovation Initiative, co-chaired by IBM's Chairman and CEO, Sam Palmisano. Separately, she led IBM's policy work in developing the Trusted Foundry, a partnership between IBM, DoD, and the National Security Agency to develop specialized semiconductors for defense applications. Prior positions include a number of

public policy, Congressional relations, information technology marketing, and marketing management positions in IBM. In addition to her work with the Semiconductor Industry Association, Ms. Kingscott founded and served as chair of the Coalition for Technology Partnerships and was a founding partner in establishing the long-running Congressional Visits Day program on Capitol Hill.

Ms. Kingscott has been a guest professor on technology and innovation policy, industry/government/university relationships, technology partnerships, corporate public policy organization, advocacy strategy and related topics at Thunderbird University and Princeton University. She has been with IBM for 38 years.

MINH LE

Minh Le is the program manager of the Solar Energy Technologies Program within the Office of Energy Efficiency and Renewable Energy, where he helps manage and balance the portfolio of Research, Development, Demonstration, and Deployment programs in achieving our national SunShot goals. Prior to his current role at the Energy Department, Minh spent his career in industry developing technologies and scaling new technologies to high-volume manufacturing. Minh earned his S.B. and S.M. degrees from MIT where he held fellowships by the Department of Defense, Department of Energy, and the Bose Foundation.

MICHAEL LIEHR

As CNSE executive vice president of innovation and technology, Michael Liehr focuses on the creation of new business opportunities, develops and manages pertinent administrative and infrastructure operations required to support their establishment, and manages integrated industry-university consortia and public-private partnerships. He is also responsible for the effective and efficient operation of the CNSE core strategic semiconductor and packaging partnership engagements, including the IBM, GLOBALFOUNDRIES, AMAT, TEL, and LAM partnerships. Dr. Liehr is also vice president for research at CNSE, responsible for strategic research and development for nanoelectronics and 3D packaging alliances at CNSE.

In a previous assignment at CNSE, Dr. Liehr served as general manager of the Global 450mm Consortium (G450C), where he coordinated the industry-first effort by consortium members Intel, IBM, Samsung, TSMC, GLOBALFOUNDRIES and the College of Nanoscale Science and Engineering (CNSE) to make available production-grade 450mm processing equipment.

Prior to joining CNSE, Dr. Liehr served as an IBM executive responsible for Worldwide Semiconductor Manufacturing Strategic Production Alliances for leading-edge semiconductor products. While at IBM, he was responsible for technology transfer, operations and supply management for outsourced semiconductor production of IBM's 90nm, 65nm and 45nm

semiconductor- on-insulator (SOI)-based microprocessor technologies to Chartered Semiconductor Manufacturing in Singapore. In addition, he oversaw management of fabricator synchronization for bulk CMOS 65nm through 32nm with Chartered, Singapore; Samsung, Korea; and ST Microelectronics, France. His experience spans research, product and process development, manufacturing, and semiconductor foundry business P&L. Dr. Liehr holds a Ph.D. in physics, is a certified executive project manager, and has authored or co-authored 20 patents and over 90 publications.

AJIT MANOCHA

Ajit Manocha is chief executive officer of GLOBALFOUNDRIES. Appointed in 2011, he has strong executive experience in the semiconductor industry, most recently as executive vice president of worldwide operations and a member of the executive management board at Spansion. In that role, Manocha managed global integrated circuit manufacturing, supply chain management and purchasing for its semiconductor division. Manocha also served as an advisor to the Advanced Technology Investment Corporation (ATIC), GLOBALFOUNDRIES' investor.

Earlier Manocha was executive vice president and chief manufacturing officer at NXP Semiconductors (formerly Philips Semiconductors). Manocha has also worked at AT&T Microelectronics and AT&T Bell Laboratories. Manocha began his career as a research scientist and was granted over a dozen U.S. and international patents for several inventions in the field of technology for microelectronics, including one for anisotropic etching, a process for treating very-large-scale, patterned integration lithographic masks to retain their shape during processing of VLSI wafers.

He currently serves as chairman of the Semiconductor Industry Association (SIA) and is a member of the boards of GLOBALFOUNDRIES and Maskless Lithography. He also serves on the TechNet Executive Committee. He previously sat on the boards of SVTC, International Sematech, the Crolles Alliance, and ASMC, and has also served as chairman of the board of directors of SSMC in Singapore. Manocha holds a bachelor's degree from the University of Delhi and a master's degree in physical chemistry from Kansas State University.

DREW MATONAK

Andrew J. Matonak assumed the presidency of Hudson Valley Community College on April 18, 2005. President Matonak's tenure is marked by record growth in enrollment and steady progress in completing a $200 million Facilities Master Plan for the college. Construction highlights include the September 2007 dedication of a new, $9.4 million Administration Building; January 2010 opening of TEC-SMART, the Training and Education Center for Semiconductor Manufacturing and Alternative and Renewable Technologies in

Malta, NY, and a new 800-space parking garage completed on the Troy campus in August 2010.

Enrollment records were set in three consecutive years–fall 2008, 2009, and 2010 when it topped 14,000. In addition, a variety of new academic programs have been introduced, most recently Adolescence Education, Alternative Fuels, Automotive Management, Digital Media, Disability Studies, Entrepreneurship, Physical Sciences, and Polysomnography for those interested in becoming sleep technologists.

Construction now is underway on a $35 million state-of-the-art Science Center to be completed by fall 2013 with 25 fully-equipped laboratories for the study of biology, chemistry, physics, biotechnology, earth science and forensics, 11 classrooms, faculty and staff offices, conference spaces, a science study center and a greenhouse. Both Rensselaer County and the State of New York contributed funding for the Science Center and related projects.

President Matonak also initiated the college's first comprehensive fundraising campaign, the $10 million "Promise of Our Region" campaign. He will help celebrate the college's 60th anniversary in 2013, while steering the Middle States Association (MSA) reaccreditation process, as required every 10 years. The college has been accredited by the MSA since 1969 and completed its last self study in 2004. The self study evaluates and assesses every aspect of the college's operations, from its mission, goals and objectives, to academics, student services, administration and strategic planning.

Off campus, President Matonak is vice president/president-elect of the New York Community College Association of Presidents, chairman of the Albany-Colonie Regional Chamber of Commerce's Board of Directors, and president of Troy 2020. He serves on the boards of the Albany-based Center for Economic Growth, Capital Region Sponsor-A-Scholar, the Rensselaer County Regional Chamber of Commerce and First Niagara Bank's Regional Advisory Board. He also is a member of the Capital Region Workforce Investment Board, the Green Jobs-Green New York Advisory Committee, and the Economic and Workforce Commission of the American Association of Community Colleges.

Prior to coming to Hudson Valley Community College, President Matonak served three years as president of Northwest Iowa Community College. His career was shaped by his decision to attend Butler County Community College in Butler, Pennsylvania: He wanted to ensure other students had the same opportunity for success that was given to him. He continued at the College of Wooster in Wooster, Ohio, where he earned a bachelor's degree in sociology, followed by a master's degree in student personnel administration from Michigan State University in East Lansing, Michigan, and a doctorate in higher education administration from the University of Houston in Texas.

He also served as dean of student affairs at Horry-Georgetown Technical College in Conway, South Carolina; assistant dean of student affairs at the University of Houston; the admissions and records coordinator at Lee College in Baytown, Texas; and assistant dean of student development and

coordinator of career development and placement for the Eastern Iowa Community College District.

CLARK MCFADDEN

W. Clark McFadden II represents corporate clients in international trade, encompassing work in litigation, regulation and legislation. He also practices in international corporate transactions, especially the formation of joint ventures and consortia, and international investigations and enforcement proceedings. Mr. McFadden has a broad background in foreign affairs and international trade, having experience with Congressional committees, the U.S. Department of Defense and the National Security Council. In 1986, he was appointed General Counsel, President's Special Review Board (Tower Commission), to investigate the National Security Council system and the Iran-Contra Affair.

In 1979, Mr. McFadden served as special counsel to the Senate Foreign Relations Committee on the Strategic Arms Limitations Treaty (SALT II). Previously, from 1973 to 1976, he was general counsel, Senate Armed Services Committee, and was responsible to the Committee for all legislative, investigatory and oversight activities. Mr. McFadden is the secretary to the Board of Directors of the Semiconductor Industry Association and the Semiconductor Research Corporation. He was also a member of the Steering Committee for Government-Industry Partnerships for the Development of New Technologies of the National Research Council of the National Academy of Sciences.

JASON MILLER

Mr. Miller is the Special Assistant to the President for Manufacturing Policy, working within the National Economic Council in the White House to lead the Administration’s efforts to coordinate policy and federal activities supporting U.S. manufacturing. He joined the Obama Administration in April 2010.

Prior to joining the Administration, Mr. Miller advised global companies as a management consultant with The Boston Consulting Group in San Francisco. He worked with senior executives in the energy and technology manufacturing sectors on strategic, operational, and organizational issues. Earlier in his career, Mr. Miller was at Marakon Associates, a boutique consulting firm, where he provided business advice on corporate finance and strategic issues in manufacturing, healthcare, and energy companies.

Mr. Miller originally hails from Chicago, Illinois. He received a B.A. from the University of Pennsylvania, an M.B.A. from the Kellogg School of Management at Northwestern University, and a M.P.A. from Harvard’s Kennedy School of Government.

FRANK MURRAY

Francis J. Murray, Jr. was appointed president and chief executive officer of the New York State Energy Research and Development Authority (NYSERDA) on January 26, 2009. Prior to his appointment, Mr. Murray served as senior advisor at the international environmental consulting firm Ecology and Environment, Inc., where he provided strategic policy and market development guidance on environmental and energy issues to a number of private sector and not-for-profit clients. Mr. Murray also represented the Pace Energy and Climate Center and the Natural Resources Defense Council in the New York Public Service Commission proceeding to establish an energy efficiency portfolio standard program.

From 1996 to 1997, Mr. Murray was policy advisor to the United States Secretary of Energy, assisting in the development of the Clinton Administration's national energy policy. Mr. Murray served from 1992 to 1994 as the New York State Commissioner of Energy and chairman of the NYSERDA Board of Directors, then a statutory function of the State Energy Commissioner. At that time, he also served as chairman of the State Energy Planning Board, a multi-agency statutory board charged with the responsibility of developing a comprehensive, integrated energy plan for the state that integrated state energy, environmental, and economic development policies.

In 1985, Mr. Murray was appointed Deputy Secretary to the Governor for Energy and the Environment, a position he held until 1992. He served from 1983 to 1985 as Assistant Secretary for Energy and the Environment in the administration of New York State Governor Mario M. Cuomo. He represented New York in numerous national and regional energy and environmental activities, including the Coalition of Northeastern Governors, the National Governors' Association, and the Council of Great Lakes Governors. Mr. Murray began his work on New York State energy issues as legislative counsel and then as an energy and environmental policy advisor to Governor Hugh Carey from 1977 to 1982. He began his career in public service as a legislative assistant to Congressman James V. Stanton (D-Ohio). Mr. Murray received his Bachelor of Science in foreign service cum laude from the Edmund A. Walsh School of Foreign Service at Georgetown University, and his Juris Doctor from Georgetown University Law Center.

LARRY NAGAHARA

Dr. Nagahara is director of the Office of Physical Sciences-Oncology in the Center for Strategic Scientific Initiatives (CSSI), National Cancer Institute (NCI), where he coordinates and directs program and research activities related to expanding the role of the physical sciences in cancer research, including the Physical Sciences-Oncology Centers (PS-OC) Program. Previously, he served as the Nanotechnology Projects Manager for the NCI's Alliance for Nanotechnology in Cancer program, for which he helped oversee the

development of promising nano-based diagnostics and therapeutics projects and turned them into applications that will eventually benefit cancer patients. Dr. Nagahara also currently represents NCI on the Trans-NIH Nano Task Force, which is tasked to develop NIH-wide scientific and policy vision for nanotechnology, as well as NCI's Project Scientist for the NIH's Nanomedicine Development Centers and NIH's Genes and Environment Initiative (GEI), Exposure Biology Program.

Dr. Nagahara has been actively involved in physical sciences and nanotechnology for over 15 years, most notably novel scanning probe microscopy development, carbon nanotube applications, molecular electronics, nanoenergy, and nanosensors. Before joining NCI, he was a distinguished member of the technical staff at Motorola and led their nanosensor effort. He is also currently an adjunct professor in the Department of Physics at Arizona State University and an associate editor of the IEEE Sensors Journal. Dr. Nagahara has published over 80 technical papers and 3 book chapters, and has one book pending as well as over 15 patents issued/filed in these fields. He is an American Physical Society (APS) Fellow and a Nano50 Awardee, and was a member of Motorola's Scientific Advisory Board.

GARY PATTON

Dr. Gary Patton is vice president of IBM’s Semiconductor Research and Development Center (SRDC), which has major facilities in East Fishkill, New York, Burlington, Vermont, and the Albany Nanotech Research Center in Albany, New York. Under his leadership, IBM’s technology and SRDC teams continue to be at the forefront of innovation in silicon technology, developing IBM’s next-generation SOI, bulk CMOS logic, embedded DRAM, packaging research and development, and 3D Integration. During his career at IBM, Dr. Patton has held various management and executive positions in IBM’s Microelectronics, Storage Technology, and Research divisions, including leadership positions in technology and product development, manufacturing, and business line management. As general manager of the Head and Media Technology business unit, he contributed to the successful merger of the IBM and Hitachi Storage Technology businesses.

LUIS PROENZA

Luis M. Proenza is chief executive officer of The University of Akron (UA). He has led its transformation into a powerful engine for regional economic development, a catalyst for collaborative initiatives, and the preeminent public university in Northeast Ohio. In 12 years of his leadership, UA’s revenue and research portfolio more than doubled, and private donations established all-time records. His initiatives have distinguished the university nationally and internationally and made it a national model for innovation. In 2001, President George W. Bush appointed Dr. Proenza to serve on the

President's Council of Advisors on Science and Technology, the nation's highest-level policy advisory group for science and technology.

Dr. Proenza also is a member of the executive committee for the Council on Competitiveness and its Manufacturing Competitiveness Steering Committee, the Government-University-Industry Research Roundtable of the National Academies, the Technology Innovation Program Advisory Board for the National Institute of Standards and Technology, and the Council on Foreign Relations. He holds a bachelor's degree from Emory University (1965), a master's degree from The Ohio State University (1966), and a doctorate from the University of Minnesota (1971).

ANTHONY RITACCIO

Anthony Ritaccio is director of the Epilepsy and Human Brain Mapping Program, the only program of its kind in Northeastern New York. He is an expert in the medical and surgical treatment of epilepsy. His team of specialists has exclusive experience in the care of difficult to treat epilepsy. The team focuses on evaluating and treating people with seizures utilizing the most modern techniques and state-of-the-art technology available in order to offer a more accurate and detailed diagnosis of a patient's condition with goals of seizure freedom through medication or cure through advanced surgical techniques.

His approach to patient care is one that is both extremely personal and highly specialized: "I treat each patient from start to finish," says Dr. Ritaccio. "We are the only comprehensive, multidisciplinary team in the region engaged to cure people with epilepsy." Apart from his clinical focus, he is engaged in Department of Defense funded research on advanced methods of detecting and using human brain signals to control computers and computerized devices "with thought."

Dr. Ritaccio, professor of neurology and neurosurgery, is also director of the Clinical Neurophysiology Laboratory and the J. Spencer Standish Endowed Chair in Neuroscience.

DAVID ROONEY

As senior vice president of business development and marketing at the Center for Economic Growth, David oversees the membership development process and implementation of marketing and sales strategies. In addition David is responsible for leading all economic development and marketing related activities specific to six industry sectors: Nanotechnology/Semiconductors, Advanced Materials, Renewable Energy, Information Technology, Bio/Life Sciences, and Homeland Security/Defense. This includes developing strategic global marketing plans for the six industry sectors; sales calls and presentations

to industry executives; prospect coordination; market research; and collaborating with local economic developers on specific projects.

David Rooney brings 25 years of corporate and government experience in economic development, marketing, public relations, business development and strategic planning to his role at CEG. He is a graduate of the University at Albany, State University of New York.

MICHAEL RUSSO

Michael Russo is the director of government relations and regulatory affairs for GLOBALFOUNDRIES, the world's second largest contract semiconductor manufacturer. He spearheads initiatives that connect his industry to civic, government, education, labor, and business leaders across the United States, and was involved in bringing President Obama to New York to talk about growing manufacturing and increasing the nation's exports. Russo has been at GLOBALFOUNDRIES since 2009, during which time he completed his B.S. in interdisciplinary studies at the Northeast Center, partly through prior-learning assessment, which incorporated his breadth of experiences as a foundation of his degree.

Soon after high school, Mr. Russo became shop steward at Owens Corning for the Glass, Molders, Pottery, Plastics & Allied Workers International Union. He rose through the ranks first to be president locally, and finally to be an executive officer at the national level, with expertise in organizational development, arbitration and negotiation. In this role, Russo was acutely attuned to politicians sympathetic to the middle class, worker-employer relationships, the problem of American jobs being exported overseas and the importance of the U.S. remaining competitive in the global marketplace. He also became a close advisor to Sen. Kirsten Gillibrand, who was instrumental in facilitating support for GLOBALFOUNDRIES. From her office, he moved to GLOBALFOUNDRIES.

DONALD SIEGEL

Donald Siegel is dean of the School of Business and professor of management at the University at Albany, SUNY. He also serves as president of the Technology Transfer Society, a non-profit organization devoted to interdisciplinary analysis of entrepreneurship and technology transfer from universities and federal laboratories to firms. He received his bachelor's degree in economics and his master's and doctoral degrees in business economics from Columbia University. He then served as a Sloan Foundation post-doctoral fellow at the National Bureau of Economic Research, under the supervision of the late Zvi Griliches at Harvard. Don has taught at SUNY-Stony Brook, Arizona State University, the University of Nottingham, RPI, where was he was chair of the Economics Department, and the University of California-Riverside, where he served as associate dean for Graduate Studies. Dr. Siegel is co-editor

of *Academy of Management Perspectives*, editor of the *Journal of Technology Transfer*, an associate editor of the *Journal of Productivity Analysis,* and serves on the editorial boards of *Academy of Management Review*, *Academy of Management Learning & Education, Journal of Management Studies*, *Journal of Business Venturing*, *Corporate Governance: An International Review*, and *Strategic Entrepreneurship Journal*. He has also co-edited 32 special issues of leading journals in economics, management, and finance.

Don was recently ranked #2 in the world for research on university entrepreneurship and #760 in the world among academic economists. He has published 97 articles and 6 books on issues relating to university technology transfer and entrepreneurship, the effects of corporate governance on economic performance, productivity analysis, and corporate and environmental social responsibility in such leading journals in economics, finance, and management as the *American Economic Review, Economic Journal, The Review of Economics and Statistics, Journal of Law and Economics, Journal of Financial Economics, Brookings Papers on Economic Activity, Research Policy, Academy of Management Review, Academy of Management Journal, Academy of Management Perspectives, Academy of Management Learning & Education, Strategic Management Journal, Journal of Business Venturing, Journal of International Business Studies*, *Journal of Management Studies*, and *Journal of Management*. His most recent books are *Innovation, Entrepreneurship, and Technological Change* (*Oxford University Press*) and the *Oxford Handbook of Corporate Social Responsibility (Oxford University Press*). He is currently co-editing the *Handbook of University Technology Transfer (University of Chicago Press*), *the Oxford Handbook of Corporate Governance (Oxford University Press*), and the *Oxford Handbook of the Economics of Gambling* (*Oxford University Press*).

Dr. Siegel has received grants or fellowships from the Sloan Foundation, NSF, Kauffman Foundation, NBER, American Statistical Association, W. E. Upjohn Institute for Employment Research, and the U.S. Department of Labor. He has also served as a consultant or advisor to the United National; National Research Council; the Council on Competitiveness; the U.K., Italian, and Swedish governments; the Department of Justice; the Environmental Protection Agency; Chase Manhattan; Securities Industry Association; Morgan Stanley; Goldman Sachs & Co; Deloitte and Touche; and the National Association of Manufacturers. Professor Siegel was a member of the Advisory Committee to the Secretary of Commerce on "Measuring Innovation in the 21st Century Economy" and a member of Governor David Patterson's Small Business Task Force. He is co-chair of the NRC Committee on "Best Practice in National Innovation Programs for Flexible Electronics" and an advisor to the NRC on the Small Business Innovation Research (SBIR) Program. In 2011, Dr. Siegel testified before the House Committee on Science, Space, and Technology regarding re-authorization of the SBIR program. He also serves on the Board of Directors of the Research Foundation of the State University of New York.

PHILLIP SINGERMAN

Phillip Singerman serves as associate director for innovation and industry services at the National Institute of Standards and Technology (NIST). In this capacity he is responsible for the NIST suite of external partnership programs, including the Hollings Manufacturing Extension Partnership, the Technology Innovation Program, the Baldrige Performance Excellence Program, and NIST technology transfer and small business innovation research awards.

The position of associate director was established in October 2010 as part of the first major realignment of NIST programs in 20 years; Mr. Singerman was appointed to this position in January 2011. Immediately prior to joining NIST, he was a senior vice president at B&D Consulting, a DC-based firm providing strategic advice and technical assistance on federal economic development programs to non-profit organizations, local governments, and universities. Previously he was a managing director of a $120 million seed stage venture fund that invested in early stage technologies.

Mr. Singerman has more than 30 years of experience in tech-based economic development; he was the first chief executive of two of the best known public-private partnerships, the Ben Franklin Technology Center of Southeastern Pennsylvania and the Maryland Technology Development Corporation. During the Clinton Administration he served as U.S. Assistant Secretary of Commerce for Economic Development, a Presidential appointment requiring Senate confirmation.

Mr. Singerman has participated on scores of local, state, and national advisory boards and associations, including the State Science and Technology Institute, the Technology Council of Maryland, the International Economic Development Council, NGA's Advisory Committee on Entrepreneurial Policy, NSF's Small Business Advisory Committee, the Pennsylvania Biotechnology Association, the Strengthening America's Communities Initiative Advisory Committee, and the Editorial Board of the *Economic Development Quarterly*.

Mr. Singerman received his bachelor's degree from Oberlin College and holds a doctorate from Yale University. He has taught at Yale College, Barnard College (Columbia University), and the Fels Institute of Government (University of Pennsylvania). After graduating from college he served as a Peace Corps Volunteer in Colombia, South America, working in rural community development projects.

Mr. Singerman is a co-author of "Beyond Recovery: Moving the Gulf Coast Toward a Sustainable Future" (February 2011), published by the Center for American Progress and Oxfam America, and the "Handbook on Climate Prosperity" (May 2009), published by the International Economic Development Council.

REX SMITH

Rex Smith is editor and vice president of the *Times Union*, the dominant communication medium in New York's Capital Region. He has led the Albany newspaper since mid-2002 to national recognition for writing, reporting, photography and design, both in print and on the Web. He is a former national correspondent and bureau chief for *Newsday*, and previously edited community newspapers in New York and Indiana. Earlier in his career, he was a congressional aide in Washington and a television reporter and anchor in the metropolitan New York region. He has received numerous professional citations and awards, including the Distinguished Service Award of the national Society of Professional Journalists, a Pulitzer Fellowship, and a Rotary Fellowship. He is a graduate cum laude of Trinity University in San Antonio, Texas, and received his master's degree with highest honors from the Columbia University Graduate School of Journalism.

Rex hosts a nationally syndicated weekly program, "The Media Project," on Northeast Public Radio, is past president of the state press association and vice chair of the state Fair Trial/Free Press Conference. He has been a national leader in efforts to build news literacy among students. Outside journalism, Rex is known as a singer: He is a member of Albany Pro Musica, one of the Northeast's premiere choral ensembles. Rex lives in Rensselaer County with his wife, the author Marion Roach Smith, and their 17-year-old daughter, Grace Yu Ying Smith.

DARREN SUAREZ

Darren Suarez is a director of government affairs, with responsibility for all advocacy on energy, environmental and occupational safety, and health issues.

Darren comes to The Business Council from Hinman Straub LLC, where he lobbied on behalf of a number of Fortune 500 companies on energy and environment issues. Before that, Darren was the program director for environmental and economic development for the New York State Senate, where he represented the Majority Leader in meetings and public event, and developed, amended, and negotiated economic development tax incentives. Previously, he was a government affairs representative for the City University of New York and Cornell University, and worked for the New York State Department of Labor as a job services representative working with employers to meet their workforce needs.

Darren holds a degree in political science from UMass–Dartmouth. He was the recipient of the 2006 Economic Development Service Award in recognition of work in attracting GLOBAL FOUNDRIES to construct a $3.2 billion 300 mm-wafer fab in New York State. He was awarded the 2005 New York Nature Conservancy's Salamander Award for working to protect New York's biodiversity and a joint recipient of the 2004 National Conference of

State Legislatures Staff Chair Award for work as a primary author of New York's Brownfield Cleanup Program.

PAUL TONKO

Congressman Paul Tonko is a third term member of the United States House of Representatives. He currently represents New York's 20th Congressional District, including the cities of Albany, Schenectady, Troy, Saratoga Springs, and his hometown of Amsterdam. Paul has been a champion for the middle class, job creation, economic opportunity, providing senior citizens the opportunity to retire with dignity and the mental health community throughout his career.

For the 113th Congress, Paul was named as a member of the Energy and Commerce Committee, the oldest standing committee in the House. First created in December of 1795, the committee has jurisdiction over national energy policy, public and mental health policy, and regulation of interestate and foreign commerce, giving it the broadest jurisdiction of any authorizing committee in the House. Paul is the first upstate New York Democratic member of the committee since Leo O'Brien, who resigned the post in October 1966. Previously, Paul has served on the Science, Space and Technology Committee, Natural Resources Committee, Budget Committee, and Education and Workforce Committee.

He continues to fight to bring clean energy jobs to the Capital Region to ensure it maintains its status as one of the fastest growing clean technology hubs in the country. Paul believes in the power of America's middle and working class families and is fighting to ensure the American Dream stays within reach for all who work hard and play by the rules. As a former member of the Budget Committee, Paul offered the lead amendment to the Ryan Budget to protect Medicare and was instrumental in fighting to protect the program from ending. Building on his work in the New York State Assembly, where he fought for one of the nation's strongest mental health parity laws, known as Timothy's Law, Paul continues to promote mental health parity at the federal level and serves as a co-chair of the Mental Health Caucus.

Prior to joining Congress, Paul was the president and CEO of the New York State Energy Research and Development Authority. Before that, he served in the New York State Assembly for 25 years, 15 of which he was the chair of the Assembly Energy Committee. At the age of 26, Paul was the youngest person in the history of Montgomery County to be elected to the County's Board of Supervisors, which he chaired until 1981. Paul graduated from Clarkson University with a degree in mechanical and industrial engineering. He is a lifelong resident of the city of Amsterdam, New York.

BRIAN TOOHEY

Brian C. Toohey is the president & CEO of the Semiconductor Industry Association (SIA). Joining the association in 2010, Mr. Toohey brings more than two decades of experience and knowledge in both federal and international affairs as well as working in innovative technology, medical device, and pharmaceutical industries. At SIA, Mr. Toohey is responsible for setting and leading the public policy agenda and serving as the primary advocate for maintaining U.S. leadership in semiconductor design and manufacturing. Mr. Toohey works closely with SIA member companies and the Board of Directors to align industry priorities and policy goals.

Prior to joining SIA, Mr. Toohey held key executive leadership positions, both in federal and international affairs at Pharmaceutical Research and Manufacturers of America (PhRMA). Previously, he was a senior vice president at DEKA Research and Development, a medical device company, and at the wireless network operator and service provider AirCell, Inc. Mr. Toohey also served as the director of international government affairs & strategic planning and a director of the European business unit at the global satellite company, Iridium LLC. Prior to joining the private sector, Mr. Toohey worked for several years at the U.S. Department of Commerce, primarily on European trade and intellectual property issues.

Mr. Toohey received his undergraduate and graduate degrees from the Georgetown University School of Foreign Service. He is a member of the U.S. Department of Commerce's and United States Trade Representative's International Trade Advisory Committee and an advisor to F.I.R.S.T., a leading nonprofit organization that brings science and technology to America's schools. Mr. Toohey has served as a member of the U.S. Department of State Advisory Committee on International Economic Policy and as an adjunct professor of science, technology, and international affairs at Georgetown University. A Boston native, Mr. Toohey and his wife reside in Washington, DC.

MICHAEL TUCKER

F. Michael Tucker was appointed president of the Center for Economic Growth (CEG) in March 2007. The Center for Economic Growth is a regional, not-for-profit, private-sector economic development organization promoting growth through accomplishment of strategic initiatives, industry attraction, and regional outreach.

Prior to joining CEG, Mike served as president of the Harriman Research and Technology Development Corporation where he was responsible for initiating and overseeing the redevelopment of the 300-acre W.A. Harriman State Office Campus into a world class Research and Technology Park. For more than 25 years Mike was a principal with Mercer Companies, Inc., an Albany based real estate and energy development firm. Mr. Tucker oversaw the development, financing and operation of Mercer's commercial office, senior

housing and hydroelectric projects throughout New York State. In addition, he was responsible for Mercer's property management and real estate brokerage services. Mr. Tucker's has extensive experience in business, economic development and energy related issues.

Mike is a graduate of Villanova University and the Villanova School of Law. He is an attorney and a licensed real estate broker. He is active in legal, real estate, and economic development organizations at the local, state, and national levels. He served as the chairman of the Town of Bethlehem Industrial Development Agency and he is a trustee of Ulster Savings Bank. He currently serves as a director of the New York State Economic Development Council and is on the boards of numerous not-for-profit organizations throughout Tech Valley.

JOHN WEN

John Ting-Yung Wen received his B.Eng. from McGill University in 1979, M.S. from University of Illinois in 1981, and Ph.D. from Rensselaer Polytechnic Institute in 1985, all in electrical engineering. From 1981 to 1982, he was a system engineer at Fisher Controls where he developed a plant-wide coordination control system for pulp and paper plants. From 1985 to 1988, he was a member of technical staff at the Jet Propulsion Laboratory where he developed new modeling and control algorithms for large space structures and space robots. Since 1988, he has been with Rensselaer Polytechnic Institute where he is currently a professor in the Department of Electrical, Computer, and Systems Engineering with a joint appointment in the Department of Mechanical, Aerospace, and Nuclear Engineering.

Since July 2005, he has been the director of a New York State sponsored interdisciplinary center, Center for Automation Technologies and Systems (CATS). He was the interim director of the Smart Lighting Center, an NSF Engineering Research Center involving six partner universities, from June 2009 to December 2009. Dr. Wen was an ASEE/NASA summer faculty fellow in 1993, a Japan Society for the Promotion of Science (JSPS) senior visiting scientist in 1997, and an Oversea Assessor of the Chinese Academy of Sciences, 2004 to 2009. Dr. Wen has over 200 technical publications in leading journals and conferences. His research interest lies in the general area of dynamical systems modeling and control with applications to high performance motion systems, robot manipulation, opto-mechatronics systems, thermal management, and aerodynamic flow control. Dr. Wen is a Fellow of IEEE.

CHARLES WESSNER

Charles Wessner is a National Academy Scholar and director of the Program on Technology, Innovation, and Entrepreneurship. He is recognized nationally and internationally for his expertise on innovation policy, including

public-private partnerships, entrepreneurship, early-stage financing for new firms, and the special needs and benefits of high-technology industry. He testifies to the U.S. Congress and major national commissions, advises agencies of the U.S. government and international organizations, and lectures at major universities in the United States and abroad. Reflecting the strong global interest in innovation, he is frequently asked to address issues of shared policy interest with foreign governments, universities, research institutes, and international organizations, often briefing government ministers and senior officials. He has a strong commitment to international cooperation, reflected in the recent honor bestowed on him with his nomination as an Officer of the Order of Merit by the President of the Republic of France.

Currently, he directs a series of studies centered on government measures to encourage entrepreneurship and support the development of new technologies and the cooperation between industry, universities, laboratories, and government to capitalize on a nation's investment in research. Foremost among these is the congressionally mandated study of the Small Business Innovation Research (SBIR) Program, reviewing the operation and achievements of this $2.7 billion award program for small companies and start-ups. He is also leading an assessment of the Manufacturing Extension Partnership that includes a review of major foreign manufacturing support programs such as the German Fraunhofer, Taiwan's ITRI, Canada's IRAP, and the French Carnot centres. He just completed directing a major study of global innovation programs, entitled *Comparative National Innovation Policies: Best Practice for the 21st Century*. The overarching goal of Dr. Wessner's work is to develop a better understanding of how we can bring new technologies forward to address global challenges in health, climate, energy, water, infrastructure, and security.

NANCY ZIMPHER

On June 1, 2009, Nancy L. Zimpher became the 12th Chancellor of The State University of New York, the nation's largest comprehensive system of higher education. A nationally recognized leader in education, Chancellor Zimpher spearheaded and launched a new strategic plan for SUNY in her first year as chancellor. The central goal of the plan, called The Power of SUNY, is to harness the university's potential to drive economic revitalization and create a better future for every community across New York.

Chancellor Zimpher is active in numerous state and national education organizations and is a leader in the areas of teacher preparation, urban education, and university-community engagement. As co-founder of Strive, a community-based cradle-to-career collaborative, Chancellor Zimpher has been instrumental in creating a national network of innovative systemic partnerships that holistically address challenges across the education pipeline. She has authored or co-authored numerous books, monographs, and academic journal articles on

teacher education, urban education, academic leadership, and school/university partnerships.

Chancellor Zimpher currently serves as chair of the Board of Governors of the New York Academy of Sciences and of CEOs for Cities. From 2005 to 2011, she chaired the national Coalition of Urban Serving Universities. She also recently co-chaired NCATE's blue-ribbon panel on transforming teacher preparation. She previously served as president of the University of Cincinnati, chancellor of the University of Wisconsin-Milwaukee, and executive dean of the Professional Colleges and dean of the College of Education at The Ohio State University. She holds a bachelor's degree in English Education and Speech, a master's degree in English Literature, and a Ph.D. in Teacher Education and Higher Education Administration, all from The Ohio State University.

Appendix C

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Appendix D

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