Building the Illinois 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

Building the Illinois 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]

[1]To date, the Committee has convened meetings to review state and regional programs in Arkansas, Hawaii, Michigan, and Ohio. See for example, National Research Council, *Building the Arkansas Innovation Economy: Summary of a Symposium*, Charles W. Wessner, Rapporteur, Washington, DC:

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.

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.[2] 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.[3] 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

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The National Academies Press, 2012. See also National Research Council, *Building Hawaii's Innovation Economy: Summary of a Symposium*, Charles W. 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*, Charles W. Wessner, Rapporteur, Washington, DC: The National Academies Press, 2011.

[2]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*, Charles W. Wessner and Alan Wm. Wolff, eds., Washington, DC: The National Academies Press, 2012.

[3]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*, Charles W. Wessner, ed., Washington, DC: The National Academies Press, 2009.

knowledge-based industries and grow innovation clusters.[4] 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.

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 Illinois. These symposium participants assessed Illinois' 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. While it did not (and indeed could not) develop in-depth analyses of the full variety of industries present in the state, the conference did focus on the biotechnology sector as a leading exemplar of an innovation driven industry. The emerging partnerships among academia, industry, and government in biotechnology are, in particular, illustrative of a wider set of initiatives underway in Illinois to grow the state's innovation ecosystem. A more complete list of Illinois innovative industries would include advanced manufacturing, bio-fuels, renewable energy, digital media, financial technologies, and retail and consumer businesses.

This summary includes an introduction that highlights key issues raised at the meeting and a summary of the meeting's presentations. This workshop

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

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.

ACKNOWLEDGMENTS

On behalf of the National Academies, we express our appreciation and recognition for the insights, experiences, and perspectives made available by the participants of this meeting. We would particularly like to recognize the vision and initiative of Jerry Lee and Larry Nagahara of the National Cancer Institute, and the leadership and support of Chad Mirkin of Northwestern University. We would also like to express the Academies' appreciation of Kathleen Cook of Northwestern University and Ted Fetters of the Illinois Science & Technology Coalition. 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.

NATIONAL RESEARCH COUNCIL REVIEW

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: Amy Francetic, Clean Energy Trust; Lisa Freeman, Northern Illinois University; Neil Kane, Illinois Partners Executive Services; 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

What policies and organizations are helping to drive innovation-based business formation, employment, and economic growth in Illinois? To address this question, the National Academies STEP Board, in cooperation with the National Cancer Institute and the International Institute for Nanotechnology at Northwestern University convened a conference of state business, academic, and political leaders as well as high-level U.S. government officials to highlight the accomplishments, challenges, and opportunities of the Illinois innovation ecosystem. The conference highlighted the contributions of Illinois universities in generating research, creating new businesses, and attracting talent to the state. Participants also considered how national and international models for innovation and cluster development could be adapted in Illinois.

In his welcoming remarks, Dr. Chad Mirkin, George B. Rathmann Professor of Chemistry at Northwestern and director of the International institute for Nanotechnology (IIN), noted the particular relevance of innovation given ongoing efforts to enhance the effectiveness knowledge-based economic development in Illinois. The attendees, he said, ranged from Governor Pat Quinn, who has worked hard to support pro-innovation policies, to academic researchers who have translated their scientific discoveries into successful businesses.

Dr. Mirkin noted that the conference would review the available innovation resources at the state level, as well as examine how these resources might be strengthened by closer cooperation with federal programs. He expected that there would be both complementarities and differences between national and state policies, and that these needed to be identified and developed to enhance the competitiveness of the region.

Specifically, he urged that Illinois strive to take advantage of federal initiatives; especially those that help establish and strengthen innovation hubs. This would include forming alliances with innovative companies able to make use of new technologies and advancing existing technologies through partnerships with academia, government, and private sources of capital.

A. THE NATURE OF AN INNOVATION ECOSYSTEM

Conference participants focused on the challenge of innovation, which involves not only creating a new idea, but also commercializing that idea into a new product or service. [1] They further noted that innovation is inherently risky; neither the ultimate value of the product, nor the state of possible competition, nor the ultimate appetite of the market place can be fully known in advance.

Robert Easter, President Designate of the University of Illinois, described innovation as pertaining "not only a discovery or intention, but a technology that been developed to the point where it has value to humanity. I'm glad the word innovation is being used in proper context today," he said, "because I think it's what we have to do to translate 'discovery science' into products that have value." In his keynote remarks, Illinois Governor Pat Quinn offered a more succinct definition of an innovation: "It is people seeing something, and seeing how to do it better."

To describe a successful environment for innovation, Dr. Mirkin used an analogy from chemistry: "The challenge is to create an innovation ecosystem," he said, "that has enough 'collisions' to expose all good ideas to the free market. [2] That is when entrepreneurs can identify which ones are likely to be winners and make the investments that lead to success."

What are the essential elements of a successful innovation ecosystem? According to Dennis Roberson of the Illinois Institute of Technology, key ingredients include a skilled workforce, modern infrastructure, responsive community services, adequate venture financing, and an effective and enabling government.

Dr. Mirkin added that sustaining such an "ecosystem," requires supportive policies that incentivize entrepreneurship. Twenty or thirty years ago, he said, scientists had little interest in innovation. "Their view was that technology was a bad word, and business was an even worse word." Today, the professors of the 21st century are concerned not only with their traditional responsibilities of teaching, research, and outreach, but also with the world of

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[1]The most basic definitions of innovation reflect its etymology: *in* = "into" + *novus* ="new." For example, one dictionary calls it "The introduction of something new; a new idea, method or device." <*http://www.merriam-webster.com/dictionary/innovation*>. Beyond this, notes Wikipedia, is the distinction between innovation and invention. "Innovation differs from invention in that innovation refers to the use of a better and, as a result, novel idea or method, whereas invention refers more directly to the creation of the idea or method itself. Innovation differs from improvement in that innovation refers to the notion of doing something different (Lat. innovare: "to change") rather than doing the same thing better." <*http://en.wikipedia.org/wiki/Innovation*>.

[2]The term, "innovation ecosystem" is an elaboration of "national innovation system," which was popularized by Christopher Freeman in the 1980s, and was soon applied to regional and state innovations systems as well. See C. Freeman, "The 'National System of Innovation' in Historical Perspective," *Cambridge Journal of Economics* 19:5-24, 1995. Freeman emphasized that while globalization is a profoundly important macro phenomenon, innovation actually occurs within regional and state economies. See C. Freeman, 'Japan: A new national innovation system?', in G. Dosi, C. Freeman, R. R. Nelson, G. Silverberg, and L. Soete (eds.) *Technology and Economy Theory*, London: Pinter, 1988.

inventions, patents, and commerce. Thanks in large part to the Bayh-Dole Act of 1980, he said, academic scientists are encouraged to translate their research into a marketable product and perhaps even a new business opportunity.[3] Many of these, including several of Dr. Mirkin's own initiatives, have been successful.

A robust innovation ecosystem also depends on a supportive environment that encourages collaboration and shares risks. While popular culture often celebrates the "lone inventor," real-world innovation is more likely the result of active collaboration among partners, mentors, and financers. Innovation happens, said Dr. Mirkin, with "willing participants and great talent, within innovation hubs consisting of great universities and government laboratories, and a population of students, post doctoral researchers, faculty members, and business leaders."

B. BUILDING THE ILLINOIS INNOVATION ECOSYSTEM

Are these elements of a successful innovation ecosystem in place in Illinois? The conference drew a variety of perspectives on the accomplishments, challenges, and opportunities facing the region.

Norbert G. Riedel, corporate vice president and Chief Science and Innovation Officer of Baxter International, averred that the region has done "an excellent job in building an ecosystem here in Illinois that is technology based." He said that he also found "an impressive new spirit of community among academic centers of excellence, industry, small and large companies, and also the governments of the state and city. " Dr. Riedel observed that repeated physical interaction and communication are important to facilitate cooperation. "Fluidity matters," he said—"the flow of people and ideas between academia and industry." In the United States, he added, we have a number of opportunities to form close partnerships between academic centers of excellence and industry. "We meet so often through joint appointments, academic visits to our laboratories, students working in our laboratories. I believe we need to nurture these opportunities. I see it as a genuine competitive advantage over most of the world."

Key Challenges

Describing the region's challenges, William Testa of the Federal Reserve Bank of Chicago, said that "what we know about Chicago is that there is a yawning gap between our capacity and what we produce in new start-ups and businesses. In the last decade, we were in the top eight cities in NIH

[3]For a review of the structural factors underpinning the effectiveness of this legislation, see David C. Mowery and Bhaven N. Sampat, "The Bayh-Dole Act of 1980 and University–Industry Technology Transfer: A Model for Other OECD Governments?." *The Journal of Technology Transfer* 30(1-2): 115-127, 2004. See also National Research Council, *Managing University Intellectual Property in the Public Interest*, Stephen Merrill and Anne-Marie Mazza, eds., Washington, DC: The National Academies Press, 2010.

funding, but we had very few biotech start-ups." Similarly, David Miller, leader of the Illinois Biotechnology Industry Organization, (iBIO), observed that the region has always been strong in generating research, but it has lacked a corresponding ability to translate that research into companies that remain in Illinois. Instead, he said, Illinois companies would leave for the coasts, and even for Wisconsin, Indiana, Michigan, and other places that had "more jobs, a good tax base, greater wealth creation, taxpayer-financed resources, and more excitement."

Offering a cultural explanation for the relative slow rate of start-ups in the state, John Fernandez, a former Administrator of the Department of Commerce's Economic Development Administration and a former mayor of Bloomington, Indiana, observed that successful innovation depends on a positive culture of entrepreneurship. "I grew up in the Midwest," he said, "where entrepreneurial failure was not okay: You were ostracized; you had huge problems with your next funding. We still penalize risk-taking in the Midwest to a much greater degree than in other parts of the country; in California, if you have not failed at least once, you are not an entrepreneur. It is a cultural mindset [prevalent] through the region's banking and the industrial community."

These perceptions about failure may be reinforced by policy. According to David Miller, another reason for the small-company exodus has been the state's reliance on a "big-company strategy." The state of Illinois has traditionally sought to attract large companies to site new facilities or expansion facilities in Illinois. "I compare this to trying to win a baseball game by hitting only home runs—or by hitting only grand-slam home runs. What we're looking for is a more diversified economy that includes a small-business strategy." This, he added, would include a more supportive business ecosystem, including what the Brookings Institution calls "catalytic organizations" and a modest amount of state assistance. "With all the advantages here, we don't need the biggest, richest, fattest set of investments," he said. "We just need to be competitive."

New Public-Private Partnerships

Several participants noted that the Illinois innovation ecosystem has strengthened and developed over the past decade. They described the emergence of new kinds of public-private partnerships, some of them non-profit spinoffs from the largest companies and universities. They expressed enthusiasm about working together, and optimism about innovative designs of the programs themselves.

David Miller noted that iBIO, founded in 2003, supports multiple sectors of the Illinois biotechnology industry, including strong companies and start-ups in medical, agricultural, and bio-industrial areas. Norbert Riedel of Baxter, a strong supporter of iBIO, noted that his organization has expanded its reach by providing more than 500 teachers with professional development, problem-based learning, and the stronger ability to teach science—a pressing regional and national need. iBIO, working with the state and the city

government, had also helped locate the Annual International Convention of the Biotechnology Industry Organization in Chicago in 2006 and 2010, and to repeat as host in 2013 and 2016.

Similarly, the Illinois Science & Technology Coalition (ISTC) has a mission "to cultivate and attract research and technology-based investment, talent and job growth in the state." Its member organizations include Argonne National Laboratory, University of Chicago, Northwestern University, University of Illinois, Illinois Institute of Technology, Abbott Laboratories, Baxter, industry groups, and non-profits. According to Mark Harris, ISTC's president, the value and the strength of this organization lie in its ability to build bridges across sectors, disciplines, and institutions. He noted, for example, that ISTC had recently helped Argonne Laboratory prepare a $100 million proposal for a storage hub. It had also worked with the University of Illinois to join the national Network of Advanced Manufacturing.

One of the ISTC's priorities has been to increase the space available for innovators. Mr. Harris said that he was especially proud of "1871," a 50,000-square-foot digital technology incubator launched in May 2012 in the Merchandise Mart. "Everybody can have a presence in 1871," he said. "And it's not just an incubator. The old incubator model was, 'Give him a copier, he can share the copier.' I'm seeing the development of an ecosystem now that is becoming more vital and connected."

Closely related to the ISTC is the Illinois Innovation Council (IIC). In his keynote address, Governor Quinn told the conference participants that that the primary focus of the Council is to showcase "the innovation excellence of Illinois in both academia and industry"—not only in health care, but also across agricultural, industrial and other applications of technology.

Dr. Riedel of Baxter said he took a keen interest in collaboration. Advancing academia-industry partnership was clearly foremost in his activities (he holds both biotech and engineering positions at Northwestern University), but he took pains at several points during the conference to highlight the development of a broad network of participants. He noted in particular "a community spirit that is very important in building this infrastructure," reflected in the new tech parks in adjacent Skokie, the Illinois Institute of Technology, the Illinois Medical District, and the University of Illinois Technology Park, which "for the most part, are filling up to capacity. "This clearly shows that we are building jobs, companies, and a technology-based industry. The industry has first-class IP law firms, and a relatively large number of start-ups and new companies."

Dr. Riedel also observed that technology transfer is improving "as university offices become more adept at interfacing with industry and creating transparency to the vast portfolios of intellectual property." Without transparency, he said, a person in industry has little access to research projects that might have potential value for industry. At Northwestern, the Innovation and New Venture Organization is not only a tech transfer office, he said, but

"really an organizational framework that recognizes and finds innovation and spins that innovation into new start-ups."

Expanding Skills

Another innovative mingling of activities is the effort of Chicago's Museum of Science and Industry to expand the science skills of teachers. "We teach science teachers—especially in middle school—how to teach science," said museum director David Mosena. "About 70 percent of the middle-school science teachers in Chicago have no background in science. It's hard to be inspiring if you're not comfortable in the subject." Over the last five years, some 8,500 teachers have attended this program, and about 500 have taken masters-level coursework offered in partnership with the Illinois Institute of Technology. One result is that about 25 percent of the Chicago Public School System's K-8 schools now have teachers of science whose skilled have been upgraded.

Robert Wolcott of Northwestern's Kellogg School of Management saw further grounds for optimism. "We are moving into a more complex and rewarding world," he said, "with diverse innovation ecosystems, networks of mentors connected to those who are new, and the ability to envision in our state a community where people together can make innovation happen."

C. CREATING INNOVATION UNIVERSITIES

Universities with active missions to educate, conduct research, and commercialize new technologies are an important part of a regional innovation ecosystem. Several speakers highlighted how Illinois universities support the efforts of faculty members to reach out to partner organizations and expand their own activities in the market.

Northwestern University: Preparing for the Future We Cannot See

A single research professor—along with graduate students and a few colleagues—can bring a new idea to the marketplace. At Northwestern University, Richard Silverman, a professor of biochemistry, did just that. In the 1980s, he began studying an enzyme that seemed to block the mechanism of epilepsy and other neurological disorders, and the activity of the enzyme convinced him that it should have clinical applications. He approached the staff of the then small Technology Transfer Office at Northwestern, and the office helped him attract the interest of a major drug company.

Although the enzyme, later marketed in 2005 as Lyrica, turned out to be a blockbuster, Dr. Silverman described the technology transfer process as challenging. As a researcher, he had actively sought—but was initially denied—information and data about the experimental work being conducted by the drug company on his discovery. Today, Northwestern's Technology Transfer Office—now the Innovation and New Ventures Office (INVO)—demands a full

two-way sharing of information between companies and Northwestern laboratories.

At Northwestern's new Chemistry of Life Processes (CLP) Institute, the goal, according to director Thomas O'Halloran, is to "break down the silos that typically separate many classic academic disciplines." This impulse, he said, is "part of Northwestern's 'genetic code'—to find ways to bring in new students as they're learning chemistry or engineering, to have them see how to integrate these subjects by watching others do it, and to help them start companies by participating in team research." The CLP, he added, is both an institute, a common playground for many disciplines, and an effort to lower the hurdles in getting scientists to work across their chosen disciplines.

Innovative ideas come from other directions at Northwestern University. Participants heard from Julio Ottino, dean of the McCormick School of Engineering, about a new model for educating young engineers. "We know that analytical skills are essential for problem solving," Dr. Ottino said. "But there is no big prize if the problem itself turns out to be the wrong one." In order to educate the engineers who are truly prepared to deal with future challenges, he said, "we need to instill two additional skills. The first is divergent thinking; right-brain thinking; metaphorical thinking; intuition." The goal is to produce leaders who "thrive at the intersection between disciplines," between theory and application, and between global problems and the knowledge needed to solve them. "The second class of advice," he said, "is not to attack the obvious—the future that is five feet in front of you. True—some of this needs to be done to solve real-world problems. But preparing to solve real-world problems presupposes we know what they are going to be. We should prepare people for the future that we cannot see."

The University of Illinois: Reaching out to Industry

Like Northwestern, the University of Illinois at Urbana-Champaign has broadened its approach to innovation. Caralynn Nowinski, Vice-President for Innovation and Economic Development, referred to the Morrill Act as a pivotal measure that has given rise to the nation's great land-grant universities. As part of their mission, these universities emphasize technology as well as science. "If President Lincoln didn't make it clear in 1862 when he signed the Morrill Act," she said, "our state legislature made it very clear in 2000 when they established economic development as the fourth mission of the University of Illinois."

In approaching the economic development portion of the mission "comprehensively," she said, the university tries to "enable research, transfer it into people's daily lives, incubate young companies that grow out of research, and invest in those companies." For example:

- I-STEM brings in public funding for pre-school education, middle and high school education, and experiences for college and graduate

students. Its goal is to recruit groups on the U of I campuses to teach students to apply STEM learning to entrepreneurial experiences.

- The Innovation Living Learning Community, or Innovation LLC, is a dormitory with 130 students from different disciplines who are interested in entrepreneurship. Facilities include a garage with a 3-D printer where they can work on prototyping.
- The university sponsors Business Plan Competitions "that have been successful in rewarding students and in providing state funding for their companies." The program introduces students with business skills to students with engineering and science skills and helps them combine skill sets and potentially find a commercial application.
- Tech Ventures encourages students from the business school to partner with the tech transfer office, create a business plan, and try to identify a commercial application for new technologies.
- ThinkChicago brings 100 college students from across Midwest to Chicago to learn about technology entrepreneurship and understand how companies function.
- Several programs are designed for faculty, including IP Coffee Breaks, where faculty and grad students discuss such topics as protecting IP. The Proof of Concept program in Urbana and Chicago provides up to $75,000 to faculty entrepreneur teams .
- EnterpriseWorks, part of the University of Illinois Research Park, is an incubator that offers SBIR consultation and a Mobile Development Center.

The University of Chicago: 'Academic Entrepreneurship'

To address the call for stronger interdisciplinary partnerships between universities and national laboratories, University of Chicago and Argonne National Laboratory have created a partnership that includes a new engineering program, built from scratch, that replaces the old silo structure of departments with themes, said Matthew Tirrell in his conference remarks. The new Institute for Molecular Engineering, which he directs, has begun construction of new facilities and has hired its first three faculty members. The near-term goal, he added, is to hire 25 faculty members, who will be chosen "by imagining the kinds of skills needed to do engineering at the molecular level."

"The idea of molecular engineering is to connect with molecular-level science and to develop solutions to problems that society cares about in energy, information, environment, health care," he said. "A major new strategy will be a more cooperative research relationship with industry, with incentives to develop innovations with commercial promise. We want to be a better partner across the whole spectrum of activities." He added, "This is entrepreneurship on the academic side, and it is risky. We won't worry about what we call our engineering disciplines, but we worry about what they can do."

D. BUILDING INNOVATION PARTNERSHIPS

With the growing globalization of research, manufacturing, and provision of services, regional innovation systems now compete internationally. U.S. Government support for research grew substantially following World War II, said University of Illinois President Designate Robert Easter, when federal agencies discovered the power of the universities to do basic and applied research. By the 1960s, the nation was spending more than 2 percent of its GDP on federal funded research, mostly in university laboratories.

This research provided the platform for new technologies and economic growth. "One could argue that science-based innovations led to economic growth and opportunity for our nation,…but with the end of the Cold War, that priority declined, and since the fall of the Berlin Wall, our investment as a nation has been modest—around 1 percent of GDP."

By contrast, Dr. Easter continued, other nations are investing steadily more in innovation. China, Taiwan, South Korea and others are increasing their research investments about 10 percent each year, and those investments are yielding "technologies and concepts that are world class." For China, a key strategy is to build innovation clusters through the development of large S&T parks and acquire technologies and talent from abroad.[4]

The response of the University of Illinois to global competition is to expand and strengthen its partnerships with both industry and government. The university has established a venture fund to enable faculty to commercialize their technology. A research park, which provides a physical locus for university-industry interaction, was built on the campus in Urbana in the late 1990s.[5] In 2011, this park was named the outstanding research park in the United States.

Dr. Easter also highlighted three university partnerships—with BP, Abbott Laboratories, and the Department of Energy—that together have increased the University of Illinois' research budget by nearly 50 percent in the past decade to nearly $1 billion. "We have done quite a lot," he said. "And we have ambitions to do quite a bit more."

E. SUPPORTING INNOVATION AT THE STATE HOUSE

In his keynote remarks, Governor Quinn noted that Illinois offers strong support for innovation. He described the State's Pathways Initiative, which seeks to encourage young people to embrace science, technology, engineering, and mathematics. Emphasizing broadband access and the

[4]Mu Rongpin, "China," in UNESCO Science Report 2010, Paris: UNESCO Publishing, 2010, Chapter 18.

[5]For a review of the strategies and scope of several leading parks around the world, see National Research Council, *Understanding Research, Science and Technology Parks: Global Best Practices—Report of a Symposium*, Charles W. Wessner, ed., Washington, DC: The National Academies Press, 2009.

development of digital educational tools, the initiative allocates more than $8 million for a "gigabyte competition" that challenges communities in Illinois to submit ideas on how they would take advantage of hyper-fast broadband.

Through the initiative of the Governor's Innovation Council, the state has also created an Open Data Initiative. The goal of this initiative is to put all state government data on-line and make it freely available, along with data of the city of Chicago, Cook County, and eventually other local governments.

F. DRIVING INNOVATION AT FEDERAL AGENCIES

The conference also reviewed how federal efforts to promote research, education, and entrepreneurship could yield tangible benefits for states and regions. Belying the widespread image of federal agencies as siloed, inflexible bureaucracies, senior representatives from the Economic Development Administration, the National Cancer Institute, the National Science Foundation, the Advanced Research Projects Agency for Energy, and the Office of Naval Research described novel and cross-disciplinary approaches to the generation and translation of new knowledge. These approaches represent new opportunities for the state's universities and research centers to participate in a wide range of federal research and to develop the regional innovation ecosystem.

Economic Development Administration

John Fernandez, formerly Assistant Secretary for Economic Development at the Department of Commerce, noted in his conference remarks that a new element in the past few years is the federal government's interest in not only studying clusters but actively participating in planning and supporting them. This shift has been gradual, he said, and slower than he would like, but nonetheless significant. "In context of the global economy," he said, "the only way you can compete is as regions. The federal government is in a unique position to finance and be a catalyst to help groups work across state or other political borders." Recognizing this need and opportunity, EDA has launched a variety of initiatives including the i6 Challenge, the Jobs and Innovation Accelerator Challenge, the U.S. Cluster Mapping project, and the Regional Innovation Accelerator Network.[6]

National Cancer Institute

In his conference presentation, Dr. Jerry Lee of the National Cancer Institute described an innovative experiment to accelerate progress on analyzing growing mountains of cancer data. "We reached out to the community 10 years ago and asked for their key needs as researchers," he said. "What we got back

[6]For a description of these programs, see <*http://www.eda.gov*>.

was a little surprising. First, everybody wanted standards and protocols. They also wanted real-time, public release of data. They wanted large, multidisciplinary teams and a pilot-friendly team environment to share failures as well as successes with each other. Finally, they wanted team members who themselves have trans-disciplinary training." Dr. Lee and the NCI leadership decided to put exactly those bullet points into their mission. Over the next few years, they found several genes never before associated with brain cancer, as well as a new subset of glioblastoma that occurs in younger patients.

He added that new insights in the flow and handling of data have generated an experiment that takes the concept of interdisciplinarity to a new level: to combine the insights of cancer biologists and physical scientists, such as physicists, engineers, and mathematicians. "Physical scientists have very different ways of interpreting data," Dr. Lee said. "We gave them the difficult charge not to do just better science, but paradigm shifting science. We asked them to build new fields of study based on their perspective of how the disease works."

Another perceived failing of federal agencies is the complexity and wasteful slowness of the grant process, said Dr. Mirkin. Dr. Lee responded that the NCI was examining ways to push projects "as we want to." The physical sciences program of the CSSI was funded in one year, he said, and our goal is "to accelerate that funding between the gaps."

National Science Foundation

The National Science Foundation is also working toward speed, said Thomas Peterson. I-Corps, one of its newest programs, he said, "operates on a quarterly basis, so that the typical time from identifying a potential project and giving a decision on a grant is a matter of weeks. It is an important experiment. The challenge is doing it at large scale, so that we are not accused of picking winners by shortening the classical review process."

Dr. Peterson also observed that NSF has been innovative in a broader sense—in funding projects more directly aimed at useful applications. "You may be surprised to learn," he said, "that the charter establishing the NSF in the 1950s contained a clear mandate to focus on activities with societal benefit." The agency supports many center-like programs that fund not only the principal investigator, but also teams of universities partnering with teams from industry. i-Corps, for example, which began in 2011, leverages small amounts of money to help researchers to push their results to the proof-of-concept or prototype stage, and from there to persuade a VC firm or other partner that the technology is worth substantial investment. The program, even though small, has been "wildly successful," he said.

Advanced Research Projects Agency for Energy

A new agency almost totally dedicated to innovation is ARPA-E, the Advanced Research Projects Agency for Energy. ARPA-E, said Deputy Director Eric Toone, differs from most federal funding agencies in seeking to identify and support "over-the-horizon" technologies that have the potential to transform some aspect of energy science or engineering. The agency's job is not to improve existing technologies, or drive them along their natural price or learning curves. "That is important," he said, "but it's not what we do. We try to identify fundamentally new technologies."

Office of Naval Research

Another innovative way to perform at the federal level was designed by the Office of Naval Research (ONR). In order to stimulate innovation, the fundamental structure of the ONR was revised by the Defense Authorization Act of 2001. The act added a "new and critical layer of management to create three virtually equal directors," said Chris Fall: the Director of Research, Director of Innovation, and Director of Transition. Virtually the entire budget now flows through these three offices, which have to compete with one another for funds. "ONR," he said, "is structured to be an innovation machine. The tension among the three directors works very well, and makes for an interesting model that is being copied by others. I don't think we ask often enough the basic question of how to structure an agency for optimal efficacy."

G. FOSTERING INNOVATION HUBS AND CLUSTERS

A pervading theme at the conference was the need for not only interdisciplinarity, but also inter-sectoral partnerships that drive innovation. Speakers agreed that such activities require the proximity afforded by various forms of technology hubs and clusters, and that these have been vital to regional innovation across the country. Dr. Mirkin said that Illinois leaders had learned to make convincing arguments in favor of its innovation hubs, and that the region was becoming better at promoting technology transfer, helping scientists secure intellectual property, and establishing relationships with companies and startup organizations.

In forming innovation hubs, Dr. Mirkin said, a region needs not only an entrepreneurial culture, but also state-of-the-art infrastructure. The infrastructure, which is required to do the initial basic research, requires funding at a level that is seldom available locally. This is where government participation is essential in the form of federal and sometimes state support for the physical innovation environment, from broadband to real estate to highways.

Box A
Powering the Internet

Innovation hubs thrive on state-of-the-art infrastructure. While a robust broadband network is widely seen as critical for innovation, supporting this network is a major engineering challenge. "We have a huge need for power to maintain the Internet and the web. Information technology is the biggest user of electrical power in the United+ States now; the big databases of Google and Amazon and Microsoft and government are the modern steel mills. They absorb power to run the electronics and then more power to cool it. Having reliable power, which is hopefully green, is essential to the IT industry."

Dennis Roberson
Vice Provost, Research Professor
of Computer Science
Illinois Institute of Technology (IIT)

The Role of the Economic Development Administration (EDA)

John Fernandez, formerly of EDA, observed that the idea of clusters as part of economic development strategy is not new but noted that its importance has never been greater. For example, EDA has supported research in this area for almost 20 years to better understand what is needed, what works, and what needs to be adapted to the new information-technology based ecosystem of today. He added that a new element had been introduced in the America Competes Reauthorization Act of 2010, where the federal government and Congress agreed on the value of regional strategies and embedded in the Act new authorities that actually drive those strategies. The Act provided a definition of a regional cluster as a geographically bounded network of similar, synergistic, or complementary entities engaged in a particular industry sector.

Mr. Fernandez made an important distinction between the government's cluster strategy and an industrial strategy. "We're not picking any winners," he said; "the applicants and people are. Based on the strength of our economy or the DNA of our regional economy, they are saying that these are the areas where we think we have the best opportunities; provide us with the investments to help us accelerate what we're doing."

H. ENCOURAGING INNOVATIVE START-UPS

Although innovation clusters provide helpful seed beds and incubators for new firms, they still face the "valley of death," the period of transition when a developing technology is deemed promising, but too new to validate its commercial potential and thereby attract the capital necessary for its continued

development. In his comments at the conference, Neil Kane of Illinois Partners Executive Services identified two challenges facing firms seeking to commercialize research ideas: The first is the technology risk, and the second is that investors are funding only companies with revenues. "It's the biggest impediment I see now," he said, "for getting these companies off the ground."

In his presentation, Charles Wessner of the National Academies drew attention to the role of the Small Business Innovation Research program (SBIR) in bridging the valley of death. . A recent comprehensive assessment of the program by the National Research Council found that SBIR, which provides over $2.5 billion in scarce pre-venture capital funding on a competitive basis, encourages the entrepreneurship needed to bring innovative ideas from the laboratory to the market.[7] He added that small firms in the state could benefit from coaching on how to apply for SBIR and on how to develop their businesses.

Norbert Riedel of Baxter described the role of corporate seed funds. Baxter, he said, has partnerships with Northwestern and the University of Illinois to create a seed fund with about $200 million for biotechnology innovations; Abbott Laboratories has a similar fund. When asked if such a modest fund could make a difference, he replied that healthy start-ups could thrive on amounts as small as $1 to $5 million.

Eric Isaacs of Argonne cautioned that some fast-growing firms, like hungry lions, require more than seed funding to stay healthy. "Lions are capable of capturing mice, one after the other," he said. "But if a lion tried to live exclusively on mice, it would eventually die. A lion needs to find an antelope or buffalo to serve its needs."

Dr. Riedel said that start-ups also need to draw on a flow of ideas and innovation. These can be encouraged by either a potential acquirer or continuing university research. Another advantage for young firms, he said, is proximity to potential funders and partners. "Proximity matters," he said, "because it enables face-to-face contact."

Conference participants attested that the path to profitability is seldom easy—even for the best-positioned start-ups. In his presentation, Roger Moody of Nanosphere, a company that emerged from Northwestern's International Institute of Nanotechnology, said that years of hard work were needed to approach profitability—even with a promising technology. In his presentation, AuraSense vice president, Van Crocker, identified the four factors most important to successful commercialization:

- the core technology;
- employee and advisory talent;
- real estate and hardware infrastructure; and
- equity and other financial resources.

[7]National Research Council, *An Assessment of the SBIR Program,* Charles W. Wessner, ed., Washington, DC: The National Academies Press, 2008.

I. TRAINING A SKILLED WORKFORCE

A strong theme throughout the conference was the need for improved training, especially at the levels of K-12, vocational and technical instruction, and continuing education. Several participants voiced concerns about students' low level of interest in careers in science and technology. One questioner posed that "If students could see this pathway, where you go through college, come to graduate school, and then have a choice of the academic route or an entrepreneurial route, it could be a major draw for students."

Dr. Mirkin advocated exposing students earlier to laboratory work "where the hands-on excitement begins." By Illinois tradition, he said, students are not exposed to laboratory work until the third or fourth year of college. "Up to that point, we tell them to read about it, and we'll test you on it; then read some more we'll test you on that. It's like setting out the bases for a baseball game and saying, Okay, for the next nine years we're going to study each of the positions. Once you've learned all those, we'll play a game. How many people will want to go into baseball?"

While nanotech laboratories typically employ PhD-level technicians, this workforce model is not scalable for private companies, where a skilled laboratory technician could do the work at half the salary. Michael Rosen of the Illinois Science and Technology Park spoke of a comprehensive effort to fill such gaps in the workforce. "They don't all have to be PhD scientists," he said. "Our goal is to interest students in many different jobs, such as nanotechnician, where they can see interesting employment. We work with Oakton Community College, nine local high schools, the village of Skokie, the State of Illinois, the Illinois Science and Technology Coalition, and technicians from the company NanoInk to create a curriculum for high school students and community college students."

Dr. Roberson of the Illinois Institute of Technology felt strongly that every sector in the innovation ecosystem has training responsibilities. These include the continuing education programs of universities, the partnerships between cities and community colleges, "and the obligation of companies to support the continuing education of their own employees."

J. BUILDING INNOVATION COMMUNITIES IN ILLINOIS

A number of speakers extolled the diversity of forces behind the emerging innovation ecosystem of the Chicago area and the state of Illinois more generally. Dr. Isaacs of Argonne stressed the essential elements of teamwork and community, "because that's how innovation gets done. Many people still believe falsely that in universities, and places like Argonne, and even in industry, the single inventor, like Thomas Edison, does things on his own. He has a dream, he creates the thing, and all of a sudden, we have a product that spreads across the globe. While Edison himself liked to burnish this image,

Edison's laboratory in Menlo Park, New Jersey in fact had over 40 scientists working on his ideas, including the light bulb."

Mr. Fernandez offered a more specific recipe, pinpointing innovation clusters as the loci for action and concluded by highlighting the role of industry. "Economic development today," he said, "is about the global economy. It requires aligning human capital with job needs; developing enabling infrastructure; increasing spatial efficiency; creating effective public and civic culture and institutions; and enhancing regional clusters. I believe that to build an ecosystem, you need an intermediary, and the best kinds are public-private partnerships organized around industry sectors. And industries are the agents that classically drive regional clusters."

Entrepreneurship, Communities, and Trust

Mr. Wolcott, of the Kellogg school, suggested that as such new ideas spread, the "innovation mindset" is starting to take root in Illinois. More potential entrepreneurs are choosing to stay there, and more people are creating an environment where entrepreneurs can meet mentors, partners, and investors. Finally, he said, change is emerging "at ground level where things actually happen."

He concluded by praising the power of community. "This is different than an ecosystem, which is the world of attorneys, entrepreneurs, technologists, university, and government. It is the places where people actually connect with an affinity and a level of trust. When you're new to things, you make mistakes. You need spaces where people feel comfortable to try an idea, to explore, to find their mission, and make things happen. I see a particular role here for larger communities, especially for universities and government, because they can act as convenors. A university is a neutral platform with spaces where people can come together. I think that is one of the most important missions we have, to help people connect with others in the community, find their mission, and then achieve it."

K. OPPORTUNITIES AND CHALLENGES

The final Roundtable session of the conference addressed the need to attract students to careers in science and technology and to encourage entrepreneurship. It also addressed the challenge of sustaining public support for these initiatives.

Growing the Workforce

Dr. Mirkin asserted that the science curriculum at the secondary and tertiary educational levels should be designed so that students are exposed early on to the excitement of laboratory work. Acknowledging that this would require additional supervision of students, Dr. Mirkin noted that such experiences "changes their view of science and maybe their lives."

Michael Rosen of the Illinois Science and Technology Parks called for an effort to develop a more diverse science and engineering workforce. "They don't all have to be Ph.D. scientists," he said. "Our goal is to interest them in many different jobs of the future."

Encouraging Innovation and Entrepreneurship

Citing the success such as the X-Prize, the DARPA Grand Challenge for driverless vehicles, the GAO's Dr. Persons said that he favored the use of prizes as incentives to innovators. These prizes, he said, provide a high return on investment and serve as an inspiration for students around the world.[8] In his roundtable remarks, Dr. Wessner suggested introducing students to 'local heroes": successful innovators from the community who could speak firsthand about the challenges and rewards of innovation and entrepreneurship. Dr. Mirkin agreed that local successes—from Midwestern universities and regions—ought to be more widely celebrated. Referring to a major nerve pain medication that was developed at Northwestern University, he said, "Here, Lyrica is the biggest deal, and no one knows about it," while "people brag about the things that Harvard and MIT have done. On the West Coast, it's the same. We [in the Midwest] don't understand how important it is to communicate about these local achievements."

Sustaining Support

The participants in the roundtable panel noted that Illinois' investments to improve its education, investment and research infrastructure, and capacity to leverage existing areas of strength to create new knowledge-based companies, will determine the region's future competitiveness and economic well-being. In his concluding remarks, Andy Ross, Governor Quinn's Chief Operating Officer, asserted that he was in full agreement on the need for the state to invest in the infrastructure—both physical and human—for innovation. However, citing the state's $83 billion in unfunded pension liabilities, he noted that key programs, including the Pathways Initiative, were "on hold" until the state took strong measures to resolve its pension crisis. "Right now," he said, "we have to get our fiscal house in order, and then we can make the investments we need to help spark new companies."

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[8]For a review of the efficacy of innovation prizes, see National Research Council, *Innovation Inducement Prizes at the National Science Foundation,* Stephen A. Merrill, ed., Washington, DC: The National Academies Press, 2007. This study finds that "Inducement prize contests are clearly not well suited to all research and innovation objectives. But through the staging of competitions they are thought to have in many circumstances the virtue of focusing multiple group and individual efforts and resources on a scientifically or socially worthwhile goal without specifying how the goal is to be accomplished and by paying a fixed purse only to the contestant with the best or first solution."

L. BUILDING ON SUCCESS

As seen in this overview, this conference report captures a rich sample of initiatives underway in Illinois to develop its innovation ecosystem, and develop and diversify the state's economy. The state, for example, is home to many of the nation's largest firms. Baxter's initiatives, described in this report, show how large companies can effectively partner with universities and small innovative firms.

While this report includes perspectives on university technology transfer from some of Illinois' leading universities and draws attention major successes like Lyrica, it also highlights participant discussion on the need for technology transfer offices to better support the diffusion of intellectual property and to stimulate the development of disruptive technologies.

This report also highlights the role of development of public-private partnerships in knitting together high technology skills, strong professional networks, and access to high-risk capital. Intermediating institutions, like iBio, show how leveraging existing assets can create the new high growth companies that can accelerate the growth of the state's innovation economy.

Finally, this conference report also identifies a number of "best practices." For example, Northwestern's Julio Ottino and of the Illinois Science and Technology Coalition's Mark Harris underscored the importance of entrepreneurship courses at universities and the need for inter-disciplinary approaches to teaching engineering, science, and business.

The proceedings, found in the next chapter, provide detailed summaries of the conference presentations and deliberations by the state's business, political, and academic leaders, along with those of senior U.S. government officials and national experts. They draw attention to the challenges, accomplishments, and opportunities facing Illinois today.

II

PROCEEDINGS

DAY 1

Welcome and Introduction

Chad Mirkin
Northwestern University

Chad Mirkin, George B. Rathmann Professor of Chemistry at Northwestern and director of the International institute for Nanotechnology (IIN), welcomed participants on behalf of the National Academies and the IIN to the conference "Building the Illinois Innovation Economy." He noted that the conference had been developed quickly, requiring a "heroic contribution from many," including Morton Shapiro, Northwestern University President, who ensured the availability of the spacious facility at the James L. Allen Center for the conference.

Dr. Mirkin noted also the particular relevance of the topic for the state of Illinois because of its many efforts to raise the effectiveness of innovation-based economic development. Among the attendees, he said, were many of those responsible for ongoing projects, from the governor who worked hard for support of innovation to scientific researchers who had translated their discoveries into successful small businesses. He welcomed those in attendance from the National Cancer Institute, Department of Energy, National Science Foundation, Department of Defense, Air Force Office of Scientific Research, Army Research Office, and Office of Naval Research, as well as many NGOs and state organizations, and Argonne National Laboratory, all of whom would bring a range of critical perspectives to the conference. He also welcomed the large number of researchers, administrators, and students from Northwestern University, the University of Illinois at Urbana-Champaign, the University of Chicago, and Illinois Institute of Technology. Finally, he welcomed the many representatives from companies both large and small, who would share their experience in launching new technologies developed in academic laboratories into the marketplace.

Among the goals of the conference, he said, were the following:

- To convene local and national leaders to highlight accomplishments of the broad innovation ecosystem in Illinois, while also identifying needs, challenges, and opportunities;
- To document the contributions of many sectors, including academia and government laboratories, in generating research and attracting talent to the state ecosystem;
- To engage Illinois businesses and political leaders with high-level government officials to better understand what is needed to drive innovation, business formation, and growth;
- To highlight the most successful innovation activities as models. "Illinois can't do everything," he said, "so we should be looking at our strengths and how focus them, as opposed to spreading our efforts like peanut butter so thinly that they have no impact."

He noted that the timing of the meeting was good, because the President's Council of Advisors on Science and Technology (PCAST), of which he was a member, had recently performed a similar exercise at the national level. One of its outcomes had been the Advanced Manufacturing Partnership, led by him and co-chairs Andrew Liveris of Dow Chemical and Susan Hockfield, president of MIT. Its goals were to survey what is available around the country, and to understand what different regions were doing well or not doing well; engage key stakeholders; and identify and invest in emerging technologies that have the potential to create high-quality manufacturing. The Committee's work resulted in a report to the President entitled, *Capturing Domestic Competitive Advantage in Advanced Manufacturing*, which included recommendations for (1) enabling innovation, (2) securing the talent pipeline, and (3) improving the business climate.

He pointed out that the conference today had a parallel goal of reviewing the available innovation resources at the state level, and determining how they might be strengthened by federal programs. There would be some similarities and also some differences between policy at the national level and the state levels, he said, and these needed to be identified and used to enhance the competitiveness of the United States.

He also anticipated that "a lot of national levers" would be moved to try to achieve innovation goals. Illinois should strive to take advantage of federal initiatives; especially those that help establish and strengthen innovation hubs. He called for participants to examine the features needed to fortify such hubs in Illinois to make the region more competitive. This would include forming alliances with innovative companies able to make use of new technologies and advancing existing technologies through partnerships with academia, government, and private sources of capital.

He looked back over the 21 years he had been at Northwestern, reviewing some major changes. When he arrived, he said, the university was very strong in research, focused on scientific excellence. That focus had broadened beyond science to include technological excellence. "I would point out," he said, "that early on, because we didn't look at the technological part, we lost a lot of opportunities. A lot of schools did, not just Northwestern." He recalled the work of a colleague, Robert Letsinger, as "a great example of this." Dr. Letsinger "invented a lot of the chemistry for DNA synthesis that is the basis for modern-day gene machines" and the backbone of much of the biotech industry. But at the time the research was done, he said, the culture was not in place to protect the intellectual property, to create spinoff companies, and to expand the companies rapidly and attract venture capital. Some of Letsinger's students, he said, did develop those concepts, which have become an important part of the U.S. technology venture, but this development did not happen in Illinois. "We want to avoid having that happen in the future," he said.

The new Northwestern model, he said, includes not just scientific excellence, but also technological excellence. Administrators have recognized the importance of expanding science in the direction of technology, and of aggressively protecting IP, establishing a favorable culture, and developing an infrastructure that promotes the success of technology-based companies.

He offered the example of Northwestern's International Institute of Nanotechnology (IIN), which he directs—an "admittedly Mirkin-centered example," he said. The IIN began 11 years ago, amid widespread excitement about the potential of nanotechnology. The Clinton administration led the way with half a billion dollars' worth of investment, and the IIN was designed to weld together not only science but also engineering, medicine, and industry. The Kellogg School of Management, which traditionally had not focused on high-tech activities, became actively involved, and desired outcomes were quick in coming, including inventions, products, and the first public company (Nanosphere) to be generated by Northwestern research—a success that was followed by 19 more. This attracted investment capital, which has reached $600 million and continues to grow. He emphasized that the IIN was generating not only new technologies, but also economic opportunities and the jobs that come with them.

Among the companies he mentioned were Nanosphere, which had just won FDA-clearance for a diagnostic test for bloodstream infections; NanoInk, a lithography company in the Research Park that commercialized Dip Pen Nanolithography; AuraSense, a new therapeutics company; the blockbuster drug Lyrica, used to ease seizures, which had been licensed directly to Pfizer; and Nano Integra, a materials-based company developing materials for both electronics and displays.

He said that the surge in technological innovation flowed not only out of Northwestern, but also from Argonne National Laboratory (Advanced Diamond Technologies), the University of Illinois at Urbana-Champaign (Mosaic), the University of Chicago (Chromatin), and the University of Illinois

at Chicago (Avanti Biosciences). "A critical mass is being established," he said, "and we're beginning to see real change. Now we need to look at what we do right and what we do wrong so that we can create a blueprint for moving forward."

An important topic, he said, was the extent to which government should be involved in the innovation process. Some, including many economists, argue that public funding should not be required, in the assumption that the free market provides both the necessary resources and the stimuli for technological innovation. The view of scientists, he said, is that the public does have essential roles, especially in sustaining a broad portfolio of basic research. This research generates the ideas that form the basis for innovations that can be translated into start-up companies or technologies that existing companies can develop.

He said he would try to present this argument in terms that are meaningful to the economist. What a scientist does, he said, could be described in terms of the basic physical laws of kinetics and thermodynamics. Kinetics, he said, is the study of rates of reactions, while thermodynamics "is the study of the natural preference of a particular reaction to go forward or not." The "free market analysis," he said, if described in terms of a chemical reaction, is that a favorable reaction will eventually go forward if given enough time. That is, the best ideas will be sorted, identified, and developed by natural market mechanisms; the free market will find them, invest in them, and, if they are sound, transform them into "the next Googles and Microsofts."

That argument, he said, is faulty, for several reasons. One is that the necessary "energy" to power the chemical reaction—in this case, the funding of venture capital firms—is often not available or appropriate. Venture capital firms prefer to invest in innovations that are already well-developed and even profitable, and they prefer to invest in their own regions. Another reason is that good ideas, by themselves, may languish indefinitely on the laboratory shelf. This is especially true for ideas that may seem to have little apparent value at first. In chemical terms, a diamond, exposed to the ordinary air of Evanston, Illinois, will eventually "burn or be converted to carbon dioxide" according to the laws of chemical behavior; that is, it will be oxidized at room temperature by natural processes into carbon dioxide—given an infinite amount of time. Despite this potential, a diamond remains a diamond—languishes on the laboratory shelf—because of the enormous kinetic barriers that must be overcome.

The challenge, he said, is to create an "innovation ecosystem" that has enough "collisions" to expose all good ideas to the free market so that entrepreneurs can identify which ones are likely to be winners and make the investments that lead to success. He suggested several keys to a successful ecosystem. The first is a "coalition of the willing." This is not a trivial notion, he said, because progress depends largely on the local culture and expectations. Twenty or 30 years ago, he said, scientists had no interest in innovation. "Their view was that technology was a bad word, and business was an even worse word." Innovation requires willing participants, great talent, innovation hubs

consisting of great universities and government labs, and a population of students, postdocs, faculty, and business leaders.

In forming innovation hubs, he said, a region needs not only an entrepreneurial culture, but a state-of-the-art infrastructure. The infrastructure, which is required to do the initial basic research, requires funding at a level that is seldom available locally. This is where the role of government is essential, applied in the form of federal and sometimes state grants to provide the physical innovation environment, from broadband to land to highways. Such investments are beyond the reach or interest of the private sector, including the capital community, and depend on close partnerships with public agencies to lay the groundwork for innovation.

He concluded with the observation that the innovation environment was finally changing in Illinois. The region had learned to make convincing arguments to develop its innovation hubs. It was becoming proactive in promoting technology transfer, helping scientists to secure intellectual property and establish relationships with companies and startup organizations. "These elements," he said, "not only help facilitate the translation of technology out of the laboratories, but they also help create relationships among all the people who make innovation possible."

Joseph T. Walsh
Northwestern University

Dr. Walsh welcomed the participants on behalf of Northwestern University president Morton Shapiro and provost Daniel Linzer, and thanked the organizers. He noted that humans had always been an innovating species, reminding his audience that the clothes they wore, the tablets they wrote on, and the chairs they sat on all had a "technological basis." Innovation was especially strong in the United States, he continued, in Illinois, and at research universities such Northwestern. The major corporate institutions of the state, including Baxter, Abbott Laboratories, ADM, Aon, Kraft, and Caterpillar, had generated more than $10 billion in revenues during the past year. The state had a broader and more impressive ecosystem than many people realized, he said, partly because of Midwesterners' reticence to talk about their accomplishments.

Universities such as Northwestern, he said, represented much of the innovative power of the United States. Northwestern was founded in 1851, 10 years before Abraham Lincoln signed the first Morrill Act. That act, he said, and several that followed, were "probably one of most significant things Congress has ever done." It provided land for the states which they could sell in order to create "what have become the great state research universities that drive innovation." A century later the major federal agencies promoting innovation were created, including the National Science Foundation and National Institutes

of Health, and in the early 1980s the Bayh-Dole Act was passed to allow universities to own the intellectual property developed with federal support.[1]

"This encouraged and one might even say forced the universities to take that which they learned and bring it out of the labs for societal use," he said. "From a university point of view, this is what drives the economies of many parts of this country—the translation of basic science to its applications. It is encouraged by the universities and by the government. For those who are economists and believe in the free market, there is a government role here. This chain of innovation that begins in the lab and has societal impact has several essential inputs, including both public and private capital."

He closed by welcoming visitors to the university and to the conference, which had been designed to bring together the sectors required to build an innovation hub.

[1]A recent report of the National Academies observed that "patenting and licensing of IP by universities is more closely regulated by national policies emanating from the dominant role of the federal government in funding academic research. Thirty years ago federal policy underwent a major change through the Bayh-Dole Act of 1980 (P.L. 96-517, the Patent and Trademark Act Amendments of 1980), which fostered greater uniformity in the way research agencies treat inventions arising from the work they sponsor, allowing universities to take title in most circumstances, and as a result accelerating patenting and licensing activity." National Research Council, *Managing University Intellectual Property in the Public Interest*, Stephen A. Merrill and Anne-Marie Mazza, eds., Washington, DC: The National Academies Press, 2010.

Opening Keynote

The Illinois Innovation Opportunity

Dr. Mirkin introduced Governor Pat Quinn, noting that he had created the state's first Innovation Council to help promote technology-based economic development. The governor was honored as Governor of the Year in 2011 by the biotechnology industry organization. He was sworn in as governor in 2009 and elected to a full term in 2010.

The Honorable Patrick Quinn
Governor of Illinois

Governor Quinn began by thanking Northwestern University and its innovation partners "in joining together on the mission of a lifetime." He stressed the importance of innovation for the country and the state in stimulating an entrepreneurial economy and helping the universities, research labs, and innovation-based companies to work together.

When Governor Quinn took office in 2009, "in a very tough economy," he pressed for a public works bill "in its broadest form" that would go beyond the traditional targets of highways and bridges. "We believe in that," he said, "because we are a transportation center, but we also wanted to build an information superhighway. So I insisted that part of our capital bill include money for broadband deployment." The state already had a broadband deployment council, which he had chaired as lieutenant governor, learning "how important it is to have everybody in and nobody left out of access to high-speed internet." He noted that the bill to construct the interstate highway system in the 1950s "had barely passed," indicating how difficult it can be to see the ultimate benefits of technological innovation. Similarly, he said, polls indicate that only 1 to 2 percent of voters feel that broadband construction should be a public priority. "But I feel that it's essential for our state to be a leader in this area."

The public works bill resulted in about $70 million in grant money for the state and was leveraged into 18 different grants. As the broadband work was progressing, he saw an article by the columnist Tom Friedman that described the importance of "gigabyte communities" using "ultra-high-speed Internet" a hundred times faster than what is available today. These communities, Friedman wrote, especially when located around universities, would offer researchers the chance to develop new IT applications, and in turn stimulate job creation. The governor decided to use $8 or 9 million of the grant money to hold a "gigabyte competition," which he announced in his State of the State speech in 2012. It challenges communities in Illinois to submit ideas on how they would take advantage of hyper-fast broadband were it available.

The state, through the initiative of its Innovation Council, has also created an open data initiative. The goal is to put all state government data on line and make it freely available, along with data of the city of Chicago, Cook County, and eventually other local governments. The initiative will also encourage competitions and other opportunities to develop applications.

To simulate biomedical innovations the state has created a "medical district" in the shadow of four large hospitals: the University of Illinois, Veterans Jesse Brown, Rush University Hospital, and Stroger Public Hospital, all located near downtown and the University of Illinois at Chicago. The district has existed in law for other purposes since 1941. The current plan, he said, is to introduce fast broadband access into the mix "to help spark innovation" among the hospitals and the large pharmaceutical companies, including Baxter, Abbott, Astellas, and Takada. He said that the International Biotechnology Convention, which Illinois has hosted twice and will host again in 2013, would be an opportunity to bring innovative people and ideas together.

To strengthen STEM education, a Pathways Initiative had been designed with major firms, universities, and schools to encourage young people to embrace science, technology, engineering, and mathematics. This program, also, was bolstered by the emphasis on broadband access and the development of digital educational tools. The state had already laid some 4,100 miles of fiber optic cable to provide online opportunities to school districts in remote areas.

The state has many programs to promote renewable energy sources and reduce carbon output, including installation of about 270 charging stations for electric vehicles in metropolitan Chicago and additional stations Downstate. Through competitive bidding, the state had purchase 15 electric vehicles from Mitsubishi and placed high priority on reducing reliance on petroleum. The city of Chicago had more LEED-certified buildings than any other U.S. city, said Governor Quinn, and one feature of the public works bill was to require LEED certification for new public buildings.

The state was active in generating its own renewable energy as well. One strategy, he said, was to use photovoltaic sources on hot days to "shave the peak" off utility usage. This strategy can reduce the need for expensive generating capacity that might be used only a few days a year. Wind energy is also a priority, the governor said; Illinois had erect 404 wind turbines during

2011—more than any state. Because the state is on the east side of the Mississippi River, he said, it is well situated to send electricity generated by solar, wind, and biomass sources to the large populations centers in the East.

He concluded by offering his own definition of an innovation. "It is people seeing something and seeing how to do it better," he proposed. "That is the purpose of the gigabyte community concept, and of the state Innovation Coalition, and the Science and Technology Coalition." He closed by urging the participants to gather on a regular basis, and to continue their support for technology-based innovation.

Panel I

The Overall Innovation Challenge

Moderator:
Alicia Loffler
Northwestern University

Dr. Loffler introduced herself as director of the innovation and new ventures office at Northwestern, where her job is to "move all this research to the public." She said that her job is very easy because the university faculty and students are "both inspirational and entrepreneurial." She said the members of the first panel would introduce innovation challenges and opportunities at the global, national, local, and institutional levels.

THE GLOBAL INNOVATION IMPERATIVE

Charles Wessner
The National Academies

Dr. Wessner began by thanking Dr. Mirkin for his leadership in designing a conference that promised to bring sharp focus to Illinois' innovation strategy. He also extended his thanks to those who had worked together to organize and implement the conference in a "very brief time indeed."

Referring to the location of the conference in Evanston, Illinois, he said that too often people who work in Washington know little about the people or practices of other regions and countries. "People talk about local and regional needs all the time," he said, "but they do so from within the Beltway. Our program at the National Academies is different in that it meets people where they live and work, and searches for best practices and new ideas that might be useful elsewhere."

Describing the innovation challenge in an international context, Dr. Wessner observed that "governments throughout the world aggressively support their innovation systems in many ways, from building new research parks to

creating trade, taxation, and manufacturing requirements that favor their own domestic economic development. The clear objective of these policies is to create an economic playing field that is tilted in ways that favor their own companies and products over those of competitors." In the United States, by contrast, we promote the notion of a "level playing field," he said, reflecting our belief in the rhetoric of "fair trade" that is grounded in a rules-based trading system, and ignoring the lessons of our own successes. This commitment to the ideal of fair trade, he noted, is shared by very few of our international competitors. "The global trading system is like a soccer game in which the referees do play favorites. The only way to win is not to complain about the refs, but to play harder and tougher." Playing harder in the innovation arena, he said, requires a strategy to coordinate the strengths of government, academic, and industrial sectors far more effectively than is now the case.

The generation of new ideas and products is an acknowledged strength of the United States, he continued. "The U.S. innovation system remains the best in the world, and there is every reason to be proud of it. I spend a fair amount of my time going around the world, and I find that people in every country admire and respect our educational system and its ability to produce the best people and innovations." Among the positive features of the U.S. innovation system are its robust research universities, generous federal funding of research and development, a vibrant culture of entrepreneurship, significant manufacturing capabilities, openness to new opportunities, and adaptability.

However, Dr. Wessner said, recent conditions and policies have threatened to reduce the relative strength of the U.S. innovation system. For example:

- State governments, weakened by the financial pressures of the global recession, have reduced their support for the public research universities and held back on incentives to stimulate small business formation.
- Reflecting surging investments in Asia and elsewhere, the U.S. share of global R&D investments by government and industry has dropped from 39 percent in 1999 to 34.4 percent in 2010.
- Stalled immigration reform results in the loss of some PhD students to U.S. competitors, even though they have been educated in the United States at considerable government expense.
- Manufacturing expertise in a wide variety of high-technology products has shifted overseas.
- Early-stage financing for small firms has fallen, with seed stage investments dropping 48 percent in 2011.
- The innovation ecosystem provides insufficient support for the translation of discoveries into successful products.

"We are still excellent at getting ideas, building prototypes, and starting small companies," he said. "We generate the innovation, but it is often someone else that takes that innovation overseas, builds out the supply chain, and creates a profitable new industry."

Dr. Wessner suggested one reason the United States allows this to happen is a tacit assumption that the country is becoming a service economy and can afford to let others become the leaders in manufacturing. In counterpoint to this assumption, he said, are the policies of major U.S. trading partners. Virtually all of them provide extensive assistance for not only R&D but also in creating policies that speed the translation of innovations toward the marketplace. Countries with such policies include Germany, France, the United Kingdom, Brazil, India, Taiwan, China, South Korea, and Japan. "The rest of the world," he said, "is also increasingly focused on providing sustained support for universities, funding for research, and help for small businesses."

As an example, he outlined China's goal to become an "innovation-driven economy" by 2020. China is a large country, he said, but still struggles with a high rate of poverty. Nonetheless, it invests boldly in innovation, doubling its spending on basic research between 2004 and 2008 and providing tax incentives for enterprises that invest in R&D. Like Taiwan and South Korea, China continues to invest in new, world-class universities, while the United States relies on universities built generations ago. Key strategies are to build innovation clusters through the development of large S&T parks and acquire technologies and talent from abroad.[2]

China, he said, has gained competency partly by compelling foreign firms that seek to sell in the Chinese market to set up manufacturing plants in China. For example, it enforces "domestic content" rules by "enhancing original innovation through co-innovation and re-innovation based on the assimilation of imported technologies."[3] The workings of such a strategy can be seen in the wind energy industry. The Chinese requirement of 70 percent domestic content has led to a drop in the foreign share of wind energy production from 75 percent in 2004 to 14 percent in 2009.[4]

An example on a very different scale is that of Singapore, which has a population of only 4.5 million people. The goal of this city-state is to be Asia's preeminent financial and high-tech hub. Singapore has a GDP per capita of about $61,000, compared with about $48,400 for the United States.[5] Singapore plans to invest about $5 billion under its Research, Innovation, and Enterprise 2015 plan. The Agency for Science, Technology, and Research (A*STAR) has

[2]Mu Rongpin, *UNESCO Science Report*, 2010.
[3]China's National Medium- and Long-Term Plan for the Development of Science and Technology, 2006-2020.
[4]U.S. Chamber of Commerce, 2011. At the same time, the share of the Chinese wind market held by China's three largest domestic wind firms, Sinovel, Goldwind, and Dongfang, has risen to more than 80 percent of wind power equipment sales within China.
[5]Comparable figures, in terms of purchasing power parity and U.S. dollars, are: Germany $39,211, the European Union $31,000, and China $8,400. Source: The World Bank, 2011.

created strategies to attract a skilled R&D work force from abroad, provide funding for early-stage firms, stimulate private-sector investments, and operate Singapore's famed research parks, Biopolis and Fusionopolis.

Taiwan's' innovation strategy is equally ambitious, and has already created a successful research and development structure of public-private partnerships. The Hsinchu Park complex houses universities, research institutes, and businesses, including two of the world's top semiconductor foundries, Taiwan Semiconductor Manufacturing Companies (TSMC) and United Microelectronics Corporation (UMC). Its Industrial Technology Research Institute (ITRI) has proven to be an effective mechanism to support research, development, and commercialization, and a mechanism that smoothly moves university graduates into positions in industry. It has also emulated aspects of the U.S.'s Small Business Innovation Research (SBIR) program to deliver generous public support for startup companies.

"Asian countries have copied some of our programs because they are diligent in observing what the rest of the world is doing," said Dr. Wessner. "Their programs don't all work; they make mistakes, some have problems with corruption, and sometimes they lack peer review. But the scale of the effort is impressive." Both the ITRI of Taiwan and the Fraunhofer institutes of Germany, he said, could be understood as training grounds for skilled scientists and technicians. "The question is not whether this strategy is the best one, but which strategies the United States needs to adopt to remain competitive."

A common perception is that the United States cannot compete with low-wage companies, but the example of Germany suggests that labor costs are only one determinant of competitiveness. German manufacturing wages average about $46 an hour, while the United States average is about $34 an hour.[6] German businesses are heavily taxed and tightly regulated, and most have representatives of labor unions on their boards, yet the Germans export massively to China.

Other features of the German innovation strategy include a focus on traditional industries, such as chemicals, autos, and appliances—a strategy criticized as low-growth by many economists. Its medium-sized firms (*Mittelstand*), many of them family owned, succeed with high-quality products for niche markets, including machine tools and appliances. The educational system features an extensive and advanced network of vocational training institutions, including continuing vocational training for workers. Manufacturing firms enjoy stable access to finance.

Germany's Fraunhofer model is also an example of a global best practice, he said. With a focus on applications, the network of 60 research institutes provides effective R&D support for both SMEs and large companies. The program's $2.4 billion annual budget is diversified by sector, with contributions from the German federal and state governments, contracts with

[6]Bureau of Labor Statistics, "International Comparisons of Hourly Compensation Costs in Manufacturing, 2009," News Release, March 8, 2011, Table 1.

manufacturing clients, and publicly funded research projects, including EU projects. Seven Fraunhofer Institutes have been established in the United States, demonstrating that this model could work here.

Germany's innovation strategy is well-funded, multifaceted, and, by some measures, quite successful. As mentioned, German industry has had considerable success in exporting goods to China, which doubled in value between 2007 and 2011 to €65 billion.[7] Even during the current recession, Germany's federal and state governments plan to raise spending levels for education and research to 10 percent of GDP by 2015, with 7 percent targeted for education and 3 percent for research. Its new High-Tech Strategy 2020 also seeks to create lead markets in Germany, intensify cooperation between research and industry, improve the framework conditions for innovations, and launch an Excellence Initiative to strengthen select universities.

He turned to the topic of government spending to support research and development. Combined public and private outlays in the United States, at $415 billion (2010), far exceed that of China ($149 billion), Japan ($148 billion), and Germany ($83 billion), the next three largest spenders. Despite this leadership, however, over half of U.S. government's R&D (which was $148 billion in 2010) is spent by the Department of Defense ($78 billion), and some 90 percent of that amount is dedicated to weapons systems development.[8]

"There are good reasons for this defense research and development expenditure," said Dr. Wessner. "We are at war, and we have to make sure military equipment works right the first time and every time." But because the amount of nondefense R&D spending by DoD is so small, there is little support for "the scientific seed corn for the future." Beyond that, he said, "we are seriously overstating to ourselves what we are spending in the research space." For example, federal spending as a share of GDP has been declining since the mid-1960s.[9] While R&D spending by the private sector has continued to rise, and provides a major source of innovation, he said, a high proportion of private-sector spending is dedicated not to fueling innovation, but to incremental improvement of existing products.

Such spending patterns reflect major risks for the United States, he said. One is complacency about the U.S. competitive position vis-à-vis its major trading partners. A second is the fiscal strain caused by current military engagements; for FY2011, the estimated spending in Iraq of $51 billion and in Afghanistan of $120 billion[10] together exceeds the total U.S. R&D budget of $148 billion. Spending also focuses on current consumption rather than investments for the future, in contrast to the strategies of Germany, China, and other countries. The United States pays limited attention to the composition of

[7] *Financial Times*, April 20, 2012. Before 2000, Germany had virtually no exports to China.
[8] American Association for the Advancement of Science, 2010.
[9] National Science Board, Science and Engineering Indicators 2012, Arlington, VA: National Science Foundation, 2012.
[10] Estimate by the Congressional Research Service.

the economy, including trade and investment policy, and fails to focus sufficiently on the commercialization of research and on manufacturing.

While some question the government's dominant role in supporting basic research, many are unaware of the government's long-standing role in developing U.S. industries. American society celebrates the "Yankee ingenuity" of the "lone inventor," but since the nation's founding, many of its most celebrated inventors have received substantial assistance from the government. He then showed a slide highlighting the important role that the federal government has played throughout the history of the republic in developing major transformative technologies and key U.S. industries.

- 1798─Grant to Eli Whitney to produce muskets with interchangeable parts, founds first machine tool industry in the world
- 1842─Samuel Morse receives award to demonstrate feasibility of telegraph
- 1903−Wright Brothers fly, fulfilling the terms of an Army contract!
- 1915─National Advisory Committee for Aeronautics instrumental in rapid advance in commercial and military aircraft technology
- 1919−Radio manufacturing (RCA) founded on initiative (equity and Board Membership) of U.S. Navy with commercial and military rationale.
- 1925−U.S. Postal Act launched U.S. Aircraft Industry
- 1940s, '50s, '60s─Radar, Jet Aircraft, Computers, Satellites, Nuclear Energy, Semiconductors
- 1969-1990s─ Government investment in forerunners of the Internet (Arpanet) and establishment of the Global Positioning System
- 2000s−Focus on Nanotechnologies, Flexible Electronics, Biomedical Research, Additive Manufacturing.

"The effects of government-supported R&D are all around us," he said. "You drive on the interstate highway system to a federally supported airport, board a federally supported airframe powered by federally supported turbines, and take off under the guidance of the federal air traffic control system to go to a federally supported university to review the prospects of a promising company receiving federal awards to commercialize its technology developed through federally supported research. Even so, some seem to forget these close linkages between public policy, private companies, and national growth."

Finally, he turned to the topic of manufacturing and its role in innovation. Manufacturing matters to the economy as a whole, he said, and the steady decline in manufacturing employment since 1980 is a cause for concern. Today, manufacturing produces $1.6 trillion of value each year; supports an estimated 18.6 million jobs in the United States, about one in six private-sector jobs; strengthens the nation's technological capacity, with U.S.-based

manufacturers conducting half of all private R&D; improves competitiveness; and expands trade.[11]

Local production is necessary to sustain innovation, particularly for process technologies; and in many cases, advanced manufacturing depends on the co-location of design and production so that a network of feedback and teamwork leads to continual product improvement and the next innovations.

Some people argue that manufacturing job losses are caused by growth in productivity, he said, an argument with some merit. But many job losses reflect actual decline of output that is neither inevitable nor normal. This is demonstrated by the fact that manufacturing is growing in many productive nations, including developed nations, such as Germany, with high costs, high taxes, and strict regulations.[12] Often ignored are the effects of "modern mercantilism" that involves combinations of currency manipulation, closed markets, tax subsidies, tariffs, direct subsidies of free land and capital, discriminatory national procurement, and forced transfer of IP and obligatory joint ventures.[13] "So this decline should be of grave concern to us," he said. "We need to develop more manufacturing onshore."

In response to the decline in the U.S. trade balance for manufactured products—including advanced technology products—since about 1988,[14] the President has announced a new National Network for Manufacturing Innovation. In addition, the President's Council of Advisors on Science and Technology (PCAST) released a report advocating a series of actions to strengthen advanced manufacturing. It makes 16 recommendations organized under three "pillars":

- Enabling innovation
- Securing the talent pipeline
- Improving the business climate [15]

In the same month, he said, the National Academies STEP Board released a report on innovation that includes detailed studies of innovation systems in the United States and other nations. [16] This report documents the rapid transformation of the global innovation landscape and recommends these four key goals for the United States:

[11]National Association of Manufacturers, 2009.
[12]The Information Technology & Innovation Foundation, 2012.
[13]See Clyde Prestowitz, "Competitiveness Council wide of its mark," *Foreign Policy* December 16, 2011.
[14]Gregory Tassey, "Rationales and mechanisms for revitalizing U.S. manufacturing R&D strategies." *Journal of Technology Transfer* January 29, 2010.
[15]President's Council of Advisors on Science and Technology, *Capturing Domestic Competitive Advantage in Advanced Manufacturing,* Washington, DC: The White House, July 2012.
[16]National Research Council, *Rising to the Challenge: U.S. Innovation Policy for the Global Economy,* Charles W. Wessner and Alan Wm. Wolff eds., Washington, DC: The National Academies Press, 2012.

- Learn about and monitor innovation policies in other countries;
- Reinforce the policies and programs that provide the foundations for knowledge-based growth;
- Capture greater value from public investments in research through partnerships and support for applied research and manufacturing; and
- Cooperate more actively with other nations to advance innovations that address shared global challenges.

"We can all see that we have to work harder," Dr. Wessner concluded. "The limitations of our system are clear for us to see, not least when it comes to education and worker training. Our current vocational training efforts are simply not enough. I know we can do better, and make better use of the tools we already have to meet the innovation challenge in the 21st century. I think this conference can be one step toward addressing this challenge."

Discussion

A questioner asked about the value of export controls on sensitive technologies. Dr. Wessner agreed that the issue presents a classic problem of exports versus security, with one solution being to in build "higher walls around much smaller number of technologies," but he argued that "universities to the maximum extent possible should remain untouched by those kinds of controls." The controls are more damaging than helpful when they prevent people from doing important research, he said, and it is not in the nation's interest to prevent talented researchers in U.S. institutions from working on critical topics on the basis of their immigration status. "A talented scientist who's a foreign national one year," he said, "might be an American citizen a few years later. Or she might have to return to work in South Korea or China if it is impossible to find work in the United States."

AN OVERVIEW OF FEDERAL CLUSTER POLICY

John Fernandez
SNR Denton

Mr. Fernandez, who introduced himself as "a Midwesterner," and who is a former mayor of Bloomington, Indiana and former assistant Secretary of Commerce for Economic Development, brought a combination of federal and regional experiences to the conference. Currently practicing law with SNR Denton in Washington, he said he would offer an overview of cluster policies at the federal level, much of which would be familiar to "people outside Washington. We tend to be the last ones to adopt these smart policies that are happening everywhere else in America."

Clusters—An Established Concept

The idea of clusters as part of economic development strategy is not new, he said. "Even the small agency I used to run has supported research in this area for almost 20 years." A body of work has been funded by the federal government, tools have been developed for practitioners, and work has been done by academic researchers and think tanks. He cited studies on cluster-based economic development, measuring regional innovation, linking regional competitiveness to investment, and clusters of green businesses.

"We were doing clusters even in Bloomington, Indiana," he said. In 1996, Bloomington led an effort to build a public-private partnership in support of the local life science and information technology industries. It used the "classic cluster model," he said, bringing together sources of innovation and research from the university and small businesses, some of which commercialized the new technologies. It aligned the development of local talent from both the university and the community colleges in trying to build an innovation ecosystem.

A new element in the past few years, he said, is the federal government's interest in not only studying clusters but actively participating in planning and supporting them. This shift has been gradual, he said, and slower than he would like, but he did call it significant.[17] "In context of the global economy," he said, "the only way you can compete is as regions. The federal government is in a unique position to finance and be a catalyst to help groups work across state or other political borders. That's always a challenge, especially for elected officials." He recalled from his days as a mayor that his constituents expected him to create jobs only in his own back yard—not the back yard of the next town.

"The federal government is different, because it can get people to move and act across borders," he said. "We saw that here in Chicago when we helped fund a regional study of the area where parts of Wisconsin, Michigan, Illinois, and Indiana come together. We can be a catalyst for some of these things."

He acknowledged that it might seem odd to emphasize the policy of cluster development in 2012 when it had been studied and acknowledged for decades. He argued, however, that changes in policy took place only slowly in Washington, and the new emphasis on innovation was accepted only slowly. An important turning point, he said, was the America COMPETES Reauthorization Act of 2010, when the Federal government and Congress agreed on the value of regional strategies and embedded in the Act new authorities that actually drive

[17]He cited several recent studies that describe this policy development, including:

- Maryann Feldman and Lauren Lanahan, "Silos of Small Beer: A Case Study of the Efficacy of Federal Innovation Programs in a Key Midwest Regional Economy," *Science Progress* 2010.
- Mark Muro and Bruce Katz , "The New 'Cluster Moment': How Regional Innovation Clusters Can Foster the Next Economy," Washington, DC: The Brookings Institution, September 2010.
- Jonathan Sallet, Ed Paisley, and Justin R. Masterman, "The Geography of Innovation—The Federal Government and the Growth of Regional Innovation Clusters," *Science Progress* 2009.

those strategies. The Act provided a definition of a regional cluster as a geographically bounded network of similar, synergistic, or complementary entities engaged in a particular industry sector. He said that cluster entities also share specialized infrastructure, labor markets, and services. Funding for cluster authorities was not yet available, he said, "but at least the structure is there, and the acknowledgment that something real can happen, with the federal government playing a meaningful role."

One essential shift in the 21st century, he said was a change in economic development characteristics. Examples include shifting from:

- domestic competition in a zero sum game toward global competition and collaboration in a positive sum game;
- a primary goal of providing jobs toward increasing productivity and per capita income;
- incentives to attract or retain cost-driven firms toward investments in talent and infrastructure to support innovation-driven clusters;
- incentives to attract cost-driven firms toward innovation networks connecting inventors, financiers, and transformers;
- performance metrics that include quantities of jobs and firms toward those that measure quality of jobs, wage and income growth, and innovation.

"We're still operating in Washington with the 20th century model," he said. "When I first started to talk about cluster policy on Capitol Hill, you'd have thought I was trying something radical."

A More Catalytic Approach

He suggested moving money away from "the old, stale, inadequate, unnecessary" models of economic development, where money is spent "on things everybody knew didn't work." Instead, he proposed moving it into "new areas we knew could be catalytic and have high impact." He noted that Congress is still dominated by legislators from small towns and rural environments, and the traditional mindset is suspicious of clusters. "Many legislators hear only that you're going to give more money to university communities. It they don't have a university where they live, they stay with the old stuff: roads, bridges, or another industrial park. While many people fear they have nothing to gain from the new economy, the truth is that they are already in that economy. There is tremendous innovation happening everywhere in America, including rural communities, but we have to get people moving into the 21st century."

A Focus on Clusters

Economic development today, he said, is about the global economy. It requires aligning human capital with job needs; developing enabling infrastructure; increasing spatial efficiency; creating effective public and civic culture and institutions; and enhancing regional clusters. "I believe that to build an ecosystem," he said, "you need an intermediary, and the best kinds are public-private partnerships organized around industry sectors. Industries are the agents that classically drive regional clusters."

From the outset of the Obama administration, he said, his agency was very involved in cluster initiatives. With clusters a priority, he had the opportunity to develop and apply new tools to support innovation. A primary objective, he said, was to "knock down some silos" between agencies with common economic development objectives. Some barriers were difficult to overcome, he said, but a group of people formed who were willing to try to improve access.

The first structure to attempt this was the White House Taskforce for the Advancement of Regional innovation Clusters (TARIC). The Department of Energy, in particular, was able to apply some cluster principles at their innovation hubs, which in themselves represented proto-clusters. These became known as Energy Regional Innovation Clusters, or ERICs. "They were an opportunity to shine a thin bright light on the concept," he said, "so all of us rallied around and did that." ERICs involved six agencies and $130 million in federal investments; the first of them was the Greater Philadelphia Innovation Cluster.

There were other opportunities for collaboration as well. The Space Coast Cluster focused the work of four agencies on clean technology and clean energy. The concept was to connect the laboratories of the Environmental Protection Administration with the small business community and support the creation of new businesses and jobs. The Southern Ohio Water Cluster, locate at EPA's Water Technology Laboratory in Cincinnati, also became an ERIC, championed by the Small Business Administration. SBA Administrator Karen Mills had been a proponent of clusters for many years, and supported a wide range of activities.

He said that many federal initiatives are opposed on the grounds that the government should not be picking winners or losers. "But we're not doing that," he said. "That's the beautiful thing about this approach. We're not picking any winners; applicants and people are. They're saying, Based on the strength of our economy, or the DNA of our regional economy, these are the areas where we think we have the best opportunities; help us accelerate what we're doing. As a result, we fund a wide range of sectors, including the smart grid, nuclear energy, hydrogen fuel cells, agriculture, and defense."

The Economic Development Administration (EDA) also collaborates with the cluster-mapping initiative of Michael Porter at Harvard University to provide tools for policy makers. Goals are to track cluster initiatives, analyze

cluster performance, and evaluate cluster composition, benchmarking, networking, and resources. This is being done in partnership with the European Community's EU Observatory to harmonize data and definitions in order to create a more global network of clusters.

A Regional Innovation Accelerator Network is being developed to help build networks of venture development organizations. The goal is to give them access to better performance metrics and other tools and begin to fill in a map of an ecosystem network all across the United States.

The I-6 Challenge

Among smaller, more focused programs was the i6 Challenge of 2010, which has the goal of accelerating proof-of-concept centers and the commercialization of research. Six regional winners were chosen for the $12 million competition. Another version of this competition is the i6 Challenge Green for 2011 that supports "green" technology commercialization and entrepreneurship. "We were being opportunistic," he said. "We had some money dedicated to sustainable development, and we worked with seven other federal agencies to create this program. We are showing that the federal government actually can collaborate."

Another program, the Jobs and Innovation Accelerator Challenge, draws on 13 federal agencies to support high-growth, regional clusters in a $37 million competition. The 20 winners, located around the country, are supported by five funding agencies. A parallel Rural Jobs and Innovation Accelerator Challenge is led by the Department of Agriculture and other agencies. The 2012 version of the i6 Challenge was underway, he said, as was a new Advanced Manufacturing Jobs Accelerator, led by 14 agencies in a $26 million competition.

He showed a map of "smart investments to accelerate job and economic growth." The majority of them were located around the heartland, with activity throughout the nation. "This goes against the notion that innovation only happens on the coasts," he said. "I was kind of the optimistic guy in this," he said, "and thought I could see what was coming, which was real progress."

He listed some of the lessons that had emerged in the effort to stimulate project-based learning. He had noted a huge difference between discussions in Washington conference rooms and actual experience in the field. In trying to integrate federal programs, he said, we learned that they all have different regulations and have to respond to different intentions of Congress, which can quickly stall progress. "You can either sit in a conference room for four years and talk," he said, "or you can go into the field, do some initiatives, and hear the feedback immediately. Then you can quickly take that knowledge back into the system and improve it."

He described some specific lessons:

- **Bottom-up beats top-down:** You have to play to the strengths of a region, and a cluster should be regionally-led from existing networks and assets.
- **Every cluster is different:** Not everyone can be Silicon Valley, nor should they try to be. If you want to be a nanotech cluster, you need to have the data that supports the plan: you have the industry, the technology, the source of talent in nanotechnology. Otherwise you're wasting your time.
- **Private/public partnerships:** The private sector should lead cluster formation and the public institutions should support it in partnership. As a former public official, I know that government should not be the leaders. The project of an elected official lasts only as long as he is in office. Clusters have to be focused on what's real in the marketplace. If you don't have real industry investment and engagement, a cluster will not be sustainable.
- **Commitment to collaboration:** In the federal government, too many programs are formulaic, completely inflexible. You get penalized for collaborating as an agency. Clusters need incentives for collaboration—with agencies, regional economic development partnerships, and other cluster initiatives.
- **Break through the silos:** In trying to run a multi-agency competition in the federal government, a more integrated system is needed: where to enter the data, how to provide easier access to multiple streams of federal funding. In the current system, working for multidisciplinary solutions with multiple agencies creates high transaction costs. Also, decision cycles are out of sync, so it's hard to get a fast decision.
- **Overhaul 'economic development':** Too many people think ED is just water systems, sewers, bridges, and highways. Those are important, but they are not economic development. A recent study by the OECD showed that building more transport infrastructure does not accelerate growth. For a lot of politicians, that is a tough pill to swallow, because we love to build roads. But 21st century infrastructure has to include broadband and smart grids; more America COMPETES than public works. What we really need is an innovation infrastructure.
- **Reorganize key agencies:** There is too much fighting over jurisdictional turf on Capitol Hill. The functions of commerce, trade, and small business should be clarified—although it will not be easy to do.

The Global Challenge

In stressing the need for quick and sustained action, he took note of the increasing tempo of international competition. As examples, he said that Brazil has spent $550 million to create 226 technology schools in the last eight years; Belgium's Institute for the Promotion of Innovation by Science and Technology has a $300 million annual budget; and China is using $1 billion in public funding to create Hong Kong Science and Technology Park. "The initiatives in our federal government that I talked about," he said, "pale in comparison to the investments that our competition is making."

He closed by referring to another, more recent study by the OECD,[18] completed just the week before the conference, which evaluated the comparative innovation status of nations. While acknowledging that the United States is still the global leader, the report noted "fissures" in the U.S. innovation system, and stated that the country needs to respond quickly if it is to retain its competitive status.

ILLINOIS SCIENCE & TECHNOLOGY COALITION

Mark Harris and Edward Fetters
Illinois Science & Technology Coalition

Mr. Harris said he would begin by describing the mission of the Illinois Science & Technology Coalition (ISTC) and some of its challenges, and then he would ask his colleague Ted Fetters to describe a Coalition report on nanotechnology being released on the same day as the conference.

He said that the ISTC is a member-driven organization that "cultivates innovation and technology-based economic development in Illinois." Its mission is to:

- Foster public-private partnerships to develop and execute research, development, and innovation (RDI) projects;
- Attract technology and innovation-driven federal resources and private

[18]According to the report: "The U.S. economy is very innovative, but fissures have begun to appear. Innovation performance has weakened according to various indicators, although from a high level. To foster innovation and economic growth, reductions in the federal R&D budget should be as limited as possible. Ideally, funds would be appropriated to continue on the path approved in the 2007 America COMPETES Act of doubling the budgets for three key science agencies within a decade. Patent reform should be taken further than in the America Invents Act by ensuring that the legal standards for granting injunctive relief and damages awards for patent infringement reflect realistic business practices and the relative contributions of patented components of complex products. In light of spillover benefits from manufacturing activity, the measures proposed by the Administration to strengthen manufacturing competitiveness should be implemented. Education reform is needed to strengthen achievement and to address lagging tertiary attainment in the fields of science, technology, engineering and mathematics (STEM)." *OECD Economic Surveys, United States,* June 2012.

investment in Illinois; and

- Raise awareness and visibility for Illinois' innovation ecosystem and advocate for state and federal policies to enhance its development.

The ISTC enhances talent, investment, and job growth, he said, through strategic public-private partnerships, leveraging the state's world class assets and federal projects to enhance Illinois' standing as a hub for innovation and entrepreneurship. "We are only as strong as our member organizations," he said, referring to many of the conference participants, including Argonne National Laboratory, University of Chicago, Northwestern University, the University of Illinois, Illinois Institute of Technology, Abbott Laboratories, Baxter, industry groups, and non-profits. The ISTC also works with partner NGOs, many of which were represented that day.

The value and the strength of the ISTC, he continued, was its ability to build bridges across sectors, disciplines, and institutions. The ISTC, he said, "is an incubator for executable ideas and fundable projects that works to advanced knowledge and create value." He saw the organization also as a "nexus between industry, government, and academia," and said he would like to position Illinois to seek "very targeted, sector-based dollars and initiatives." The ISTC had recently worked with Argonne, for example, on a $100 million proposal for a DOE energy storage hub. It had also worked with the University of Illinois to join the national network of advanced manufacturing discussed earlier in the day. The Coalition has a global focus, he said, including a partnership in smart grid technology with the Korean government and another in bioscience with Shanghai and Brazil.

He said the ISTC has three objectives in building an Illinois innovation economy. The first was stakeholder engagement, or harnessing diverse stakeholders, to bring more of them into contact through networks and pathways. "We have a lot of brainpower in the state," he said, "and oftentimes the key is to get the right mixture of people and connect them across institutions and industries." The second objective was to expand early-stage financing. This was especially urgent, he said, because the economic downturn had driven financing toward later, less-risky stages of company growth. Without early-stage funding, "promising technology takes far longer to commercialize." The third challenge was infrastructure and asset alignment. While Illinois has a strong knowledge and research infrastructure through its national labs and universities, these assets need to be better mapped and aligned to create a more efficient and productive ecosystem.

He noted that Governor Quinn had taken the leadership role in cultivating the Illinois Innovation Council, which he called "a dynamic group of public-private partners," to develop and facilitate the state's strengths. The Council, chaired by Brad Keywell of Lightbank, works to "connect the dots among research, talent, and ideas." The organization is very open, he said, welcoming anyone to attend and present ideas.

He followed up on the Governor's description of the Open Data

Initiative. Placing government data sets online, he said, was inspired by federal government policy and intended to find creative new ways to use state government data sets locally, both for policy makers and in support of new entrepreneurial activity through new data applications. "We do plan to expand this initiative," he said, "to have more municipalities take part at the local level and competitions that invite developers to use the data in new ways."

An active area for the ISTC, he said, is the Policy Academy on Advanced Manufacturing, which originated with discussions by the National Governor's Association. Illinois was one of seven states selected to participate in this Academy, partly because of its global leadership in not only food and agriculture, but also in the manufacturing fields of biomedical devices, heavy machinery and equipment, and green technologies. He said that since 2010, some 36 percent of all new jobs were created in manufacturing, and that the group seeks to ensure that U.S. companies can continue to compete globally in innovation. The ISTC's role is to better connect the efforts of industry, government, and research institutions, "which aren't as connected as they need to be."

Another key element of the Coalition's mission, he said, was to make sure that state legislators and policy makers are aware of innovation activities, especially those in science and technology. To build this awareness, the Coalition has helped to establish the Research, Development, and Innovation Caucus of the Illinois General Assembly in Springfield, the state capital, in order to advise state leaders on efforts appropriate to state policy. "This is a bipartisan group we created last session," he said, "and right away it has had some tangible impact by extending the life of the R&D tax credit and reauthorizing the Treasury's Investment Fund."

The ISTC also generates an Illinois Innovation Index, in partnership with the Chicago Metropolitan Agency for Planning (CMAP), World Business Chicago, and the Chicagoland Chamber of Commerce. The function is to educate stakeholders through a monthly publication that reports on key metrics of the Illinois innovation economy, including analysis, benchmarking, and promotion of innovation and entrepreneurial activity metrics. It tracks data on such topics as venture capital growth, STEM education, patents, and trademarks.

A second major area of interest to the ISTC is early-stage financing. As described earlier by Governor Quinn, the state was able to leverage $78 million in treasury funds from the State Small Business Credit Initiative. The funding has been used to support three programs that spur institutional lending to small businesses and one program to leverage private venture capital in start-ups and high-growth businesses. The VC fund, or Invest Illinois Venture Fund, received $20 million of that allocation to support young, innovative companies judged to have high potential for future growth. By the time of the conference, this fund had invested $4.2 million in 14 deals, leveraging about $16.7 million in private investments.

The ISTC also works to align various assets with infrastructure to improve available space for innovation, especially in technology parks. Current

efforts are focused on the 1871 Digital Tech Incubator, a 50,000-square-foot technology park to launch and grow early-stage technology start-ups.[19] The state has made a capital commitment of $2.3 million, and is being joined by private firms, including Comcast, Cisco, and Chase. A number of universities have opened offices there, as has the ISTC itself.

The ISTC has also helped to promote the state's research and technology parks, including the Illinois Science and Technology Park in Skokie on a site once occupied by Searle and Monsanto laboratories. This site is being "reinvigorated" as a public-private partnership with the initial stimulus of a $20 million capital commitment from the state government and the collaboration of the Forest City Science + Technology Group. The site is designed as a home for spinouts of Northwestern University, already including NanoInk, Nanotope, Polyera, and NanoSonix, and will also serve as a hub for STEM learning. Partners include the village of Skokie and community colleges that will use the site for technical training programs.

A parallel infrastructure project is the Open Innovation Network, intended as a statewide database of researcher expertise, publications, patents, grants, and unique facilities or equipment. For a long time, he said, policy makers and planners had felt the need to gather information that is fundamental to building university-industry collaborations and better equipping research leaders to build teams ready to compete for federal funding opportunities.

He then introduced his colleague Edward Fetters, director of program management at the ISTC, whose primary responsibility is the Illinois Nanotechnology Collaborative (INC). Mr. Fetters said that the INC was a good example of what the ISTC does—working in different sectors that have overlapping strategic strengths. This project began with a planning grant from the Small Business Association (SBA) in September 2010 to develop a road map based on the potential of nanotechnology to be a major economic driver for the state. The road map calls for the pursuit of challenges based on current talent and assets, including the fields of energy, clean water, personalized medicine, and advanced manufacturing. Current assets, he said, include more than 70 nanotech companies, including both pure-play nanotech companies and others with nano-enabled products. The state has more than 20 departments or divisions conducting nanotechnology research at its major universities and national labs, as well as at the clusters already located at Northwestern's Illinois Science and Technology Park and the Research Park at the University of Illinois.

The nanotechnology report just being released by ISTC carried a full market analysis of nanotechnology assets, research talent, and infrastructure. It also described federal funding trends and identified a series of grand challenges

[19]The organization 1871 was named for the year of the Chicago fire. In the words of the organization's website: "The story of the Great Chicago Fire of 1871 isn't really about the fire. It's about what happened next: A remarkable moment when the most brilliant engineers, architects and inventors came together to build a new city." <*http://www.1871.com/about-us/*>.

the state is advised to pursue on the basis of the nanotech ecosystem in place. The first such challenge was energy and energy storage, because of its "great global importance, funding priority for the federal government, and the assets already present in Illinois." Technologies developed in the state, for example, power the batteries of the Chevrolet Volt—although the batteries themselves are manufactured in Holland, Michigan. Other energy-related nanotechnology efforts include:

- Nano-structured materials to improve hydrogen membrane and storage materials and catalysts for fuel cells;
- Nanoscience-based options to convert waste heat from computers, automobiles, homes, and power plants to usable electrical power;
- Wires containing carbon nanotubes to reduce power losses in the electric grid during transmission.

A second grand challenge for nanotechnology, he said, was the provision of clean water. For example, nanoparticles may someday be used to clean industrial water pollutants from groundwater through chemical reactions that render them harmless—at much lower cost than pumping the water out of the ground for treatment. Also, in Milwaukee, startup companies are using nanotech filtration for water from Lake Michigan, he said, and "we should be doing the same."

The next set of opportunities he listed under the topic of personalized medicine. For example:

- Nanotechnology can make the tools of medicine cheaper and more effective through large-scale replication of nanostructures;
- Research and diagnosis can be made more efficient, as single-molecule detection technologies increase efficiency and decrease misdiagnoses;
- Sensors and implantable devices can be developed to allow for continuous health monitoring and semi-automated treatment.

Finally, the grand challenge of advanced manufacturing is designed to collaborate with the White House's National Manufacturing Initiative to apply nanotechnologies or nanomaterials to new or existing manufacturing. Opportunities include the application of novel process to known nanoscale materials, components or devices, or the use of wholly new nanomaterials or processes.

The Illinois Nanotechnology Collaborative has the potential build a strong new infrastructure for Illinois, said Mr. Fetters, but only if the research can be commercialized and connected to real-world applications and companies. The INC, he said, can help aid these commercialization efforts, act as a clearinghouse for nanotechnology activities, educate the public and public

officials, and advocate for the nanotechnology ecosystem in Illinois. The group's report on nanotechnology was made available during the conference on its website.[20]

To implement its plans, the INC has developed a portfolio of supporting resources:

1. Its **Proof of Concept Centers** are designed to accelerate the commercialization of innovations by facilitating the exchange of ideas between university innovators and industry via mentors associated with the center. Both Northwestern and the University of Illinois were named by a recent report of the Kauffman Foundation as model locations to establish such centers.[21] According to the plan, the centers will be virtual, not requiring physical structures.
2. **A Shared Facilities Program** is essential for the complex endeavors of nanotechnology, which require specialized and expensive tools. Nanotech start-ups seldom have access to such tools, while larger institutions do. The ISTC supports a nanotech commercialization grant program to ease the financial burden of facilities that wish to help start-ups but need to offset the staff and overhead costs.
3. A **Workforce Development Program** is needed to train people to work in companies as they scale up. Currently, many nanotech companies employ PhD-level lab technicians, who are the only people with the requisite skills. This model is not scalable for a profit-motivated companies, when an A. A.-level lab technician with proper training could do the work at half the salary. Because companies prefer to be located where a skilled workforce is located, Illinois is likely to benefit from reinforcing the skills level of its young people through two-plus-two high school and community college programs or standalone community college programs.

   A new project providing hands-on training to students is the Nanotechnology Employment, Education, and Economic Development Initiative (NE3I) run jointly by Illinois Science + Technology Park, NanoInk, Oakton Community College, the State of Illinois, and the Village of Skokie. It is reinforced by Illinois Pathways STEM Learning Exchanges, a partnership between the state Department of Commerce and Economic Development and the state Board of Education. "The goal," he said, "is to create a pipeline of students and professionals with the skills needed to work in nano labs."

[20] *<http://ISTCoalition.org>*.
[21] "Proof of Concept Centers: Accelerating the Commercialization of University Innovation," Ewing Marion Kauffman Foundation, January 2008.

4. **Matching SBIR Grants** for small firms. "As venture funding moves toward later stages, we need that early-stage financing. Illinois both needs to capture more SBIR funding and to create the support to make that happen. The ISTC approach is to create technical assistance programs to help folks in their applications, and to provide matching grant funding to accelerate the research itself that is funded by SBIRs."

A PERSPECTIVE FROM THE IT INDUSTRY

Dennis Roberson
Illinois Institute of Technology (IIT)

Dr. Roberson, who has worked both in academia at the Illinois Institute of Technology and in the private sector, at Motorola, said that he would offer a "decidedly different, very personal" perspective on the information technology (IT) industry and what is required to "create true innovation in that area."

He began with the assertion that innovation occurs most often where innovation has occurred before. "That may seem odd," he said, "but it is the case. We talk about it daily: an innovative company or individual or institution. The reason we talk about it is that people establish themselves and move in a progression engendered by their environment. This environment is an essential ingredient of some institutions."

Such an environment is progressive and desirable, he said, and it can be supported by forums, recognition, facilities in universities, and government entities. "It can also be squelched," he added.

Underlying innovation is a well-educated, creative workforce, and there are many ways in which the innovation ecosystem falls short in generating this workforce. Such a workforce depends "training in innovation itself," he said, and in entrepreneurship. Innovation occurs in large as well as small companies, but large companies often lack the structure that "allows innovation to take flight." Other elements needed to create this workforce are the continuing education programs of universities, the partnerships between cities and community colleges, "and the obligation of companies to support the continuing education of their own employees." This last notion was often forgotten, he said, when businesses overlooked their responsibility in the continuum of education. "I become angry listening to companies complain about not finding the people they need. It is the job of these companies to educate people who are emerging into new jobs, and even to train students who are new and raw but who have great talents."

Also required as a platform for innovation, he continued, is infrastructure, for which Chicago is well known. The first major route for sending goods east and west across the United States, he recalled, was the waterway linking the Mississippi River to the Great Lakes, with a portage from the Chicago River to the Illinois River. To this form of transit was added the

railroad structure, including both transcontinental and many local lines, and later the Interstate Highway System. Illinois ranks third in the nation in total Interstate miles, after the much larger states of Texas and California.[22]

In addition, he said, the highways and railroads of Illinois provide all-important rights-of-way in laying fiber-optic cable for the internet and "Internet 2." The availability of broadband is not only critical for innovation, he said, but its production is also becoming a greater engineering challenge nationwide. "We have a huge need for power to maintain the Internet and the web," he said. "Information technology is the biggest user of electrical power in the United States now; the big databases of Google and Amazon and Microsoft and government are the modern steel mills. They absorb power to run the electronics and then more power to cool it. Having reliable power that is hopefully green is essential to the IT industry."[23]

Innovation requires the right physical spaces to support creative activity, he continued, including environments that promote interaction. "It's nice to talk about working at the beach, or at home," he said. "But for innovation you need places to interact with other people.[24] Being together as human beings is really important. You need access to one another as well as to the equipment supply."

He added several more features essential to an innovation ecosystem:

- Community: In addition to actual work spaces, innovators need inviting living spaces in safe communities with a wide array of entertainment opportunities: parks, restaurants, culture events, sports. "If you're going to have an innovation infrastructure, you need an environment that supports human activities."
- Services: Innovation requires the nuts and bolts used by business if an idea is to find a smooth transition toward the marketplace, including the functions of accounting, business planning, payroll administration, and taxes. The ecosystem needs both general and specialized legal services to support business formation, agreements, and intellectual property issues, as well as marketing, public relations, human resources, and event planning.
- Financing: The Midwest, unlike Silicon Valley, does not have a strong tradition of capital formation and venture investment, he said. For IT start-ups, a range of private investment forms are needed, including personal investment, sweat equity, willing friends and family, IT-knowledgeable angels, category-specific venture capital firms, accessible private equity, and IT industry-savvy commercial banks. "People have to learn that it's okay to invest in a start-up," he said.

[22] *<http://interstate50th.org/>*.
[23] The largest supercomputers, such as IBM's Sequoia, may draw more than 5 megawatts of electricity.
[24] The conference was held at the Allen Center at Northwestern University.

"We need IT-savvy banks in Chicago that are ready to invest here, and IT start-ups that grow past the habit of going to Silicon Valley banks."

- Government: Local and regional governments need to offer a more supportive structure for innovation, featuring clear regulations, competitive tax and fee regimes, support for major conferences, and better access to International connections, such as consulates.

He concluded with his own personal assessment of the innovation ecosystem. He offered a grade of "B" for the first six areas he emphasized: conducive environment, educated workforce, network infrastructure, supportive work environment, community, and services. He gave financing and government the grade of "C."

"We're not where we need to be to support an IT industry here in Chicago," he said. "Things are happening, and the governor and mayor and agencies are working hard to support them. But we don't have the maturity we need. And in some cases we have a financial deficit we're trying to work our way out of. Government and financing operate in very conservative ways that don't always lend themselves to what is needed to build an innovative IT ecosystem."

DISCUSSION

A questioner asked Dr. Wessner if there were innovation models the United States should understand and possibly emulate. Dr. Wessner replied that the U.S. needs to be more aware of policies and programs underway in other countries and to adapt (rather than emulate) these to our own circumstances, where appropriate. To do this, we need to pay better attention to what other governments are doing. The Office of Naval Research does a good job at this, he said, with its global reach, but a problem for the federal government generally is its difficulty in coordinating relevant information from many sources. And while the armed services have a long history of tracking other countries' technological developments, he said, hardware is not sufficient to assure our national security. We rely on the whole civilian economy to ensure our security, and "making the kinds of investments described at this conference is a key to national security, going forward."

A questioner noted a consensus among speakers regarding the scarcity of early-stage financing and the effect of that scarcity in limiting growth. "What we need is innovation in science parks, using SBIRs and other early financing," he said, "but the ideas that come out of the academy are starving to death. What do we need to do to build a local venture ecosystem in which part of the investment is early stage? Is there a role for government and the private sector in working together?"

Mr. Fernandez advised looking at the entire spectrum of innovation activities. "There used to be a steady flow of angel money and early-stage money as people made leveraged buyouts and then reinvested some of the proceeds back

into the system. There is not a very active LBO market now, so we don't see that flow of money. Revising tax policies and regulations that hold back the start-ups can help attract more investment money without having to comply with onerous SEC requirements.

When asked how long it might take to bring about regulatory changes, Mr. Fernandez said that a shortage of funds was not the central problem. "Remember that not every new business is worth funding. But for those that are, there is a lot of money out there. If you have the right technology and the right business, you can find the funding."

Mr. Fernandez added that there is funding in Illinois as well, despite its distance from Silicon Valley. "There are funds that focus on niches, and investors who invest locally. Here we have several funds that invest in IT and digital technologies. The ICT ecosystem has been developing over a series of years into different areas. The capital is here, the talent is here; now we want to eventually grow here as well."

Dr. Wessner advised that Illinois should secure a better share of SBIR money, and that small firms in the state could benefit from coaching on how to apply. Coaching could not only bring a higher chance of being selected for a grant, but also of making optimal use of it to develop the business. An added benefit of receiving an SBIR award, he added, was the intangible "seal of approval" it bestowed, and this often attracted private investment.

Dr. Roberson observed that "we in academia tend to believe that our ideas are more open than they are." In an SBIR application, as in many aspects of innovation, "very often the challenge is to make sure that your idea really is right." For ideas that are indeed "right," he said, funding is likely to be available—even in Illinois, where the financing picture has "enormously improved" in the last decade.

Dr. Mirkin commented on the conservative economic understanding of innovation, which is that the economic success or failure of new products and firms should be determined solely by the free market. "Many economists and even smart people in business don't understand the need for substantial public investment in basic research," he said, "and then participation beyond that." The research process is essential in providing the ideas and raw material for innovations, and government has an essential role in supporting both the research and the climate for translational development of the research. Venture capital can be an active participant, he said, but most venture funding is "follow-on money" that does not participate at the early, riskier stages when help is needed most. He argued that the National Academies had an essential role in educating people about the innovation process.

Mr. Fernandez added that successful innovation depended "on more than institutional mechanics. I grew up in the Midwest, where entrepreneurial failure was not okay. You were ostracized, you had huge problems with your next funding. We still penalize risk-taking in the Midwest to a much greater degree than in other parts of the country; in California, if you have not failed at least once, you are not an entrepreneur. It's a cultural mindset [prevalent]

through the banking system and the industrial community." He recalled growing up in Kokomo, Indiana, where the founders of Eli Lilly, Ball Company, Firestone and many others took great risks as pioneers in building up regional economies in the Midwest. "Now we've got all this money and we don't apply it to new risk."

Dr. Wessner commented that the nanotechnology center directed by Dr. Mirkin, like the modern university in which it is embedded, was very different from how such a center would have been organized 30 years earlier. The professors of the 21st century are concerned not only with their traditional responsibilities of teaching, research, and outreach, but also with inventions, patents, and the possibility that they might be able to translate their research into start-up firms.

Like Dr. Mirkin, Dr. Wessner rejected the view of some academic economists that the free market alone should determine the success or failure of technology-based start-up firms. He said that the development of even the most promising firms could easily be derailed by a variety of market failures, such as those arising from imperfect information for potential investors. For markets to behave perfectly, he said, they need perfect information—about the potential of an innovation, the workings of competing firms, and market demand. But perfect information is not available in real world innovation. He noted that analysis by Joseph Stiglitz, Michael Spence, and George Akerlof of "asymmetric information," has been recognized with an Economics Nobel Prize. In the case of small-firm development, he said, asymmetric information makes it harder for small companies to raise money because the investment community cannot fully understand the potential of their innovation.

This underscores the essential role for public funding and policies designed to support small firms. For example, he said, states should make sure that bankruptcy laws do not reinforce an anti-failure culture. The federal government should ensure that the Economic Development Administration (EDA) is adequately funded to promote the growth of promising young firms. The Small Business Administration should reverse certain reforms that offer awards only after a spinoff company is formed rather than when it is still in formation.

Neil Kane of Illinois Partners Executive Services said he had been working for well over a decade to help commercialize the results of research in universities and federal labs that is funded by taxpayers. "What I'm observing," he said, "is that in the late '90s, the state of Illinois had money which provided early-stage seed capital, frequently in the form of grants, to do a lot of university-stage commercial development. I agree that most technologies taken out of universities aren't yet ready for commercialization, and therefore not good candidates for venture capital. Clearly there's a gap, and it's worse now, because the 'smart' VC money is all chasing mobile, social, and internet opportunities. That's where you don't have to move atoms around, so you grow much faster." There are two problems for the research-based firms, he added. The first is the technology risk, and the second is that investors are funding only

companies with revenues. "It's the biggest impediment I see now," he said, "getting these companies off the ground. And I'm not sure I have a suggestion. Maybe proof-of concept centers will help, and maybe finding sources to match SBIR money will help."

Dr. Roberson said that Illinois is now moving to a point where its focus is on the new economy, "which is good; but when this focus excludes the old traditional economy, that's not so good." This is especially true for Illinois, he said, where there is great strength in traditional institutions, which generate many innovative ideas. Such ideas added value to "old economy" areas, he said, transforming them in the process—something that local investors were not taking advantage of. He added that two recent investments in promising new Illinois research developments had been made not by U.S. investors, but by one venture capitalist from Russia and another from China.

Arthur Pancoe, a successful investor and medical research analyst with deep roots at Northwestern, said that he had worn many hats in his long career, and that he was "not quite as pessimistic" about the ability to find alert Illinois investors ready to support good ideas. Having personally donated $10 million to fund a medical research building at the university, he advised that certain government tax policies were a major barrier to small-firm formation and development.

Keynote

Innovation and the Clean Energy Challenges

Eric Toone
Advanced Research Projects Agency for Energy (ARPA-E)

Dr. Toone began by saying that starting the new Advanced Research Projects Agency for Energy (ARPA-E) reflected the fact that energy was "one of most challenging issues of our time." He offered a review of the history of energy use, which he said is "a history of modernity; the two are indistinguishable." Even more surprising, he said, is "how short that history is." Modern life had not yet begun as recently as the first half of the 19th century in America, when most people worked in agriculture; in 1830, 70 percent of the population did so. The work was back-breaking, with 56 hours of hand labor required to farm an acre of wheat which produced about 15 bushels. With no artificial light, the farmer's day began at dawn and ended at dusk. The household heat came from wood, and transportation was provided by animals. While a few emigrated to new regions, most people seldom traveled more than 50 miles from where they were born. In that year, per capita GDP in 2011 dollars was less than $5,000. Per capita energy use was about 10 million BTUs, almost all of which was used for heating and cooking.

Artificial light was among society's greatest needs, he said. By the middle of the 19th century, whale oil had emerged as the lighting source of choice. But the resource was finite; whales quickly became scarce, and fleets had to travel ever farther to find new stocks. Whale oil became unaffordable for most people, and by 1860 the industry was in severe decline. A new technology was required.

That industry had already begun. By 1846, Adam Gatsner, a Canadian geologist, had demonstrated that a liquid he termed kerosene could be distilled from coal. This means of extraction was not economical, but in 1851 Samuel Card developed a process for extracting kerosene from oil and began selling it as "carbon oil."

The last piece of the fossil fuel puzzle was an abundant, affordable source of oil. Oil seeps had been observed for many years in Pennsylvania, and in 1859 a well was drilled at one of these sites in Titusville, providing a revolutionary solution. John Rockefeller was involved almost from the beginning, and in 1870 he and his friend J.D. Flagler organized Standard Oil Company. Standard Oil quickly became the largest company in America and then in the world.

The ready availability of cheap, clean, dependable light changed the world in ways hard to imagine today. With access to artificial light the work day lengthened and productivity increased. New forms of energy enabled cooking and new diets. The amount of artificial light used by the average American rose from about 5 kilolumens at the end of the 19th century to an average of 60 megalumens today, a 12,000-fold increase. Gross domestic product began to rise just as rapidly, and almost from the beginning of the fossil fuel industry, the two values rose essentially in lockstep.

Other innovative forces were at work. Several inventors, beginning with Sir Humphrey Davy at the beginning of the 19th century, had experimented with the idea of producing light by passing electric current through a filament. But none of these techniques was viable until 1879, when Thomas Edison illuminated devices by passing current through a carbon filament that was isolated in a vacuum. At that point, electric light became a practical reality and kerosene prices plunged.

Over the second half of the 19th century, oil was still used primarily for the production of kerosene, while gasoline was treated largely as a waste product. But many inventors saw the possibilities of other uses, especially in transportation. In 1908 the first Model T rolled off the assembly line, the first time an affordable gasoline engine was use to power transportation. By 1914 a model T took only 93 minutes to create on Henry Ford's assembly line, and only 20 years after the introduction of the first Model T, 18 million of them were registered in the United States. A parallel interest grew in using oil to power airplanes, and in 1903 the Wright Brothers made this happen for the first time at Kitty Hawk, North Carolina, initiating the era of air transportation. By the time Lindbergh crossed the Atlantic in an airplane, air transport based on cheap and abundant energy became the new norm.

Cheap oil also changed both the motivations for and the means of war. Immediately before World War I, Winston Churchill made the fateful decision to transform the energy source for the fabled British fleet from coal to oil. This decision had profound consequences. The first was to enable a much quicker Allied fleet, with savings in weight, space, and required manpower. Indeed, at the end of the war, Lord Curzon, the British foreign secretary, suggested that the allies had ridden to victory on a wave of oil.

A negative consequence, however, was that Great Britain had huge domestic supplies of coal—but no oil. Without it, the British faced profound logistic and supply issues. These led to increased activity in the Middle East, with enduring consequences.

The link between energy and prosperity became steadily stronger for reasons that today seem obvious. By the turn of the 20th century, the percentage of the American labor force in agriculture had fallen to 41 percent and, by the end of World War II, to less than 7 percent. The productivity of the American farm rose just as quickly. The acre of wheat that took 56 hours of labor to grow in 1830 and produced 15 bushels now took three hours of labor and produced 30 bushels, a 50-fold increase in productivity.

By the middle of the 20th century most workers were employed not in farming but in manufacturing. Electric lighting rather than the rising and setting of the sun controlled the amount of daylight. Heating came not from firewood but from oil or coal, and people traveled by car rather than horse or foot. Construction of the modern highway system meant that Americans could travel from coast to coast. Per capita energy use rose three-fold over the first half of the century, and GDP per capita grew at the same rate.

In the second half of the century those trends accelerated as more innovators saw the true potential of cheap and abundant energy. By 1980, six of the world's 10 largest corporations were oil companies. Today, although less than 2 percent of the American work force is involved in agriculture, the United States feeds a large proportion of the world. Energy use and prosperity continued to rise in lock step throughout the century, and access to cheap, abundant energy increased real per capita GDP by five-fold in a single century.

While those trends brought unimaginable opportunities, problems lurked just beyond the horizon. The resources we depend on—primarily oil, coal, and natural gas—are finite. "We can have a reasonable debate on whether those fossil resources will last 50 years or 200 years," said Dr. Toone, "but they are finite. And extraction of that resource has real consequences. We can again debate what fraction of global warming is anthropogenic, but it is undeniable that the extraction and use of fossil resources has real environmental consequences."

The push to a new energy future, he said, must also address long-standing global inequities. While the application of energy has led to prosperity, it has done so unevenly. With less than 5 percent of the world's population, the United States has for many decades consumed about a quarter of the world's energy. Not surprisingly, the United States also generates about a quarter of the world's GDP. But one-quarter of the inhabitants of the planet have no access to energy services—"and have never seen an on-off switch." A much larger fraction has sub-optimal access to energy. "Growth in the so-called BRIC countries in the coming decade," he said, "and in the developing world over longer periods will place massive new pressures on our finite resources."

At the same time, he said, as we pull away from the current fossil-based energy economy, we feel "an incredible pull to a new future. There can be no doubt that our energy economy will be rebuilt." In the same way the energy revolution that began in the second half of the 19th century rebuilt every aspect of the American economy, the coming transformation will reconfigure both the American and the global economies. "Make no mistake, this transformation will

happen. There will be winners and there will be losers. Choosing to sit it out is a choice, but you can't choose not to participate."

Against that backdrop, he said, the ARPA-E was created in 2007. The impetus for the creation of the agency came from the National Academies' *Rising Above the Gathering Storm*[25] report. That report, which recommended the creation of a new energy agency modeled broadly after the DARPA, was delivered to the Congress in 2006. The new agency was created under the Bush Administration in 2007, and received its first funding in spring 2009 under the Obama administration, a bolus of $400 million in Recovery Act funding. To date the agency has disbursed over half a billion dollars to 180 projects, universities and companies, and in 2012 was scheduled to obligate $275 million in funding.

ARPA-E, he said, differs from most federal funding agencies in its mission of seeking to identify and support "over-the-horizon" technologies with the potential to transform some aspect of energy science or engineering. The agency's job is not to improve existing technologies, he said, or to drive them along their natural price or learning curves. "That is important," he said, "but it's not what we do. We try to identify fundamentally new technologies. Our job is to start fundamentally new learning curves."

In addition, the agency does not continue funding these new technologies long enough to know if they will be disruptive enough to displace existing technologies from the marketplace. The job is to give the market place a range of choices and new technology opportunities, "some of which will scale and some will not. So we're willing to take on a lot more risk than other funding agencies. When we look at a proposal, the first question we ask is not will this work, but if it worked, would it matter. Then we manage that risk through close and intensive program administration."

President Obama announced the first solicitation of ARPA-E, which was very broad in nature. It resulted in 3,500 pre-proposals, which were winnowed to 320 full applications and ultimately to 37 projects that were selected and funded "across the entire energy landscape." The first round made investments in energy storage, biofuels, efficiency, carbon capture, solar fuels, vehicle technologies, renewable power, waste heat capture, and water. A total of $151 million were invested, in amounts ranging from $500,000 to $9 million. The "canonical" ARPA-E award is for $2 to 3 million to be spent over a three-year period.

After the first solicitation, he said, the agency fell into a pattern of focused investments in specific technology areas. This, too, was different from the strategies of other federal agencies in that ARPA-E does not have line items for particular areas. Instead, the agency invites "the very best technologists and scientists from the private sector and academia to Washington for a period of

[25]National Academy of Sciences, National Academy of Engineering, and Institute of Medicine, *Rising Above the Gathering Storm: Energizing and Employing America for a Brighter Economic Future*, Washington, DC: The National Academies Press, 2007.

about three years. We don't tell them what to do, we ask them to spend some time identifying for us a 'white space' where the application of $30 to 40 million over a dozen or so projects might really 'move the needle' and start us down one of those new learning curves."

Over the past three years, ARPA-E has initiated programs in transportation, end-use efficiency, and stationary power (see BOX). These programs are supporting research in many cutting-edge technologies, including biofuels, storage of energy for transportation, storage of thermal energy for electrical uses, higher efficiency air conditioning, carbon capture and sequestration, power electronics, grid-scale storage of power for better deployment of renewables, smarter ways to distribute power across existing infrastructures, and construction of generators and engines that do not require rare earth elements.

In choosing areas to support, he said, the agency begins with fundamental issues of high priority to the federal government and the nation. For example, biofuels are obviously high in priority because of their central role in enabling transportation. Rather than seeking incremental improvements for existing biofuels, however, ARPA-E addresses the issue at its most fundamental level: the process by which biofuels are created in the first place.

By now it is well known that most gasolines have up to 10 percent biofuel content, and that most of this fuel is processed from corn. Less obvious

CURRENT ARPA-E RESEARCH PROGRAMS

Transportation
BEEST—Batteries for Electrical Energy Storage in Transportation
Electrofuels—Creating transportation fuels from microorganisms
PETRO—Plants Engineered to Replace Oil

End-Use Efficiency
BEETIT—Building Energy Efficiency Through Innovative Thermodevices
HEATS—High Energy Advanced Thermal Storage

Stationary Power
ADEPT—Agile Delivery of Electrical Power Technology
GENI—Green Electricity Network Integration
GRIDS—Grid-Scale Rampable Intermittent Dispatchable Storage
IMPACCT—Innovative Materials and Processes for Advanced Carbon Capture Technologies
REACT—Rare Earth Alternatives in Critical Technologies
Solar ADEPT—Solar Agile Delivery of Electrical Power Technology

is the larger context in which we have achieved this early means of producing a biofuel. That context is the fact that the only energy input to planet Earth is solar radiation. Over millions of years, most of the Earth's plants have learned to absorb the photons of solar energy and capture some of its energy by the complex but effective process of photosynthesis. Some of this stored energy is used immediately by the plants themselves and organisms that feed on them; some is buried and gradually converted to petroleum. The energy locked in petroleum is now being converted rapidly by refineries from the viscous raw form to the easy-flowing, high-energy liquid fuel that can be stored in tanks and used to power vehicles.

The fact that photosynthesis can achieve this remarkable feat of storing solar energy in the form of chemical bonds is truly remarkable. However, our energy-hungry modern world is impatient with the low efficiency of photosynthetic conversion. The job of Dr. Toone's colleagues at ARPA-E is to speed up the natural process. "At some level," he said, "the name of the game is to imagine that the corn or other plant that converts photons is a black box. We want to maximize the efficiency of what goes on in that box, which is the conversion process. How do we do that?"

If a farmer plants an acre of land in Texas with one of the North America's highest-yielding energy crops, he said, such as sorghum, the land would produce about 12 dry tons of biomass a year. This biomass has a heating value of about 8,000 BTUs per pound, which seems remarkable. Viewing that process from the point of view of efficiency, however, reveals that the energy captured in those chemical bonds represents only about 1 percent of the radiation falling on the acre of sorghum—about the amount that would arrive every three days. Nor does this percentage include many factors that reduce the efficiency of the process, such as the costs of growing the crop, harvesting it, moving it, and converting it to a product. Including those costs, the efficiency of photosynthesis—"solar photons in, liquid fuel out"—is really only a few tenths of a percent.

Researchers at ARPA-E are optimistic. Early fundamental research into the metabolic processes of organisms, especially vascular plants, algae, and bacteria, has shown that the diverse biological life forms on Earth harness energy in many ways aside from photosynthesis, some of them highly efficient. This diversity of strategies is so great, he said, that the "surface has not even been scratched." For example, a still-unknown number of organisms occupy ecological niches where they do not have access to reduced carbon or sunlight.[26] Many of them make use of hydrogen, ammonia, reduced metallides—or even grow directly on electric current as "electrofuels," using pathways other than the

[26]Most autotrophs, or "primary producers," transform the energy of sunlight into protein, carbohydrates, fats, and other complex molecules that provide food for it, and for many animals that feed on them. Many others, however, make use of the energy in inorganic compounds of the Earth's crust, such as hydrogen sulfide, ferrous iron, and ammonium, as reducing agents for biosynthesis or chemical energy storage.

familiar Calvin cycle that describes the photosynthetic process of carbon fixation. Until recently, none had been carefully studied as potential sources of biofuels. Under ARPA-E, this is a major current emphasis. For example, the small chemical company OPX Biotechnologies, of Boulder, Colorado, is engineering a microbe that can produce biodiesel-equivalent fuel from carbon dioxide and hydrogen under ARPA-E's electrofuels program, and has calculated that it is 10 times more efficient than photosynthesis.[27]

Liquid fuels are not the only transportation emphasis at ARPA-E, he continued, the second being its extensive research on vehicle electrification. While two commercial vehicles—the Nissan Leaf and the Chevrolet Volt—successfully came to the U.S. market in the year 2012, he said, current technology still faces fundamental problems. The primary basic research challenge is to store enough electrical power for adequate distance of travel, which he called "range anxiety."

For example, the Leaf is an all-electric vehicle that uses lithium-ion batteries and has a published range of a little over 100 miles. But this figure does not include the power that must be set aside for the heating or air conditioning that drivers expect. Unlike an Internal combustion engine, which provides essentially unlimited heat at no cost, an all-electric vehicle must give up some of its power to heat the passengers. Similarly, an air conditioner on any car requires considerable power. These combined needs of heating and AC reduce the range of an all-electric vehicle to about 50 miles.

There seems to be little hope that lithium-ion technology can overcome this challenge. The fundamental problem, he said, is that this technology delivers only about 60 watt-hours per kilogram, with a theoretical limit around 200 Wh/kg. By contrast, gasoline stores about 14,000 watt-hours per kilogram. "If I asked the smartest chemists in the world to come up with the ideal storage medium for transportation," he said, "it would be gasoline."

To deal with this problem, he said, the ARPA-E BEEST program, Batteries for Electrical Storage in Transportation, was funding research in a number of new technologies. The first is metal-air batteries. Lithium-air batteries, for example, have a theoretical energy density maximum approaching 11,000 Wh/kg, close to that of gasoline. Considering how much of the energy in gasoline is lost as waste heat, he said, these batteries could have even a higher practical energy density than the 14,000 Wh/kg of gasoline.[28] A major barrier in developing the lithium-air battery is that its electrodes must be protected from water. One of the companies in the current BEEST program, PolyPlus, is currently developing, in collaboration with Corning, just such an electrode "with tremendous promise for the development of metal-air batteries."

In the area of stationary power generation, he said, which accounts for about 65 percent of the energy used in our society, an urgent challenge is to

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[27] <*http://www.opxbiotechnologies.com*>.

[28] The Li-air battery, first proposed in the 1970s, gain their high energy density by using oxygen from the air instead of storing an oxidizer internally.

store some of the energy produced for times when it is needed. This is especially true for solar and wind power, renewable sources which are being deployed rapidly in many regions of the United States. He said that electricity produced by wind generators is "pretty much at grid parity"—in other words, it costs about the same as power generated by traditional sources—and in some cases even below parity. Solar energy "is not there yet, but it will be soon."

Despite this progress in generation efficiency by renewables, he said, it must still face the problem of intermittency: that is, wind and solar power function best when wind and insulation are strongest. If renewables generate more than the grid requires at these times, or more than about 20 percent of the total demand of a service region, the excess energy must be stored efficiently for when it is needed. These new forms of energy also have to be generated on a vast scale in a country that "now uses about 600 Hoover dams of electricity a day." The GRIDS program, he said, has the goal of providing stored renewable energy from any point on the energy grid at an investment cost of less than $100 per kilowatt hour. Working with private companies, universities, and national labs, ARPA-E supports 12 projects in this field. These include the technologies of magnetic energy storage, next-generation flywheel energy storage, flywheel composite rotors, flow-assisted alkaline batteries, zinc-air energy storage, soluble lead flow batteries, and fuel-free compressed air energy storage.

One example is a partnership between 24M, a spinout from MIT, and A123, a battery technology company. This project is using semi-solid flow cells that combine advantages of a battery with the power density of a fuel cell to generate "very low cost and very scalable energy storage." The chemistry of this system resembles that of a standard Li-ion battery, but in a flow battery the energy storage material is held in external tanks. This means that storage capacity is not limited by the size of the battery itself, making it possible to add storage capacity by simply increasing the size of the tanks and adding more paste. In addition, 24M's technique is also able to extract more energy from the semi-solid paste than conventional Li-Ion batteries, creating a cost-effective, energy-dense battery that can improve the driving range of electric vehicles or store energy for the electric grid.

Another form of renewable energy of interest to ARPA-E is geothermal heat, of which the United States has enormous resources. Most, but not all, are located in the West, but virtually all share the problem of access. Geothermal sources tend to be seven to ten kilometers below the surface and (unlike petroleum reservoirs that are usually covered by soft sandstone or limestone) they are buried within basalt or granite, which does not yield to ordinary drill bits. A partnership of scientists from MIT and FORO Energy has addressed this challenge by fixing a powerful continuous wave laser[29] on the front of a drill bit. The laser is able to heat and thermally fracture the rock as it descends through the rock, leaving the bit the relatively easy task of clearing away the fractured

[29]A continuous wave (CW) laser, unlike the more familiar pulsed-wave lasers, emits a continuous wave of light energy.

rock. Project engineers have used extremely high-quality fiber-optic cable to power a 50-kilowatt laser to a depth of 5 kilometers. The optical quality of the glass fiber is so high that a 10-km block of the glass would have less distortion than an ordinary window pane. "This is a truly spectacular achievement," he said. "They have drilled through some of the hardest rock on earth at 10 times the world [speed] record with basically zero weight on the bit."

He said that ARPA-E would soon announce a series of new projects for 2012, and that the agency would be supported by $275 million in new funding. He said that one project would develop novel approaches in storing natural gas for personal rather than fleet vehicles. Although natural gas is rapidly penetrating the long-haul trucking sector, he said, its use in personal vehicles is "much more problematic." Also, the AMPED program would be trying to develop battery control technologies that allow extraction of much more energy from existing batteries.

He concluded with the news that the 2012 FOA, which was then open, had drawn "even more applications than we got the first time. This is a tremendous demonstration of pent-up demand for support in the energy space. We look forward to many successful new programs in the future."

DISCUSSION

Dr. Wessner asked whether large-scale deployment of such new technologies faced regulatory and financial challenges. Dr. Toone agreed that his agency faced more challenges than DARPA, primarily because DARPA always knows that it will "market" its output to the Department of Defense. ARPA-E does not have a single customer, so it has built its own technology-to-market operation, helping its partners develop their technologies toward a market after ARPA-E support ends. That team is lead by Sherrill Martin, who has had 20 years of experience as a vice-president of Rohm and Haas and as an entrepreneur-in-residence at a leading venture capital firm. The agency consults with all partners to determine the best strategy for each, which might be another round of federal support, a joint development agreement with a large company, a venture-funded startup, or other approach. "We work hard to address these concerns," he said.

Panel II

Federal R&D Strategies

Moderator:
Tyrone Taylor
Capital Advisors on Technology

Mr. Taylor Introduced himself as "born and raised" in Washington, and said that he believed strongly in the innovation power of the federal government after a career with NASA, including responsibilities for technology transfer. While the infrastructural roles of government were well known, he said, such as building highways and bridges, he felt strongly that the range of activities described at this workshop were typical of the agencies' efforts to apply the results of research to innovation, firm formation, and economic growth.

THE NSF ROLE IN THE INNOVATION ECOSYSTEM

Thomas Peterson
Directorate for Engineering
National Science Foundation

Dr. Peterson began with an overview of the National Science Foundation (NSF)—a national funding agency with no labs of its own. "All the money that comes in, goes out—primarily to universities—to support basic research in science and engineering, as well as educational activities." He said he would review the parts of the NSF mission that focuses on innovation, with emphasis on the importance of public-private partnerships.

He referred to Dr. Mirkin's early comment that innovation must begin with people—a talented work force. "We invest a lot in programs related to that work force," he said. "Then we provide research support so that faculty and students can develop their good ideas. Third, we provide mechanisms to facilitate innovation."

One such mechanism, he said, is the design of the professional staffing at the NSF. "These are people like me," he said. "We are rotators. We come in from other locations, typically universities, spend three or four years at NSF, and then return to our institutions. The advantage of this process is that it brings in people who have direct experience in universities and the challenges they have. The disadvantage is that sometimes it takes us two or three years to figure out the procedures of government and how to work with them."

He began with the President's Innovation Agenda 2009, which has three levels. The first is basic research to "catalyze breakthroughs for national priorities." This level provides the ideas and "raw material" for innovation and further development. The second level is "translational work" to promote competitive markets that spur productive entrepreneurship. The third is to tackle "grand challenge" issues through investment in the building blocks of American innovation.

He noted that the National Academies, as well as the NSF, are familiar with the role of basic research, which is "our bread and butter." At the same time, he said, many people are surprised to learn that the charter establishing the National Science Foundation (NSF) in the 1950s also contained a clear mandate to focus on activities that have societal benefit. "So it's not outside the purview of NSF to ask what some of its investments are doing in terms of eventual market value and application."

Of the NSF's $7.5 billion budget, he said, "almost all that money goes out the door." The overhead budget is about 5 percent, he added, and suggested that the agency should "invest at least a small fraction in helping those researchers who may have a potential commercial idea to take it to the next step."

He said that basic research is an integral part of broad research topics, such as advanced manufacturing, "in which there are not only engineering questions, but also many fundamental issues," with research investment made throughout many of the NSF directorates. Examples of basic research areas within advanced manufacturing included complex systems design, cyber-based approaches, materials design, and scalable manufacturing.

The National Science Foundation is also investing substantially in "secure and trustworthy cyber space (SaTC)," which is "a huge issue right now." NSF support is focused primarily on the engineering aspects of the Networking and Information Technology Research and Development (NITRD) strategic plan. The NSF is allocating its investments across a number of directorates in a program titled Enhancing Access to the Radio Spectrum (EARS). The objectives are to develop more efficient radio spectrum use and energy-conserving device technologies.

Dr. Peterson said that some investments by NSF might be surprising, such as its translational research programs. The agency supports many center-like programs that fund not only the principal investigator, but also teams of investigators and teams of universities partnering with teams from industry. These investments span the spectrum from fundamental discovery to potential

commercialization. NSF's first priority in these translational research efforts is not commercialization per se, but while most such activities fall under the category of basic research, many look simultaneously at potential applications. At the same time, they gather input from industry to adjust existing basic research programs or design new ones. He noted that many of these translational programs are not new—some have been operating for as long as three decades. The Industry-University Cooperative Research Centers (I/UCRC) started in the late 1970s, the first SBIR program was launched at NSF in 1982, and the Engineering Research Centers (ERCs) were first funded in 1985. The newest of these programs, the i-Corps, began in 2011. Additional translational research programs include the Science and Technology Centers (STC), Materials Research Science and Engineering Centers (MRSEC), Grant Opportunities for Academic Liaison with Industry (GOALI), Partnerships for Innovation (PFI), and Nanoscale Science and Engineering Center (NSEC).

The role the NSF can play in economic development is greatly extended by partnerships with universities and industries. For example, the I/UCRCs are usually located not only near or at universities, but also near industries with strong research in engineering, computing, or information science, such as Corning, BASF, Kyocera, Kennametal, and Ceradyne. The ERCs also have an extensive geographic reach, with locations in nearly every state, and unexpected endurance. The official lifetime of an ERC under NSF support is only 10 years, but virtually all are still in existence after raising their own continuing support from local, state, federal, and industry partners. About half of them focus on some form of engineering, but mathematics, physical sciences, social sciences, and health sciences are well represented. Industrial partners include Applied Materials, Corning, Raytheon, IBM, Michelin, Genencor, Cisco, Boeing, Agilent, BASF, and many others. "These are fantastic anchors for regional innovation," he said. "They are especially important at NSF, because unlike DoD, NASA, and some other agencies, we will never buy a product we have invested in. So we can invest in any good idea." Some companies built on NSF SBIR research include IntraLase Corp, Bluefin Labs, Inc., and ABS Materials.

The NSF has focused on the most effective ways to leverage small amounts of money to allow the fruits of basic research to develop to the proof-of-concept or prototype stage, and from there persuade a VC firm or other partner that the technology is worth a substantial investment. He pointed to i-Corps, which began in the summer of 2011, as an example of that strategy. Even though the FY2012 budget for i-Corps is only $7 million within a $7.5 billion agency, and the maximum award is $50,000, the program has been, according to Dr. Peterson, "wildly successful." Its purpose is to provide support for current or recent NSF grantees that are just past the discovery stage but not yet ready to apply for an SBIR or SBA grant. "This i-Corps grant provides not only some modest financial support," he said, "but it is also an educational tool, and a hypothesis-driven process. It helps teams of researchers, who really aren't

skilled at evaluating the market potential of their idea, to get to a point where they can do that."

i-Corps projects are team-based, including an entrepreneurial lead, who may be a postdoc or student charged with moving the enterprise forward; an i-Corps mentor, who is a volunteer guide with experience in the subject area; and the PI, a researcher with a current or previous award. The project provides a 30-hour, hypothesis-driven curriculum for the entire team. The program made 25 awards in FY2011 and 100 in FY2012, with participation by all but one NSF directorate. Among examples are Graphene Frontiers, with the University of Pennsylvania, which develops a process to produce high-quality, low-cost, large-area graphene films for thin, flexible devices; and Ground Fluor Pharmaceuticals, with the University of Nebraska, developing a single-step fluorination for positron emission tomography (PET) imaging.

He concluded with several examples for which initial basic research investments by NSF provided substantial momentum toward successful commercial products or companies:

- SBIR support of Qualcomm: In 1985, Andrew Viterbi and six colleagues formed "QUALlity COMMunications", and in 1987 NSF provided $265,000 in SBIR funding for single-chip implementation of the Viterbi decoder. This led to high-speed data transmission via wireless and satellite and to a company that is presently worth about $80 billion and holds more than 10,100 U.S. patents.
- Developing DNA as a forensic tool: Basic biological research led to the PCR technique behind DNA fingerprinting. The NSF Directorate of Bioscience made numerous investments in this technology, which has become a key to the U.S. legal system.
- Memory storage devices: NSF funding for the ERC at Carnegie Mellon University in the early 1990s supported fundamental advances in computers, including the nickel-aluminum under-layer that enables high-capacity memory storage. This storage is today used in laptops, MP3 players, and other consumer electronics.
- Internet search engines: "Sometimes things develop by pure serendipity," he said. In the 1990s, NSF chanced to fund Stanford professor Hector Garcia-Molina's Digital Library Project. The university's annual report, in describing "what else came from this research," included the following footnote: "Graduate student Larry Page developed a new approach for a search engine. See www.google.com."
- Retinal implants: NSF-supported researchers at Johns Hopkins Intraocular Prosthesis Group, North Carolina State University, and, more recently, the University of Southern California are creating retinal prostheses to electronically capture and transmit images to the brain, enabling patients to see light and shapes.

- Nano-patterning and detection technologies: The NSF funds the center for Nano-patterning and Detection Technologies at Northwestern, directed by Dr. Mirkin, who holds more than 350 patents in the field. Among two companies spun off from this work are NanoInk, founded in 2001 to develop the Dip Pen Nanolithography (DPN) tools for fabricating MEMS and other nanoscale devices; and Nanosphere, founded in 2000, which offers nanotechnology-based molecular diagnostic testing. Said Dr. Peterson, "We take credit for a lot of his success."

Dr. Peterson summarized his theme by saying "we like to refer to ourselves as the Innovation Agency; or Where Discoveries Begin. I think these catch phrases are oversimplified, but they do have a strong element of truth. We rely substantially on public-private partnerships to help our academic community be successful in developing their innovations and translating them into products and companies in the innovation space."

THE OFFICE OF NAVAL RESEARCH A UNIQUE INNOVATION ORGANIZATION

Chris Fall
Innovation Fellow
Office of Naval Research

Dr. Fall began by acknowledging the need for more knowledge about innovation activities both at home and abroad. "We don't have a lot of situational awareness about what's going on," he said, "even across our own government agencies." He said he would try to make the case for this need by describing the activities of his own agency and its structure. The Office of Naval Research, he said, with a central role in generating technologies for the nation's defense, must have a technological edge in innovative operational concepts and the science and technology behind them.

He called ONR "the Navy-Marine corps bank for funding research." More formally, the ONR mission, as defined by Public Law 588 of 1946, is "to plan, foster, and encourage scientific research in recognition of its paramount importance to future naval power and national security." Among the innovation milestones of ONR, he said, were development of a "drone" airplane in 1916 that could fly by radio control; the timing mechanism that allows the GPS system to work; and early technologies to launch terrestrial satellites.

He proposed a fundamental distinction between innovation and invention. Invention, he said, was working to create ideas, while innovation was putting ideas to work. "ONR," he said, "is structured to be an innovation machine," and the office is organized to carry innovations through to practical uses, whether commercially or for the government.

This emphasis dates back nearly a century, when the corporate laboratories were made subsidiaries of the ONR. The lab itself was founded by Thomas Edison, who was brought into the government in 1916 to establish a new research approach. The real acceleration of this strategy, he said, occurred with the government's decision to use public funding to support science during the Vannevar Bush era after World War II. With that decision, the ONR became the first federal funding agency, predating the NSF, and DARPA.

The Defense Authorization Act of 2001 revised the structure of ONR. Before that date, the office had closely resembled the NSF in its emphasis on basic research. In 2001, all of the ONR's translational R&D, he said, "was brought into the building to manage the Navy's basic, applied and advanced research to foster transition from science and technology to higher levels of research, development, testing, and evaluation." A new and critical layer of management was added to create three virtually equal directors: the Director of Research, Director of Innovation, and Director of Transition. Virtually the entire budget now flowed through those three offices, which had to compete with one another in arguing for the relative importance of the work they were doing and wanted to do in the future. "In the end," said Dr. Fall, "this creates a better product. I don't know of any other agency organized like this. It results in an engine for innovation that works well."

He described the ONR's mission in budgetary terms. The majority of the annual budget of approximately $2.25 billion is divided roughly as follows:

- 45 percent to basic research: This is fundamental science, or "seed corn," that forms the basis for solutions expected to bear fruit five to 20 years in the future.
- 12 percent to innovative naval prototypes: These projects are disruptive technologies or "leap-ahead innovations" expected to ripen five to 10 years in the future.
- 12 percent to future naval capabilities: This category, which he also called "acquisition enablers," refers to evolutionary or component improvements expected to occur in three to five years.
- 8 percent to quick-reaction science and technology: These are fleet-driven (i.e., generated by Navy personnel) solutions that can be achieved in one to two years.

He elaborated on the kinds of technologies assigned to each category. Quick reaction research is aimed at solving specific practical problems described by users within the fleet. ONR deliberately reaches out to sailors and marines, asking for input. A typical problem is one that cannot be solved by existing technology, but might require as much as a year's worth of research costing about $1 million. An example has been to revise lighting systems to reduce the glare and noise from overhead lights in submarines. The ONR was able to

reduce both annoyances by replacing fluorescent lighting with silent, less harsh LEDs.

The program to develop future naval capabilities (three to five years) is "the pot of money where we squeeze every bit of risk out that we can." He called it "the engine that takes the basic science and turns it into the stuff people want." The military is good at finding out what warfighters need, he said, and the ONR's job is to match the need with the available basic science, and to develop that science to the point of utility. "We have an elaborate framework to accomplish technology transition agreements," he said.

The projects under the category of innovative naval prototypes are the technologies that "sailor or marines don't know they need yet, but the best science can produce." For example, the ONR can see that in order to sustain its technological leadership, it will have to develop complex new systems, such as directed energy,[30] ship-borne laser weapons, tactical satellites, electromagnetic railguns,[31] and persistent littoral undersea surveillance. Such high-risk, high-payoff programs may cost hundreds of millions of dollars over five years and require the involvement of department leadership.

For basic research, he said, activities are not directed, "but clearly we guess there might be a military use in the future." This program is basically an investment in people, he said, and is diverse and long-term. Topics being supported by ONR include graphene, electronic warfare, advanced GPS research, spintronics, arctic research, weather modeling, and laser cooling. Investments in this category involve extensive high-level discussions on broader levels of military strategy.

When the Defense Authorization Act of 2001 allocated S&T funding authority to the three categories of research, innovation, and transition, it also brought the directors and staffs together under one roof. This, in the opinion of Dr. Fall, has created a uniquely integrated decision structure that is far more effective than a traditional silo-oriented structure. At ONR, a program officer is well-versed not only in one of the three phases of R&D, but in all three phases. That is, each program officer overseas the development of a program through its basic research (6.1), applied research (6.2), and advanced development (6.3) phases, with all oversight done in the same building. In the other services, he noted, program officers for each phase tend to be different people located in different locations.

The R&D investments of the ONR are distributed among naval labs and centers, universities, and private industry firms. The proportion of these investments varies by type of research. For 6.1 projects, 62 percent of funding goes to universities, 31 percent to naval labs and centers, and 7 percent to

[30]Directed energy refers to the use of aimed energy, without a projectile, as a weapon or other application, such as a high energy laser and high power microwave. *<http://www.deps.org/index.html>*.

[31]An EM railgun, according to the ONR website, is a long-range weapon that fires projectiles using electricity instead of chemical propellants. *<http://www.onr.navy.mil/Media-Center/Fact-Sheets/Electromagnetic-Railgun.aspx>*.

industry. For 6.2 projects, 47 percent of funding goes to industry, 30 percent to naval labs and centers, and 23 percent to universities. For 6.3 projects, 65 percent goes to industry, 21 percent to naval labs, and 14 percent to universities.

The ONR presence in Washington, DC is modest, consisting of only the headquarters and program staff. It connects with a widely-placed network of naval labs and their corporate R&D centers that are associated with acquisition. The ONR funds part of that R&D work. It is unusual in spending considerable funding in its presence abroad, which includes 25 PhD-level scientists whose job is to understand new technology trends internationally. It supports R&D programs in 70 countries, all 50 states, 1,078 companies (including 859 small businesses), 1,035 universities, and nonprofits. ONR, together with its sister DOD international agencies, are among the few federal agencies that can fund abroad. It also spends about $8 million a year on STEM education, from the high school level to programs for young researchers.

In conclusion, he said that the features of the ONR, which few people have heard of, constitute a model worthy to be emulated at the national scale. While responsible for the Navy's applied and translational needs, it fights to retain its core basic research, "the seed corn for innovation. We fight off people who want to change our budget and get rid of the basic research in order to buy weapons today. We understand the importance of both, but we also maintain an independence." The office must struggle to do that, he emphasized, given the constraints of any federal program, including Federal Acquisition Rules, the DoD 5000 process flow chart, Office of Personnel Management rules, and other bureaucracy. "With all those constraints," he said, "it still looks and functions a lot like the best of corporate innovation frameworks. Our corporate labs, special basic research, and funding structure are balanced between what we want to do now and what we want to do later. And all of that is set up in a reasonable risk profile. We believe that it works for us, and can work for others."

ADVANCING INNOVATION AND CONVERGENCE IN CANCER RESEARCH

Jerry S. H. Lee
Center for Strategic Scientific Initiatives
National Cancer Institute
National Institutes of Health

Dr. Lee proposed an innovative approach to research on one of the most intractable research challenges—discovering cures for cancer—and demonstrated that even the largest federal agencies can have the flexibility to experiment with unusual strategies.

The need to innovate in this case, he said, was apparent because of three stark realities. First, cancer continues to be heavy disease burden in the United States. About half a million Americans died of cancer in 2011, and some

1.6 million will be diagnosed with the disease in 2012. In 2010, cancer care cost Americans $124.6 billion.

Second, there is virtually no saving therapy for disseminated or metastasized cancers, which cause more than 90 percent of cancer deaths. "As the disease begins to spread," he said, "no matter where it starts, the data shows your ultimate outcome grows dismally worse the farther the disease spreads."

Third, there has been virtually no change in this reality in the four decades since the "war on cancer" was proclaimed by President Nixon.[32] In fact, unlike other major disease killers, cancer continues to take nearly the same toll it did in 1950. For heart diseases, the death rate per 100,000 Americans has dropped from 586.8 to 203.1; for cerebrovascular diseases, it has dropped from 180.7 to 44; and for pneumonia and influenza it has dropped from 48.1 to 18.5. For cancer, the rate has barely changed, declining from 193.9 to 186.2. The cancer health burden is also global; the rate of cancer mortality worldwide is estimated to reach 10 million per year by 2020, with an incidence of 16 million cases per year. Almost every area of the world has suffered a 50 percent increase in cancer deaths since 2002.[33]

It is difficult to blame this slow progress on a lack of knowledge. In fact, new knowledge is accumulating at an unprecedented rate. Just a decade ago, the world was abuzz when scientists succeeded in identifying all the approximately 20,000-25,000 genes in human DNA, and determining the sequences of the 3 billion chemical base pairs that make up human DNA. Today researchers are launching programs to examine many thousands of genomes.

"It's not that we aren't generating enough knowledge in this area," said Dr. Lee. "But we have to ask whether this additional knowledge is yielding more solutions for patients." He noted that at present it takes 10 to 15 years to develop a new drug, and the cost of doing so has increased exponentially from 1990 to 2006 to $1.8 billion.[34] Over the same period, total industry R&D expenses for drug discovery and development have risen from less than half a billion dollars to more than $35 billion. The results of this increase in spending have brought no more drug approvals today than there were around 1980.

"This is not sustainable," he said. "In 2009 we were able to get approval for only 24 new molecular entities through the FDA; and of those only 17 were considered brand-new. That is very disheartening. Likewise, the situation with biomarkers is even more dismal, with 1.5 biomarkers being approved per year from thousands of samples."[35]

Researchers in different sectors have debated whether too many papers are being published by public-sector research institutions, but Dr. Lee doubts that this is the cause of the problem. Over the last 40 years, 153 FDA approvals

[32]The National Cancer Act of 1971 is generally viewed as the beginning of the war on cancer, although the term "war" did not appear in the legislation.
[33]IACR, WHO.
[34]Paul et al, *Nature Rev Drug Discovery*, March 2010.
[35]Leigh Anderson, *Clin Chem*, 2010.

were done on drugs that were started in public sector research institutions, he said, or about 9.3 percent of all approvals. "If you just look at the priority review, 20 percent of those were done by public sector research institutions, and virtually all important, innovative vaccines introduced in the last 25 years have been created by PSRIs. So that level of innovation does exist in this sector. The question is how to accelerate it."

The current paradigm for drug creation, which Dr. Lee called "turning the crank," has been used for many years. It begins with gene studies and moves through target identification and validation, drug creation, and finally three stages of clinical trials—the "traditional costly and slow route of drug development." The challenge, he said, was how to break out of this cycle.

Dr. Lee is experimenting with one possible way. "We reached out to the community 10 years ago and asked for their key needs as researchers," he said. "What we got back was a little surprising. First, everybody wanted standards and protocols. They also wanted real-time, public release of data. They wanted large, multidisciplinary teams and a pilot-friendly team environment to share failures as well as successes with each other. Finally, they wanted team members who themselves have trans-disciplinary training. We thought all of these would be difficult at the time, especially public release of data. We felt that if we were able to meet just a few of these needs we would have the potential of transforming how we do drug discovery and diagnostics for cancer."

This idea was greeted with enthusiasm by Dr. Anna Barker, former deputy director, and continues to be embraced by Dr. Douglas Lowy, the current deputy director of NCI, who "took all of those bullet points and put them right into our mission. He said we absolutely needed to build programs that had broad deployment of data and tools for everyone in order to empower the entire cancer research continuum—not just basic science or treatment or diagnosis or prevention."

At the NCI, Dr. Lee's Center for Strategic Scientific Initiatives (CSSI) was just one piece of the $18 billion National Cancer Program, budgeted at a mere $145 million. Nonetheless, the CSSI began its bold plan in 2003. It began with a "Technology Dashboard" called IMAT, or Innovative Molecular Analysis Technologies, announcing to the research world that the program would have two pieces:

- Innovative Technologies for Molecular Analysis of Cancer, for which proof-of-concept technologies and projects were encouraged, and were driven by milestone and technology development, without biological content;
- Application of Emerging Technologies for Cancer Research, including validation and dissemination of platforms, and demonstration of impact on basic and clinical research.

"We said, Come with your best ideas. Many people still don't believe us when we tell them we want new technology-driven ideas with minimal biology. What we got in 2003 were some of the 'same old-same old,' but then we also were surprised to find a lot of genomic platforms, some proteomics platforms, and some nanotechnology platforms in the innovation space, and an overwhelming amount of genomics platforms in that emerging technologies space. So we responded to the scientific community and took the "easy" path to go after each one of these systematically."

The first program was to examine how many types of genomics platforms were being studied, and the different reasons people thought cancer was a disease of the genes. They did not try to pick the winner, but let the proposers compete head to head, as in engineering. "I'm a chemical engineer by training," he said, "so we thought of this as a means to generate an analog of a 'steam table' for cancer. To do so, we needed to catalog all the genomic changes using orthogonal platforms with the same patient sample, repeat this on 10-fold more samples than was previously being done in the literature, and finally do this for not just one but for as many cancers as possible. Most important we took seriously that bullet point of making the data public quickly."

They quickly launched The Cancer Genome Atlas (TCGA) for three pilot diseases—brain, lung, and ovarian cancer. They funded genome sequencing and characterization centers to not only generate all the data, but also data coordinating centers to quality control the data and to analyze the data orthogonally.

By 2008, the TCGA program released its first reference cancer genome of glio-blastoma for public use. It was published under one author, the Cancer Genome Atlas Network, which listed more than 300 authors. It was described as a "comprehensive genomic characterization that defines human glioblastoma genes and core pathways."

"We found," he said, "despite everybody's disbelief, a couple of genes no one had ever associated with brain cancer." This energized the scientific community, many of them not funded by CSSI, to use this reference genome, like a chemical engineer would use a steam table, to find additional signatures. In 2009, a group using the reference data found that response to aggressive therapy differs by subtype, which allowed new ways to exclude patients who were unlikely to respond to the drug. In 2010, another group identified a new subset of GBM that occurs in younger patients and brought evidence of better prediction of outcomes.

He then showed a figure he generated using data he downloaded from The Cancer Genome Atlas, which he described as his genomic steam table across diseases, and encouraged conference participants to try downloading the data. The picture depicted rows, each of which represented one patient, and columns, each of which represented one of the 23 human chromosomes. "This shows not only how cancer truly is a different disease, depending on the patient," he said, "but also how lucky we were that we started with glioblastoma in being able to find a reproducible signature."

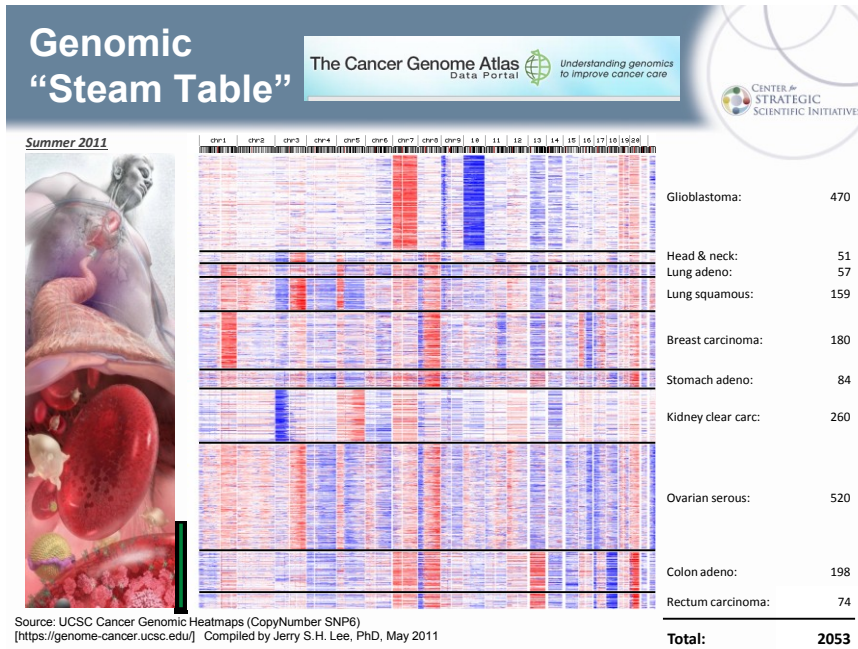

FIGURE 1 Genomic "Steam Table" (Summer 2011).
SOURCE: Jerry S. H. Lee, Presentation at June 28-29, 2012, National Academies Symposium, "Building the Illinois Innovation Economy."

He noted that the figure used only data available through the summer of 2011, representing approximately 2000 patients. He then showed an updated figure that now captured data till February 2012, where an additional 2000 patients were added and reflected the rapid pace of the project. "The ease of obtaining this data is providing the equalizer for everybody to innovate together," he said. "Those who are not able to afford to do this type of characterization can still benefit from using the data."

Dr. Lee then reminded everyone that while impressive, this data can only benefit the patient if it is translated into clinical interventions. As such, he said that the first follow-up to the genome program was the Cancer Target Discovery and Development Network (CTD2) which accelerates the translation of patient genomic data into clinical application. "The pilot phase was possible using stimulus funds in 2009 to launch a network to computationally mine large-scale genomic data to identify new therapeutic target candidates and to subsequently confirm novel modulators, such as small molecules and siRNAs," he said. Models, reagents, analysis tools, and data from this network continue to be shared with the scientific community with the goal of finding and testing new clinical interventions.

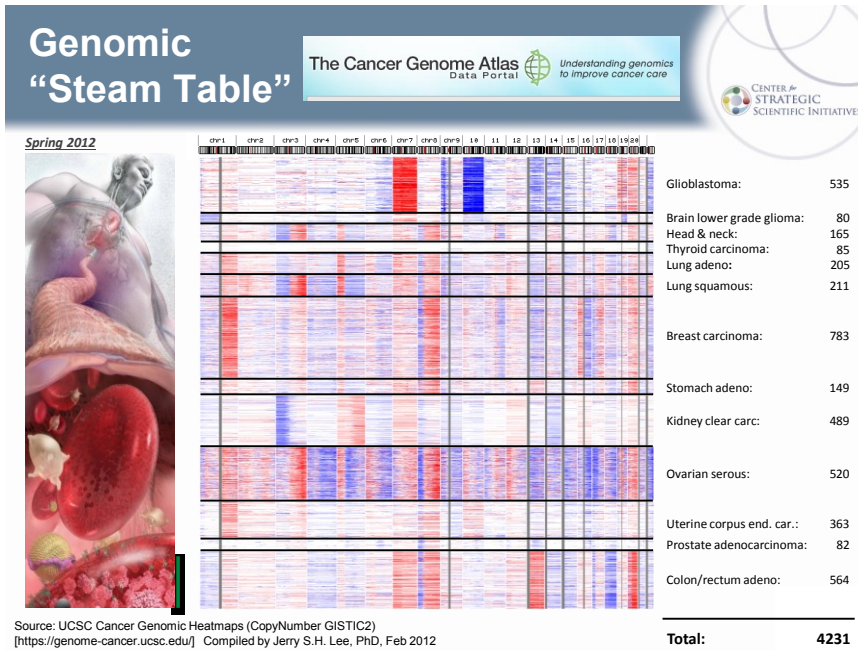

FIGURE 2 Genomic "Steam Table" (Spring 2012).
SOURCE: Jerry S. H. Lee, Presentation at June 28-29, 2012, National Academies Symposium, "Building the Illinois Innovation Economy."

The second follow-up is the Clinical Proteomic Tumor Analysis Centers (CPTAC) program. As not all genomic aberrations are reflected as proteins, the purpose of the program is to identify the modified proteins using the same samples characterized by the TCGA program. This program was launched in September 2011 with some samples already been processed. Data from this network will be shared at opening of a public data portal in summer 2012.

Dr. Lee then noted that through programs such as TCGA and CPTAC, we began to understand more about the molecular aspects of cancer and recognized that perhaps the best interventions would occur at the micro/nanoscales. Fortunately, a pilot program to push nanotechnology into clinical studies had been launched by CSSI in early 2005. "Amid much skepticism," he said, "we believed that nanotechnology could be used in the clinic, not just for basic life sciences." He noted that Dr. Mirkin and others agreed, and helped persuade then NCI external scientific advisors that this was possible. This effort has now entered its second phase, he said, which builds upon more than five clinical trials launched in the first phase, and would be even more clinically focused. "Already we have more than a dozen nano-enabled diagnostic therapy and imaging trials in this network."

He returned to the topic of data, and the challenge of interpreting and understanding the large new flows generated by the various CSSI program. "Who is going to interpret and understand it all?" he asked. To tackle this, CSSI began a bold move of inviting participation of scientists outside of the cancer fields for whom large data sets are a familiar part of their own work. These included physicists, engineers, mathematicians, computer scientists and other quantitative scientists to look at the data with a different perspective and offer their own ideas of what causes cancer and how they thought the disease works.

"Physical scientists have very different ways of interpreting the data," he said. "We gave them the difficult charge not to do just better science, but paradigm shifting science. We asked them to build new fields of study based on their perspective of how the disease works. We want them to build trans-disciplinary teams and infrastructure to better understand and control cancer through the convergence of physical sciences and cancer biology." He then noted that Dr. Nagahara would be describing this Physical Sciences-Oncology Centers (PS-OC) program in further detail the next day.

Seeing many of the unique programs launched by CSSI, he said that when the new NCI Director Dr. Harold Varmus began in 2010, suggested that the Center implement a new project that has become known as the "NCI's Provocative Questions (PQ)." Dr. Varmus wanted to challenge the scientific community to think about important but non-obvious questions in cancer research. "He asked: how can we get some of the people who have really good ideas to come and talk to us." The "PQ" project is now underway, through workshops, the web site, and other inputs. The first round has elicited proposals from many countries, and Dr. Lee said he hoped to announce awardees shortly.

He closed with some reflections about the progress of CSSI. "I don't think we can actually generate innovation," he said. "It just happens. We're still trying to figure out how you actually talk about innovation across sectors without comparing apples to oranges." He discussed the uncertain passage from creativity to feasibility, the journey of an idea from the pilot stage ("This won't work") to early stage ("Will this work?") to mid-stage ("This might work") to last stage ("This works!"). Many researchers bring a new idea to the NIH for funding, he said, and each time, they face an "innovation funnel" that looks like the mouth of a shark. "Every time the investigator clears the funding hurdle, and moves through the funnel to the next level, they have to run the same gauntlet, perhaps less prepared than they were before. How do we retain the ones who want to give up not because their idea was weak, but because they were not prepared to go through that next stage?" After they clear the innovation funnel, he said, they face the final headache of the clinical trial, where the chances of success are low. "Trying to keep them moving forward with a smaller and smaller carrot is difficult—even though many of our investigators are actually outperforming our expectations. How do we capture that beyond just counting publications and patents? Have we now started to subject initiatives to a "tenure track" mentality and reward quantity of output versus the innovation of the output?"

DISCUSSION

Dr. Mirkin commented that the programs developed by CSSI are truly innovative, and are "beginning to pay off." He described a "fundamental flaw in the way funding is done across the agencies." In all the start-up companies he had worked in, he said, the time and effort spent in writing and rewriting proposals proved to have little if any value by the time the project was finished. Similarly, research centers have to run an equivalent gauntlet, such as proving the value of a diagnostic or therapeutic candidate, only to find that after clinical trials, "the funding just stops and you face a different group now and there is no connection between the two. Unless we close those gaps it's hard to imagine progress." He asked whether there was a strategy within NCI to adopt a model that more closely resembled that of DARPA, which was "We want to see you at the next level fast, here is a check." They can't do that currently, nor can the SBIR program or other agencies do this. "The timeline is way too long."

Dr. Lee said that at the upcoming NCI retreat a topic on the agenda was how to push initiatives from concept to funding projects as fast "as we want to." He noted that CSSI has already set the bar high, where the PS-OC program was conceived and funded all within one year, something that had never been done before. "An issue for us is to accelerate the funding between the gaps, and not the development of the programs themselves," he said.

Dr. Peterson said that the i-Corps uses this model of rapid funding. "If you look at the process for identifying those areas that have developed good ideas for basic research investments, i-Corps does just what you say. It operates on a quarterly basis, so that the typical time from identifying a potential project and giving a decision on a grant is a matter of weeks. The review is done by the program officer, and often the contact is made by the program officer as well. He already knows about the work so far, and asks the applicant whether this is something you want to pursue. It's an important experiment. The challenge is doing it at large scale, because we may be accused of picking winners and not having the classical review process."

Mr. Taylor said he was left with the impression that the landscape is changing in government. The term innovation was not used 20 years ago, nor 10 years ago. Each agency is trying to be more efficient in using public funds. He said he applauded agencies in their ongoing efforts. "It takes inputs from people like you to nudge agencies in the right direction."

Dr. Roberson followed up on Dr. Mirkin's point on the importance of timing. "Some deals move very fast. Some require a large amount of money, some a small amount. What is the best vetting process to determine that what you're doing will actually have impact?"

Dr. Fall added that part of the problem is that the federal government "is incredibly risk-averse. It's hard to get people to accept the possibility of failure, and fund things with the intention of squeezing the risk out. And it isn't enough to have a process that makes sense. It has to allow you to accomplish the goal in the right time frame."

Cmdr. Stuart Walker, a naval reserve officer, asked how well the restructuring of the translational layer of ONR was proceeding. Dr. Fall answered that it created an "ongoing tension" among the three directors who must compete for their share of the R&D budget, including the basic research director "who is there to protect the seed corn." He added that the tension "works very well" and was an interesting model that was being copied by others. "I don't think we ask often enough the basic question of how to structure an agency for optimal efficacy, like ours or NCI's CSSI."

A questioner asked whether during these austere times agencies were able to achieve savings through collaboration and leveraging their respective resources. Dr. Peterson agreed that many agencies described challenges in trying to work together, but that he had found the opposite for NSF. "All the really good collaborations happen where the action is. That is at the program officer level, where people are specifically looking for partnerships, such as groups at NCI, DOE, and ONR." He cautioned, however, that he sometimes "almost has to be careful about describing all the great collaborations" because of potential criticism from those who misunderstand collaboration as duplication. "With well-designed collaboration," he said, "both agencies benefit from using complementary resources."

Panel III

Illinois Innovation Initiatives

Moderator:
William Testa
Federal Reserve Bank of Chicago

Dr. Testa introduced himself as director of Midwestern research at the Federal Reserve Bank of Chicago, where he works to analyze the Midwest economy, "including its technologies and initiatives." He said that after 30 years of studying the Midwest, he sees today that many regions "are trying to re-establish their entrepreneurial DNA." He sees places such as Detroit, northwest Ohio, and others "trying to find what they lost, and the innovative impulse behind what they had done in constructing the Midwest."

In comparing these initiatives, he said, he sees that Chicago and Illinois have at least two of the three assets. One is its entrepreneurial bent, which had never been lost to mass production as it had been elsewhere. Chicago had always been the business capital, and had never been a one-industry town dependent on mass production. It continued to support new firms, business services, and finance, as well as manufacturing. Also, it had always been a place of immigrants, who "self-select—they bring that impulse to innovate, they have to build new businesses. Those that have come from afar tend to be the most ambitious, he said. Chicago is located far from both the South and East. "We have that impulse and capacity to build technology transfer and new industries," he said.

"But from the literature," he continued, "what we know about Chicago is that there is a yawning gap between our capacity and what we produce in new startups and businesses. In the last decade, we were in the top eight cities in NIH funding, but we had very few biotech startups. "What we lack," Dr. Testa said, "is the programs, the institutional capacity, the coming together from both bottom up and top down to translate and put technology into commercialization."

He welcomed the panel, and asked each member to address these issues and the task of "building an innovation culture and making science exciting to the people of Chicago."

INSPIRING INNOVATION

Julio Ottino
McCormick School of Engineering and Applied Science
Northwestern University

Dr. Ottino said he would talk about the role of the university as an element of the complex innovation ecosystem "and how we see our contribution." Universities are only one part of this ecosystem, he said, intertwined with high-tech employers, venture capital, government, and a foundation of intellectual protection. But because "talent is the critical element of the ecosystem," and part of the university's mission is to nurture this talent, the responsibility of the university is high. In the case of Northwestern, he said, as with Stanford, Princeton, and other top universities, retention is not a problem, and the universities have the opportunity to do their best for students. "About 94 percent of the students who start with us finish with us," he said.

The McCormick School, established just over a century ago in 1909, has a budget of $98 million, supporting 182 full-time faculty, 95 adjunct lecturers, 196 staff, about 1600 undergraduates, 820 PhD students, 300 postdocs, 300 departmental masters, and 400 professional masters. The research budget is about $125 million a year.[36] The school is large and complex, he said, but "at the core" it produces two things: ideas and people. The ideas, he said, can be papers, intellectual property, tangible innovations, or even a style of thinking. Deciding what kind of talent the school should produce is not so simple, he said. "For this we need to read the future. I often say, life is like driving in an impenetrable fog; in front we can only see five feet away, but in the rear view mirror, everything is perfectly clear. We prepare for the future by focusing on the development of our students' thinking skills that will serve them for the long haul."

In engineering, he said, the foundation of education is analytical skills—logical, left-brain thinking; rational, analytic, pattern seeking; solution solving; sorting and organizing. The people who come to the school, he said, do a good job of self-selection, "and we can pick the best."

Analytical skills are essential for problem solving, he went on, but "there is no big prize for correctly solving what turns out to be the incorrect problem." In order to truly educate the engineers who are the best prepared to deal with the challenges ahead, "we need to instill an additional skill: divergent,

[36]The engineering school was named in 1989 after Robert R. McCormick, owner of the Chicago *Tribune* and descendent of Cyrus McCormick, co-inventor of the mechanical reaper and founder of the company that became International Harvester in 1902. The McCormick Foundation and other members of the family also helped support Northwestern's schools of journalism and law.

right-brain thinking, which includes metaphorical thinking and intuition. This skill allows us to frame problems and connect them to the big picture, not to just randomly and instantly solve them as they come to us. In short, innovation requires both sides of the brain, and people who are not afraid of anything. If there is something to be learned, they will learn it. If there is something to be learned, they will learn it. We want people to have that breadth."

The goal, he went on, is to produce leaders who thrive at the intersection between disciplines, between theory and application, and between global problems and the knowledge needed to solve them. The innovation landscape consists of many pieces, and the challenge is to learn how they can fit. This landscape is like a city, and this is good, because it mimics reality. Cities can be chaotic, and maybe inefficient, but they are stable. You can bomb a city and it will be reborn.

"Cities also change over time," he continued. "It's tough to predict, for example, where the arty neighborhoods will emerge in a city. But cities are also magnets for creativity, innovation, and economic output. They are organized, and organization correlates with wealth. More than half of the world population now lives in cities, generating about 80 percent of global output."

He said that innovation happens in many ways: one is structured, the other is unstructured. At McCormick, the most structured approach is offered through the Farley Center for Entrepreneurship and Innovation in a course called NUvention; Medical Innovation, launched in 2007. The format combines students from McCormick, the law school, the Kellogg School of Management, and the Feinberg School of Medicine. The students pool their knowledge and insights with the objective of producing new medical devices. "They have been extremely successful," said Dr. Ottino, "and this week, one of the teams won the tech week launch competition." That course has been joined by similar programs focusing on web, energy, social entrepreneurship, and digital media."

The second route to innovation, he said, is design, which is less structured. McCormick students encounter design and design thinking from the first week they arrive. They are put into teams where they learn to solve problems. "But what they learn to uncover is the main issue behind the perceived problem. When you are 18 or 19 your brain is plastic; it is open to new ways of thinking. These skills stay with people and they carry them through their career. This is different from the typical engineering curriculum, where design is only encountered at the end."

He mentioned also Design for America, a group started at McCormick three years ago to use design for social impact. It has quickly spread through Northwestern and now has chapters at Cornell, Stanford, Brown, Dartmouth, UCLA, the University of Oregon, and other universities. Several students have established their own companies based on Design for America projects, including two working in the Health Box incubator in Chicago.

He said that like many of the government officials in attendance, University administrators are the recipients of lots of free advice. One area of advice is often about customization of degrees, allowing the student to take only

courses they like. "A fitting analogy," he said, "is music. In the past, you had to buy CDs, but now you can buy singles from iTunes. A CD is like a four-year degree, which may include songs you don't like. The single is the future. Why buy songs you don't like? This approach depends on viewing the student as customers, which they are, but the university is one of the few businesses in which the customer is also the product.

"The university is one of the few businesses in which the customer is also the product. The entire value of the university resides in the people that the university has produced. My entire reputation depends on the supply of people who are out there still alive doing great things. That's why the university is so slow to change things. Students may be forced to take courses they don't like, and they don't have the perspective to understand why. However, it is the finished individual that counts. An album of collected singles has value only in the context of the whole album. Using the same music analogy, a composed album beats a set of disconnected singles. Hopefully the people here get an integrated experience along with their education.

"The second class of advice is what I call attacking the obvious, the future that is five feet in front of you. This is connecting education to immediate needs. Some universities offer specialized degrees in supply-chain management or specific aspects of solar power to solve real-world problems. But preparing to solve real-world problems presupposes we know what they are going to be. The reality is that we see only what's just ahead, right in front of us. Every generation misses the real problems right in front of their noses because they are looking only in the rear-view mirror. Why do we think we are different and that we can read the future?

"This approach resembles the specialized degrees given in the Soviet Union about gear making," he said. "Or degrees on making CD-ROMs without wondering how useful that would be in the year 2040. The value of engineering is not in what one makes; what one makes will change with time. The real value is the way engineers think. They should think for the long haul. We should prepare people for the future that we cannot see. It's true that we need to hedge our bets, to focus engineering education on the quantitative stuff, which is non-negotiable. But adding humanities, for example, also seems like a good bet, as is adding anything to the right side of the brain."

In conclusion, he speculated on Chicago's advantage in the competition for talented people. "Talent is a competitive advantage. It attracts capital, but more important, it attracts additional talent, and people want to work where the best talent is. New York City offers the features of finance and the arts; San Francisco offers digital consumer technology, Boston biotechnology, LA lifestyle, San Diego telecom, Minneapolis medical devices, and so on. Chicago could offer logistics, transportation, energy, nanotech, architecture, music. But if we integrate a lot of this we find design. No one has claimed the title of design capital yet. Operating at the intersection of so many fields should be our advantage. My job is to produce the kind of talent that can join domains, operate at the intersection, and drive innovation."

ENGAGING THE PUBLIC IN SUPPORT OF SCIENCE AND TECHNOLOGY

David Mosena
Chicago Museum of Science and Industry

Dr. Mosena said that he would take a different angle on innovation to describe what the museum does to inspire the children who would go into Dr. Ottino's program by making science exciting to them. He said he would also focus on nanoscience as a new field that he was now ready to take to the public at large.

At the museum, he said, "we do a lot of work talking to moms. They are important because most of our visitors are families with middle school children, and the person who makes most of the decisions about what they do on the weekends is the mom. So we talk to them about what drives them, and why they come to the museum." Their number one concern, he said, is "the future," and their kids' education. They are worried about their children's jobs and about preparing them for tomorrow.

"They all tell us to 'do more about the future'. They say, we all know we desperately need to build a stronger work force in science and technology if we want to remain the world leader in innovation. The museum's vision is important. It filters our choices of things to do so that our children can achieve their full potential in fields of science and technology, medicine, and engineering."

Today's sixth graders, he said, are going to be entering the work force and voting in 10 years. So middle schoolers are in the early stage of the pipeline. The museum's responsibility—even in a city the size of Chicago—is a large one. It is number one in total attendance among the museums in Chicago. The Shedd Aquarium is slightly ahead in the number of organized school groups. The museum teaches 20,000 children who attend in-depth learning labs every year, and 5,000 who attend after-school activities. There are 70 science clubs. An important statistics about the public's awareness of the museum, he said, is that one-half of the attendees are adults without children.

A year and a half ago the museum completed a $200 million capital campaign, and as a result, 85 percent of the museum's exhibit space is new or renovated. It includes new exhibits, refreshed exhibits, and an enriched education program called the Institute of Quality Science Teaching. "We teach science teachers—especially in middle school—how to teach science. About 70 percent of the middle-school science teachers in Chicago have no background in science. It's hard to be inspiring if you're not comfortable in the subject matter." Over the last five years some 8,500 teachers have attended the museums programs. About 500 have taken coursework in a masters-level science education program offered in partnership with the Illinois Institute of Technology. One result is that 25 percent of the Chicago Public School

System's K-8 schools now have teachers of science who have been trained in a museum program.

Nanoscale science, which has the slogan "Scale changes what's possible," connects the public with the extensive nanotechnology activities in the Chicago area. Because Chicago and Illinois are a hub for nano-activity, he said, every aspect of STEM education is influenced.

"The museum is building a beautiful exhibit, which will be the first permanent nanotechnology exhibit in any museum," he said. The museum has worked with Northwestern University and other organizations to design the $2.5 million program. "Scale is the issue," he said, "because scale changes what's possible. A key message is to get guests thinking about 'small'—how tiny nanoscience really is. These interactive exhibits demonstrate what unique things can happen at the nanoscale and what game-changing innovations are possible in the fields of medicine, energy, electronics, materials, and the environment. Finally, we're going to showcase the work that's going on here, the people involved in it, and the work going on in the institutions here in Chicago and Illinois."

DRIVING ENTREPRENEURSHIP IN ILLINOIS

Robert Wolcott
Kellogg School of Management
Northwestern University

Dr. Wolcott, who said that his ancestors arrived in Illinois in 1812, and that he had arrived at Northwestern as a student in 1987, praised several previous speakers for taking a long view of what it means to be a university, a museum, a federal agency, a company, and the responsibilities these institutions have to society. He said he would examine the state of entrepreneurship in Illinois, and its place in both large and small companies.

On the basis of his own experience, he predicted strong opportunity for Illinois in entrepreneurship. "We'll never be Silicon Valley, but it seems that everyone here finally understands that. We need to find our own way," he said, but he cited encouraging signs that the Chicago region was gathering critical entrepreneurial abilities and building its own kind of innovation ecosystem.

He began by disputing the popular notion that only small companies were truly entrepreneurial. "We have a lot of big companies here," he said, "and it is true that they don't take the risks we would love them to. There is some support for the belief that big companies are not innovative enough. But I will propose to you that no small entrepreneur could bring a Boeing 787 Dreamliner to market."

Big companies hold all the cards when it comes to commercializing a new product, he said. When new entrepreneurs start out, they have "absolutely nothing." They might have brilliant technology, and they may have some friends who can help. But compared to Boeing, he said, or to Kraft, "they have

nothing." He asked how many in the audience had been independent entrepreneurs, and the few who responded said they had been "lonely" and "scared" when they set out on their path. He thanked the respondents, and added that the path to entrepreneurship is "a fabulous path, but entrepreneurs can't do everything alone." It requires encouraging the local culture, an innovation ecosystem, mentors, and communities of people committed to entrepreneurial activity.

When one starts out as an entrepreneur, he said, or even thinks about the possibility, power comes from seeing other people nearby who have done the same thing and are interested in supporting you. In the earliest stages, he said, this support can be even more important than capital.

"When I first started out," he said, "I was doing my PhD program in industrial engineering at Northwestern and I got into a start-up. We were able to raise a little over a million dollars, which we spent on a bunch of exciting stuff. We were getting some momentum when the technology economy collapsed in 2000. We even kept things moving until September 11, 2001. Then we knew it was over."

He told of going to two parties just after the air went out of the dot.com balloon. The first one was in San Francisco, with friends from undergraduate days at Northwestern. He recalled people's lively interest in what he was doing, questions about his experience, and eagerness to connect him with other entrepreneurs in Silicon Valley who might be involved in similar technologies.

At the second party, in Chicago, he found the usual conversation about sports, real estate, and banking. When someone asked what he was doing, he said he was an entrepreneur. A questioner asked how big his company was, and when he said he had just started his company, and the times were difficult, the questions ceased and the conversation returned to real estate. "I knew what was in their minds: 'He's between jobs'."

"I am pleased to say that this is starting to change in Chicago," he continued, citing the importance of 1871, the public-private incubator space recently opened by state and industry sponsors. "Everybody has a presence in 1871," he said. "It's not just an incubator. The old incubator model was, give him a copier, he can share a copier. And let's protect him from the antibodies of the world and hope that he'll grow. Insulating a young chick from the dangerous environment is a good insight, but problems come when insulation becomes isolation. I'm seeing the development of an ecosystem now that is becoming more vital and connected. And 1871 is a great example."

He turned to the importance of networks, which he considers vital for those who hope to become entrepreneurs. Students, in particular, need contact with experienced business people - colleagues who can give the new entrepreneur guidance, open doors, and lend credibility. "When you're brand-new and no one has heard of you," he said, "it's hard to get a mentor, much less capital. Finding a mentor often happens by serendipity, but it begins with a network."

Another encouraging sign, he said, was that more potential entrepreneurs are choosing to stay in Chicago. The traditional route to entrepreneurial success, he said, was to leave and find support elsewhere. Today many people are working hard to create an environment where entrepreneurs can meet mentors, partners, and investors.

Finally, he said, change is emerging "at ground level where things actually happen." He called this the notion of community. "This is different than an ecosystem, which is the world of attorneys, entrepreneurs, technologists, university, and government. It is the places where people actually connect with an affinity and a level of trust. When you're new to things, you make mistakes. You need spaces where people feel comfortable to try an idea, to explore, to find their mission, and make things happen. I see an important role for larger communities, especially for universities and government, because they can act as convenors. A university is a neutral platform with spaces where people can come together. I think that is one of the most important missions we have, to help people connect with others in the community, find their mission, and then achieve it."

He said that one important achievement of the Kellogg School of Management has been to create the Kellogg Innovation Network (<*http://www.kinglobal.org*>). The KIN, he said, was based on the desire to include more "real-world" perspective for the school. That is, while Kellogg researchers had long examined business functions from an academic vantage, this complementary model taps the expertise of people who actually run businesses. "We're in the middle of research on this now," he said. "We are seeing that successful innovation communities tend to be good at three things: education, so the people in the community improve their skills; economic development, which includes a reasonable fiscal and regulatory climate; and just as important, a supportive emotional climate where people can find that safe space, find their mission, and believe they can achieve it."

He added that the number of such innovation communities has been increasing, with 1871 and the KIN as examples. Traditionally, universities hold study sessions on entrepreneurship and economic development, but they are only beginning to understand the need for convening the people who create ongoing community. "We're starting to see this happen around the globe," he concluded. "We are moving into a more complex and rewarding world with diverse innovation ecosystems, networks of mentors connected to those who are new, and the ability to envision in our state a community where people together can make innovation happen."

DISRUPTIVE ENVIRONMENTS THAT SEED DISCOVERY AND PROMOTE TRANSLATION

Thomas O'Halloran
Chemistry of Life Processes Institute
Northwestern University

Dr. O'Halloran said that the Chemistry of Life Processes Institute, "a new type of entrepreneurial center," was intended to "break down the silos that typically separate many classic academic disciplines."[37] This impulse is part of Northwestern's "genetic code," he said; that is, it was not "an emergency intervention," but "something we did so well that we needed to take our game to the next level." In particular, the goal was to "find ways to bring in new students as they're learning chemistry or engineering, to have them see how to integrate these subjects by watching others do it, and to help them start companies by participating in team research."

The institute promotes new types of discovery and helps translational advances, especially in the biomedical sector. "One of the first things I did as director," he said, "was to bring in an entrepreneur-in-residence, Andrew Mazar, as a member of the faculty. The purpose was to have someone you can go to and say, I've got a result, I've got a patent: what do I do next? Making those connections are so critical in each stage of the rapid development of a company, whether the task is to apply for a SBIR, or even just to sit down and chat about how to start a company."

He said that another critical element of the institute is that the director of operations, Sheila Judge, has a PhD in biochemistry and is able to work directly with faculty to put together team-based science grants and facilitate connections between areas as diverse as materials science, endocrinology, and synthetic chemistry. "All those people need each other," he said, "but don't necessarily speak the same language."

Much of the impetus to build the institute, he said, came from former Provost Lawrence Dumas, who worked hard to encouraged interdisciplinary research and build a better environment for students to begin new types of companies. "The infrastructure and raw material of science and discovery are abundant across the Chicago region," he said. "We have every kind of powerful tool and multiple sites of leading edge research, such as Argonne National Labs, multiple research hospitals, leading companies in drug development, and prominent research universities. In spite of those assets, we just haven't seen enough companies starting here." The Chemistry of Life Process is both an

[37]According to the CLP's website, "The Institute's role in promoting scientific discovery is shaped by the fundamental recognition that established institutional boundaries must be transcended to produce transformative scientific advances. … the CLP fosters collaborative research at the interface of the chemical, physical, engineering, and life sciences. <*http://www.clp.northwestern.edu/*>.

institute, a common playground for many disciplines, and an effort to lower the hurdles in getting scientists to work across their chosen disciplines.

"We have lowered that barrier without creating a new department of interdisciplinary anything," he continued. "We house a host of centers: it's both a nanotechnology building, and a biology building; it fosters any type of interdisciplinary research involving molecules and cells."

He described the building, which was occupied in 2009, as designed so that faculty from different disciplines work together on every floor. Their laboratories open into one another in an open design structure, and the environment itself is designed to optimize the "collisions" between programs. "In traditional science and engineering universities," he said, "professors close the door and they crank out discipline-specific studies. in this institute the doors are open and there is more flux across boundaries."

Leading scientists were recruited to the CLP to head efforts in proteomics, synthetic chemistry, molecular imaging, synthetic biology, materials science, and other overlapping specialties. "We are working at many levels to stimulate new types of partnerships and facilitate the recruitment of entrepreneurial faculty, particularly ones who have a talent at directing research teams to go where no one has gone before in experimental science."

He described a joint grant proposal the CLP created when Dr. Lee's program at the National Cancer Institute reached out to the physical sciences community, including mathematicians, modelers, and engineers, to invite a new perspective to the study of cancer. "This mechanism," he said, "led by a clinician and myself, is bringing new types of thinkers into cancer research and educating the next generation of cancer researchers regardless of their parent discipline. We've built a collaborative network around the country, including Caltech, and with the Weizmann Institute in Israel. The grant mechanism supports pilot projects for new investigators in addition to 47 people already involved in the center."

He mentioned two companies that have already emerged from CLP labs:

- A biomedical engineer, Phil Messersmith, has founded a company based on the adhesive qualities of the byssal threads (or beard) used by mussels to cling to intertidal rocks or other substrate. Because of their strength and biodegradability, these threads are candidates for many applications.
- Dr. O'Halloran started Viamet Pharmaceuticals with his colleague Holden Thorp, chancellor of the University of North Carolina at Chapel Hill. It now has two Phase I compounds he hopes to use against prostate cancer and as an antifungal—both as an agricultural commodity, to protect crops, and also as a direct treatment for humans who have fungal infections.

Although Dr. O'Halloran and Dr. Messersmith attempted to interest venture capital firms in Chicago in both of these companies, the investors they found were in North Carolina and in Madison, Wisconsin, where the companies are now operating. He said that a variety of additional companies had also formed at the CLP, and new start-ups were in the process of formation.

He created one of these new start-ups with a former student in his laboratory, "which is exactly the kind of thing we were hoping to stimulate. This exposes the student to the research, lets him go out into the world, and then come back and work either here or elsewhere. This company has been sold and its product will be tested on patients in Europe in the fall." Dr. Tom Meade, CLP member and founder of OhmX Corporation, provides another example of how this institute stimulates translation of basic science results into innovative new companies. OhmX is a bioelectronic detection company developing protein-specific monitoring devices to be used in the point-of-care (POC) setting. A CLP Board member led the investment team that ultimately funded OhmX up as an Evanston, IL based startup company.

THE BENCH TO BEDSIDE STORY OF ONCOFERTILITY

Teresa Woodruff
Northwestern University

Dr. Woodruff began with a description of the "epidemic of obesity and diabetes" which in Illinois has generated a "disproportionately unhealthy population." She also said that "silent killers," including infectious diseases, "put us on a par with many developing nations," and that patients suffer an uneven distribution of care. At the same time, she said, "we have a tremendous potential to think through these problems and put in place heath care management programs for women and men living in our state."

Beyond these better-known handicaps, she said, is a less familiar health problem that stems from significant differences in health factors and overall biology between the male and female sexes. "My work," she said, "starts with the hypothesis that advances in medicine in the 21st century requires a fundamental knowledge of sex differences that exist at the molecular, cellular, and physiological levels."

She said that certain gender disparities have been well known for years, including different kinds of presentation in atherosclerosis and cardiovascular disease. "This meant that for decades women disproportionately died from CV disease because diagnostic imaging didn't see the kinds of small vessels that exist in women and don't exist in men." Again, in hip joint replacement, she said, most procedures in the United States have been done using the prototype of the male hip. This meant that women faced a disproportionate amount of pain and failure because the anatomy of those replacement parts was not correct for them.

"Historically," she said, "the research community has assumed that beyond the reproductive act there aren't many gender-based differences, but in fact there are, and they are relevant." An example of relevance is the traditional barring of women from clinical studies. In part, this exclusion was driven by the possibility of pregnancy, which led to the wholesale exclusion of women until about 1993. At that point, Congress began to recognize the fact that the health of women was being jeopardized because they were not included in studies.

Many people argue that looking at gender differences for each disease would be too expensive, and that the menstrual cycle adds complexity and error to the data. In fact, she said, it would cost less to examine the gender differences early in clinical development than examining them later—when it was discovered that half the population does not respond to a particular drug, for example. She said that despite a mandate set in 2004 that principal investigators on NIH grants address the issue of inclusion, 64 percent of studies still do not report any outcome by sex. "So we're still missing the boat on these indices. We also have a problem at the basic science level in that animal research is not reported by sex differences."

To address these disparities, Dr. Woodruff and others started an initiative five years ago and developed a platform of activities, including education, advocacy, and seed funding for studies. She told the story of one surgeon who studies peripheral vascular disease (PVD). "I asked her how she could address PVD with both male and female animals, and she told me she didn't study female animals. I convinced her to take one of our first seed grants to study the same drug that had clinical approval and was used every day in PVD. She soon came into my office and told me the drug was not effective on female animals, only on males. She went on to study it in humans, and found the same result—that the drug was effective for only half the population." The objective of her initiative, she said, is to ensure that the next generation of women is not disproportionately disadvantaged because most of the clinical trials on treatment efficacy are done only on male animals.

Her group also started the Illinois Women's Health Registry, a database of self-reported information on all women 18 years old and above. The goal of the registry, which now has more than 6,500 participants, is to include women in all studies, not just studies of women's issues. Clinicians used to object that women would not take the time to appear for studies, she said, "but we've found that this is not the case. Women will volunteer for these studies."

The basic conclusion, she said, was that "biological differences between men and women affect health, illness, and disease treatment across the life span. If we can understand those differences, we can improve the health of all people."

Her group had also thought about the economics of this new view," which is how Washington sees things. We've found that the study of sex-based biology is a cost-effective way to increase quality and reduce overall health-care cost." If women were routinely included in the clinical trial of a drug, she said, researchers could determine early if the drug has adverse effects on women—

rather than taking it all the way to approval with only male subjects and later discovering the effects on women. "As we move toward personalized medicine," she said, "we have to cut the population at least in half in order to better tailor and understand our medicine."

From a personal point of view, she said, "a lot of what women's health is all about is having a baby and waiting until you get breast cancer. I grew up during the '80s and early '90s, and I can tell you that women's health was all about breast disease." And yet, she said, the common drug TPA (tissue plasminogen activator) was never tested on women. In one test in 1991, it was tested on 50,000 men and no women. "We have to get to a point where that does not happen." To do this, she said, a major effort is to educate scientists and clinicians, try to catalogue all the evidence-based disparities, and calculate the losses in human health if it is not done correctly.

One particular area of importance, she said, is fertility management for young cancer patients who are still of child-bearing age. "There are more and more life-preserving treatments for cancer patients," she said. "These include aggressive use of targeted radiation, broad chemotherapies, and extensive use of surgery. Each of these can be life-preserving, but can also harm fertility."

Her current focus on oncology and fertility began in 2004, when the NIH supported a grant mechanism for Interdisciplinary Research Consortia intended to invite solutions for the most intractable problems. She was studying follicles in human ovaries at the time, trying to understand how the follicles and their tissues "make the decision to ovulate." In other words, she said, she wanted to know what restrains most follicles during the years between puberty and menopause, and what stimulates the ovulation of a few follicles so that fertility is available every month.

"I was working on that question," she recalled, "and working at a cancer center where I saw large numbers of young women who had been sterilized by cancer treatment." She found that many of the cancer doctors and many of the patients were not focused on the question of fertility, especially for young women who were not married. "This did not compute for me," she said. At the time, she said, fertility options for men were available,[38] but young women with equal chance of survival had no options, and the physicians were not talking to the oncologists about this. "They were saying, that's not us; that's cancer."

There were three gaps, she concluded: "an information gap, a data gap, and an options gap. So we created consortium to solve this problem using large teams. We also coined the term oncofertility, which happened on Christmas Eve with my family, because we agreed that those two words—oncology and fertility—belong together in one word, not separated even by a hyphen." Thus was born the Oncofertility Consortium, based at Northwestern, which has the

[38]She cited a booklet authored by Lance Armstrong on testicular cancer entitled "Families After Cancer: A Discussion with Cancer Survivors and Fertility Experts."

motto "....exploring and expanding options for the reproductive future of cancer survivors."

She described some of the activities run by the consortium, and some of the products developed over the last five years. "Five and six years ago," she said, her voice choked by emotion, "no one was given these options. We're making a difference. We have a national hotline. We've started a national physicians' cooperative to help people and educate them. We're actually making life better for men as well, because good health for anyone is good for the health of all of us."

DISCUSSION

Dr. Mirkin applauded the progress made to date by the Oncofertility Consortium, and by other members of the panel, and asked the panelists for their opinions on what else could be done to "really move the needle with respect to innovation."

Dr. Wolcott replied: "ecosystems, communities, and networks. There are lots of ways to do that, but if we build more of these collaborative systems, in addition to promoting interdisciplinary work and mobilizing capital, we're going to see more commercialization over time."

Dr. Mirkin rephrased his question, asking for what is missing in the current structure—"beyond those things that are constantly thrown out there. I would say, we have this great business school and we have this great technology operation, and it was a long time before there was interaction. That wasn't because they didn't like one another; they just did things differently, and there wasn't a strong connection. It seems to me that a program that forces those relationships and interactions would be a significant advance."

Dr. Wolcott said he agreed, but observed that in the last few years he had seen significant progress of this kind. He praised Dr. Ottino for taking a leading role, and said he was starting to see more active engagement between institutions. "When institutions are paying for conferences and interdisciplinary programs, it suggests that these programs are generating value." He said that he and Dr. Michael Lippitz, his collaborator on the Innovation Communities research, had counted the formation of more than 35 new groups worldwide in the past few years ."So we're seeing emergent models, and some are generating outcomes, such as commercialization and business deals."

Dr. Ottino said he would like to propose "more convening" and "less comparing." He said that he had been in Dallas recently, and "they showed me how proud they were of their architecture, as though they had more architecture than Chicago. He said that Chicago should stop comparing itself to the East, or the West. "I hear it in every talk," he said. "It's like we have a second-rate mentality. There is so much potential if we just bring together the elements we already have, that are loosely connected now, and avoid the comparisons. I would put a sign at the entrance of every conference saying that it is forbidden to make reference to any other part of the country."

Dr. Woodruff offered "a practical suggestion," triggered by her experience at NIH, when it was attempting to connect its own institutes. It ran an experimental program with different parts of the grant funded by NCI, NIH, and five other institutes. "Those kinds of links within NIH are harder than a link between Kellogg and McCormick," she said. A problem was many scientific organizations pushed back against that mechanism, fearing that big science would take over from RO1-level science. In fact, she said, the program offered many types of grants, most of which were RO1s, and "the ordinary researchers connected in ways we wouldn't have had otherwise. Eight research groups had tangible outcomes by working together. It was very broad, and allowed us to reach clinicians in practice. Our metric was not papers published, but lives changed. The outcomes tell the story. More of this kind of linked science is going to make a difference—not where you do it, but in ways that bring in clinicians or health economists or others. Still, five years afterward, we have strong metrics of success."

Dr. O'Halloran agreed with the value of community—not to get rid of established disciplines, but to facilitate translation. He emphasized that this would require better coordination at the state level. He noted that state government in Texas would invest $10 million in a startup. "It could be transformative to have university-based gap funding, as well as state-based funding. Something we have to do in partnership with the business school is to build a culture that brings in a few venture firms."

Dr. Wessner said that while the federal government is providing some funding for start-ups, in graduated stages, more has to come from the universities and the state. He asked about the role of foundations in Chicago, which had received little mention during the conference. In Cleveland, Pittsburgh, and other places, he said, foundations are important in filling gaps between state and federal programs. He also asked how successful the 1871 incubator had been.

Dr. Wolcott said that 1871 had opened only two months earlier and programs were already under way, with emphasis on community, capital, and startup companies, including those seeking start-up funding. "There's no way to know whether it's going to be successful, but given what I've seen, I feel good about it."

Dr. Ottino said that entrepreneurship and interdisciplinary leadership now "have to be part of the discussion" for engineers, which was not true 10 years ago. "We need a critical mass of these people," he said, "over the next two to three years."

Dr. Wolcott cautioned against expecting universities to change too rapidly, given their long history and conservative traditions. When the first universities were founded in the Middle Ages, their primary purpose was to review the revealed knowledge of religious texts. They gradually began to add Greek and Roman culture, based primarily on the rediscovered works of Aristotle and others, adding the training of lawyers to their mission. Not until several hundred years later did they begin to create new knowledge, and only in

the 18th and 1th century did the pursuit of scientific knowledge truly displace the handed-down truths of theology in priority. After that, the mission of public service was added to teaching and research, but not until the past decade were universities expected to add yet another responsibility—that of commercializing the results of their own research.

"There are great challenges in doing this," said Dr. Wolcott. "Because of the way markets work, it is not easy, and university people have not been trained to think this way. Nonetheless, it is the direction that universities worldwide are moving."

Michael Kasen, a graduate student at the University of Illinois at Urbana-Champaign, said that despite the good collaboration of the chemistry and materials science departments in his studies on lithium-ion batteries, he "had no idea what is going on in the electrical engineering department that has to do with batteries." He said that research on the control systems that moderate charging and other studies were relevant to his work. "I could be more proactive," he said, "and go to more seminars. But for students it's easy to get tunnel vision. The idea of getting from the fundamental work to something bigger, like commercialization, can be a challenge; most PhD students don't usually get those experiences. Having programs with multiple departments and even universities would create more participation and a broader view. One way is to encourage conversations, maybe a gathering once a week for grad students and faculty, to get people talking."

Dr. Ottino agreed that in his department he advises students in different disciplines and sends about 20 PhDs to a nine-day course where the topic is cross-linking. He proposed that because value is added through interdisciplinary work, universities would profit by hiring a full-time member to find and fund faculty who do the best interdisciplinary research. This broader structure, he added, must be accompanies by an adjustment of student funding to allow graduate students to shift their "laser focus" on one research topic to broader exposure to related topics.

Harry Gilman of Northwestern endorsed the idea of "once-a-week parties." He also elaborated on the role of universities with respect to building innovation capacity. University endowments, he said, are invested in "intergenerational equity." They invest not for the present but for the future. "They don't see that some of the endowment ought to be invested in the raw materials for innovation, but they should, because that is the future. That would be a major policy change for a university, but it ought to be one of the criteria that the government uses to support research. That would make a massive difference in allowing the university to create raw materials for innovation and advancing them toward the marketplace. It's a big change, but someone ought to start the ball rolling. NU could certainly do it because of its large endowment and the quality of its programs."

A representative of Northern Illinois University proposed the idea that "the Midwest has a culture." He made a distinction between the "primary culture" that had been discussed by many, including such institutions as

universities, centers, and incubators, and "secondary culture," which are less formal, including weekly parties, the governor's broadband initiative, coaching on how to get SBIR awards, and the rich environment of foundations that could further support innovation. The significance of the secondary culture, he said, was that it can help move an innovation culture faster than it might naturally move. "I saw this along the Route 128 belt 20 years ago," he said, "where there was a lot of that secondary infrastructure building. I think direct attention should be paid to this."

Dr. O'Halloran said that this was the third time foundations had been mentioned "at critical points." There are already some templates in Chicago for foundation involvement, he said, such as the $50 million investment by the Searle Funds into the Chicago Biomedical Consortium (CBC) over a 10-year period. This organization has provided vital links between major Chicago-area research institutions, leveraged a number of major new team-science grant awards, provided common research assets, and stimulated a variety of scientific meetings and poster sessions. "This is a beginning, and will just scratch the surface of the Chicago philanthropic community. It's time for that to happen."

Dr. Testa closed the panel by suggesting that in place of a general call for funding, the innovation ecosystem could best benefit from a prioritized list of what needs to be done, along with the organizational changes required. This might include not only an agenda, but also ways to create new innovation communities, sub-communities, and "super-communities." "Some of this is brick-by-brick work," he said. "You couldn't write a single check for this and have it be effective. Some clearly are shovel-ready projects that could be very productive in your university and Chicago region. But many require leadership, organization, and the communities that so many of us have discussed."

DAY 2

Welcome and Introduction

Julio Ottino
McCormick School of Engineering and Applied Science
Northwestern University

Dr. Ottino introduced the keynote speaker of the second day, Norbert Riedel of Baxter International, which is headquartered in nearby Deerfield, Illinois. He is deeply involved in leadership roles at Northwestern, serving as an adjunct professor of medicine at the Feinberg School of Medicine and a member of the advisory boards of both the McCormick School of Engineering & Applied Science and the Kellogg School of Management's Center for Biotechnology. He was recently appointed by Governor Quinn to the newly-formed Illinois Innovation Council and, in the spirit of community, has helped developed an alliance within Northwestern between the medical and engineering schools.

Keynote Address

Norbert Riedel
Baxter International

Dr. Riedel expressed his pleasure at being able to discuss innovation, innovation clusters, and an innovation ecosystem with the conference attendees. "Of course," he began, "I do it in the context of asking why innovation is such a strong focus here, and why we need to stay focused on innovation. The obvious answer is because our society, like our global economy, depends on innovation to drive industry's economic progress and also to provide solutions to other large challenges," including provision of healthcare, food security, drinking water, clean energy sources, and others.

"I don't believe those challenges can be addressed without making sure innovation is in the forefront of everything we do," he said. "For Illinois in particular, we must as a community do a much better job in creating industries that are technology-based, create high-paying jobs, and make us more visible on the map of an ecosystem."

"When I ask in particular what it is that creates and defines an ecosystem," he said, "I think it is important to recognize the parts of the value chain that lead from discovery of a concept all the way to the commercialization of that concept. I believe that in our ecosystem there are players involved early in the process, who help advance technology toward the marketplace, and then others who help it reach the marketplace through interdependencies and a value chain where everybody has a well-defined role. That, in my view, is part of what we are trying to do and what we have to a large extent done here in Illinois."

At a recent meeting, he said, he asked himself what it takes to create innovation hubs and truly substantive networks, and why five or six years ago Illinois had yet to develop them. "I now believe," he said, "that we have what it takes, and that we have created an ecosystem that in 2006, 2007, and 2008 did not exist." The challenge for today is to drive more critical mass into that ecosystem, he said, but he finds himself less often asking what is missing in Illinois.

How has this happened so quickly? First was the "obvious correlation between innovation on one hand and highly skilled and trained individuals on

the other." This was the responsibility primarily of academic centers of excellence, he said, of which there are many in Chicago and Illinois. "Whether you measure excellence by the number of degrees we give in the life sciences and engineering, by the amount of intellectual property being filed, by the inventions that come from our academic centers, I think it is fair to say that we stand out—not only within the United States, but at a global level." He praised also the clinical centers of excellence in Illinois' "fantastic" medical schools. "We conduct hundreds of clinical trials annually, not just for Illinois-based companies but for global companies that seek clinical studies in our centers of excellence."

Despite this excellence, he said, the extent to which Illinois and Chicago is a hub for large healthcare companies is largely unrecognized. "I believe we are the largest hub of healthcare/pharma in the country by now," he said, "especially with the downsizing that has occurred on the East Coast and certainly in comparison to the West Coast, where the strength is primarily in biotech. With Abbott, Baxter, and others, we have a large number of companies headquartered here where they have been for decades. This local ecosystem is a critical element in driving innovation to commercialization."

He also cited "unusually successful partnerships with the state and the city government." He said that the Department of Commerce and Economic Opportunity had worked with the industry to locate the Annual International Convention of the Biotechnology Industry Organization, or iBIO, in Chicago in 2006 and 2010, and to repeat as host in 2013 and 2016. "I think this is an important element in creating visibility and transparency," he said.

He described both local alliances, including partnership with i-BIO and "a community spirit that is very important in building this infrastructure." This was reflected in the new facilities in Skokie, Illinois Institute of Technology, the Illinois Medical District, and the University of Illinois Technology Park, which "for the most part, are filling up to capacity. This clearly shows that we are building jobs, companies, and a technology-based industry. The industry has first-class IP law firms, and a relatively large number of start-ups and new companies. "Just five or six years ago we would have selected them by name because we only had a handful. Now we have many, and the growing numbers clearly show that we are building an infrastructure here and an economy here that is technology based."

Technology transfer is improving steadily, he said, as university offices become more adept at interfacing with industry and creating transparency to the vast portfolios of intellectual property. INVO, the Innovation and New Venture Organization at Northwestern, is not only a tech transfer office but "really an organizational framework that recognizes and finds innovation and spins that innovation into new startups." There is also more venture money in the region, he said, beginning to provide essential funding for young firms. Baxter was part of a new $200 million fund started the year before, which joins the funds of Abbott and several others totaling more than $500 million available for equity investments. "We support these funds not only because we have a strong interest

in helping to build an economy here," he said, "but also for the selfish reason that if I have a partnership with universities or new enterprises, proximity matters. Proximity is vitally important for the vital alignment between a small company and a large company, as it is for interaction and personal partnerships."

He emphasized one point, he said, because of his European background and his frequent traveling. That is, the United States has a unique ability to form close partnerships between academic centers of excellence and industry. "We have so much fluidity, because we meet so often through joint appointments, academic visits to our labs, and students working in our labs. I believe we need to nurture this unique ability. I see it as a genuine competitive advantage to most of the world."

INVO, the Innovation and New Venture Organization of Northwestern, has about 30 companies in its portfolio, representing about 300 jobs and more than $200 million in successful fundraising. "This is another clear sign that the system is working and actually delivering," he said.

He turned to the Illinois Innovation Council, created by Governor Quinn, and said that its primary focus is to showcase the innovation excellence of Illinois in both academia and industry—not only in health care, but across agricultural, industrial and other applications of technology. "This is brought about by a combination of our great location as a transportation hub, the efficiency of O'Hare, and the beauty of the Midwest. A big opportunity is to make sure that when we travel around the world, we act as ambassadors for the state of Illinois and educate others about what we have," he said. "Other people are surprised to learn how much we have here."

The second priority of the Innovation Council, he said, is to create jobs—"well-paying jobs that can sustain an economy." The third priority is to improve education. "When I look around the United States, but also when I travel the world, it is deeply concerning to me how far we are behind in STEM education. This is without any question the vital line between our remaining innovative or not. I'm also concerned that many students who receive the best education in the world here go back home to compete with us head to head. We need to find new ways of retaining them and ensuring that they contribute to our country and our goals here in this state."

The reason behind his emphasis on education, he said, is its fundamental importance to sustainability. "We are doing a number of things as a company, such as iBIO, and in collaboration with the state and city governments to make sure we provide enough funding for Chicago public schools, create opportunities for students to learn about science, have basic equipment in the labs, and make sure the teachers are capable of teaching science at every level. This is what we need if students are to be prepared and enthusiastic about entering STEM educational paths."

He offered examples from the iBIO educational program, which has provided more than 500 teachers with a degree of professional development, problem-based learning, and the ability to teach science. It has also initiated a science investigation database where students can look up career opportunities

and industry data both in science and related fields. "It provides them with a much-needed understanding of what these industries look like and what they can accomplish. Another program provides after-school science teaching for girls."

He summarized his talk by saying that "over the last few years we have done a pretty impressive job in building an ecosystem here in Illinois that is technology based." He attributed this in large part to a new spirit of community among academic centers of excellence, industry, small and large companies, and also the governments of state and city. "We all understand better what it takes to do this," he said, "and do it well. It is a matter of driving it and improving it to create more and more opportunities for us to become what I believe we can become, namely a technology hub in the country that can easily measure itself against the East Coast and the West Coast.

"What I think speaks for us in particular is technology applications across healthcare, agriculture, and industrial applications, for which we are particularly well suited. What we need to pay attention to, as I mentioned, is transparency and making innovation more visible, and being willing to talk more about it outside of Chicago and the state. We also need an even stronger effort in advancing STEM education, because otherwise what we are doing cannot be sustained.

"I am very optimistic, and I am also cautious. I don't want to become too confident with what we have accomplished. But as the industry representative at the symposium here, I think we can look back and say we have begun to build the ecosystem. So let's continue to build it, make it larger with respect to the jobs it creates, make it better known with respect to opportunities it creates, and move innovative solutions to the marketplace."

DISCUSSION

Cmdr. Walker of the U. S. Naval Reserve asked whether the venture capital money available in Illinois had increased or decreased. Dr. Riedel said he was quite involved with a large network of VC firms, and said that funding of very early-stage discoveries is difficult to find. For later-stage developments it is easier "and continues to be very achievable." He said that many companies have managed to attract funding in Illinois rather than the old custom of moving to the East Coast or West Coast to catch the attention of VC firms. He said that in the cases of very early-stage development, corporate venture funds have an important role. "The Baxter fund I mentioned is comfortable investing early on, when technology is spun out for the very first time, so we are trying to bridge the valley of death gap that needs to occur. I am concerned about using the easy excuse of being unable to create technology-based companies simply because there is not enough venture money. When there is good technology, you can be certain there will be venture people who recognize that and invest in it. I am very, very confident of that."

Dr. O'Halloran said that Dr. Riedel had painted a "fabulous portrait" of recent progress. He said that a key asset still not being unlocked in the Chicago

region are the academic discoveries, which are "almost by definition" those in need of early-stage venture funding. He asked Dr. Riedel what percentage of the new Baxter fund will be aimed at early stage, and where could similar small, well-targeted funds be created.

Dr. Riedel emphasized the importance of transparency for the portfolio of innovations within the universities. "That is why I mentioned INVO, because traditionally it is hard for someone like me to know what you have that I could tap into. I think INVO is doing a great job making the pipeline of innovation more visible and accessible. Once I recognize an innovation that I like, I have multiple mechanisms for investing. We have partnerships with Northwestern and the University of Illinois where we put seed funding into laboratories. The goal is not to influence the research but only to support research we recognize to be attractive. When that research matures, Illinois Ventures[39] can be the obvious next vehicle to help to spin it out. I think it is more about the mechanisms of doing it than about the funding itself. I cannot imagine that we would be limited by resources if indeed we have a recognizable, logical path. I will always be as critical of research here as I would be of research anywhere, because I consider innovation to be independent of location, but if I can get it here, I want to stay here because of the importance of proximity."

A questioner asked whether the venture community might direct more of their funding toward early-stage research. Dr. Riedel said that the venture funds he knew were most interested in syndicate investing after the proof of principle or pre-clinical work had been done. "I think they expect corporate strategic funds to take on that early financing responsibility. I don't think their investors have the patience to wait the 10-plus years for returns."

Dr. Wessner asked whether the size of corporate funding programs was large enough to meet the needs of early-stage firms. Dr. Riedel said he thought it was. He said that a typical start-up might need about $1 to $5 million initially, in which case the $200 million Baxter corporate fund would be able to engage in "quite a few equity investments on an annual basis, and that's just speaking for one company. I think the critical phase of enabling technology to go from an academic lab into a startup is a very modest investment, and yet it brings validation that can attract more funding. In our environment, where large companies are desperate to acquire technologies and products, you will find more acquisitions and partnering early on. So I don't think the venture money per se is insufficient."

[39]Illinois Ventures is a seed and early stage technology investment firm with a focus on Midwest universities and federal laboratories. <*http://www.illinoisventures.com*>.

Panel IV

Innovation in Illinois: A Regional Case Study

Moderator:
Daniel Biss
Representative, 17th District
State of Illinois

Mr. Biss introduced himself as a state representative for the state of Illinois. He said that regional innovation was "pretty much my favorite topic," and said that his introduction would be very brief in deference to the distinguished panelists to follow. He introduced Robert Easter, President Designate of the University of Illinois, Eric Isaacs of Argonne National Laboratory, David Miller of iBIO, and Dan Berglund of the State Science and Technology Institute.

THE ROLE OF ILLINOIS UNIVERSITIES

Robert Easter
University of Illinois

Dr. Easter thanked Representative Biss for his efforts in the legislature not only to advance innovation in science in Illinois, but also to resolve some very difficult issues around pension reform, which is "critical to the future success of our public universities," and other issues.

He said that he had a vision that perhaps 20 or 30 years from now, someone would write a case study titled "Innovation in Illinois: A Regional Case Study." It would be a study of success, and of how a region came together to advance the economic well-being of the entire region and state. Illinois has invested enormously in both public and private universities, he said, and they have built considerable reputations for their world-class research and educational programs. He said he was proud that the University of Illinois is one of only about 60 members of the American Association of Universities (AAU),

a century-old organization that supports about 60 percent of the federally funded research of all universities. He said the university owed much of its own reputation to the quality of its science, as well as to the quality of the students it attracts, "and I do take pleasure as I travel around the world when I see technologies that I realize came from a lab at the University of Illinois or another Illinois institution. I believe we have much to bring to the conversation about innovation, and how innovation can lead the development of a state's economy."

He said that the word innovation is an interesting one because it describes not only a discovery or intention, but a technology that been developed to the point where it has value to humanity. "I'm glad the word innovation is being used in proper context today, because I think it's what we have to do to translate discovery science into products that have value."

He said that the past week had been a good one, because he had spent the first three days of it in Washington to celebrate the 150th anniversary of the passage of the Morrill Act, passed by Congress in 1862. The Act granted federally owned land to each of the states. The land could then be sold and the proceeds from the sales used to build public universities. One mandate for these universities was to educate the "industrial classes." "In other words," he said, "there was a realization that America was emerging as an industrial society, and needed to go beyond educating the elite to include all the potential intellectual capacity of the nation." The Congress saw that education could allow the sons and daughters of all classes to make contributions to the growing nation—to build railroads, factories, and the technologies involved in factories.

"And as the nation industrialized," he said, "there was a great need to liberate people from subsistence-level farming by increasing the efficiencies of agriculture and allowing more people work in the factories that became the powerhouses of the industrial revolution. It was a great success story."

Much of this success in the Midwest, he said, could be attributed to innovations developed between the 1860s, when the great land grant universities were established, and the mid-1900s, when the nation began to industrialize. "Now once again the nation is looking to both the public and private universities across the landscape to foster economic development, and I think that's a reasonable expectation. We can provide the training that creates the kind of workforce needed. We can provide mentorship for small business and especially for our students who aspire to become entrepreneurs." He recommended a recent report by the National Academies that assessed the status of research universities in the United States.[40] "It begins with the thesis that innovation is the driver of economic development, and that innovation is very often the result of basic research. But research doesn't get done without public funding, which has been an American tradition since the 1940s."

[40]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.

With World War II, he said, the federal government discovered the power of universities to do research. And some of the basic science behind the Manhattan Project was generated "just down the road" at the University of Chicago. "As a consequence of that," he said, "after WWII, as we went through the Cold War, the nation invested very heavily in research, and at some point during the 1960s was spending more than 2 percent of our GDP on federally funded research in the labs around the United States. We landed the Apollo spacecraft on the moon as a consequence of that, and generated many technologies. "One could argue that science-based innovations led to economic growth and opportunity for our nation. But with the end of the Cold War, that priority declined, and since the fall of the Berlin Wall, our investment as a nation has been modest—around 1 percent of GDP."

By contrast, he said, other nations are investing even more in innovation. China, Taiwan, South Korea and others are increasing their research investments about 10 percent each year, and those investments are yielding "technologies and concepts that are world class." He said that his university had been invited a decade ago to build a relationship with Singapore, and "we were impressed by the way that nation has organized its priorities around economic development. They create opportunity not only for their business sector but for employment of their citizens in very high-quality jobs. That is driven by innovation and development of new technologies."

A major shift over the past several decades, he said, has been the change in research portfolios in both the private and public sectors. In the 1950s, roughly 70 percent of U.S. investment in research came from federally funded projects and 30 percent came from the private sector. "Today that situation has reversed. What's does that mean?" He said we should learn from our heritage, by which we learned we were capable of commercializing research and maintaining global competitiveness. We did this through a formula developed more than 100 years ago: providing a public education for Americans, gaining access to all the intellectual capacity that exists within our society, continually modernizing our infrastructure, and keeping our doors open to immigrants. He urged continued investment in research and maintenance of a regulatory environment that allows the private economy to grow dynamically and nimbly.

He described several recent efforts, which he called "Sputnik moments," at the University of Illinois. He reminded his audience that Mosaic, a technology that underlies the world-wide web and gave rise to Netscape, was developed at the University of Illinois. In the 1990s, when Mosaic emerged, the university had a limited capacity to capture technology or to foster its development toward the market place. Therefore that technology went to the West Coast, as many other technologies have done. The leadership of the university realized that something had to change. They created research, infrastructure, and facilities on each campus to support state-of-the-art science, with the state being a very significant partner. The university also established a venture fund to enable faculty to move their technology, secure licensing, and create a new company. A research park was built on the campus in Urbana in the

late 1990s which in 2011 was named the outstanding research park in the United States. "We have done quite a lot," he concluded." We have ambitions to do quite a bit more."

One ambition he has for the university is to create closer partnerships between university and industry. He said that as an agriculturalist, he has been particularly interested in how other countries bring academia and agriculture together. "I've been especially envious of the Dutch. It seems that whenever I go to a developing country and visit a farming operation, I see a Dutch scientist there and just behind him is a Dutch businessman with an order book. The connection between the technology, the transfer of technology, and then the commercial opportunities is very close and strategic. We can learn some lessons from that."

He also highlighted three partnerships developed at the university in recent years. One grew out of a half-billion-dollar international competition held by BP about six years ago to establish an energy bio-sciences institute. The prize is shared by the University of Illinois, the University of California at Berkeley, and Lawrence Berkeley National Laboratory to support some 70 research programs over a decade, the world's largest project of its kind.[41] "The challenge for us," he said, "is to ensure that some of that value will stay in a commercial form in the state of Illinois, within our region. In addition, within the past year the university has signed a large agreement with Abbott Laboratories to study the nutrition of neo-natal infants. "This makes use of our capacity not only in biological sciences, but also in engineering sciences and our capacity to use imaging technologies to measure changes in the brain." Finally, he said, a major initiative has begun with funding by the Department of Energy to explore carbon sequestration, performed jointly with ADM, adjacent to the ADM headquarters in Decatur. "Through these aggressive efforts to capture research grants," he said, "we've increased our research budget by nearly 50 percent in the past decade to nearly $1 billion. Our ambition is to continue this growth, and we continue to look to our legacy to inform how we support discovery science, innovative technology, and the transfer of innovations into applications that have value to the region's economy."

THE FEDERAL LABORATORY CONTRIBUTION

Eric Isaacs
Argonne National Laboratory

Dr. Isaacs began by thanking Dr. Mirkin, Dr. Walsh, and the National Academies for organizing the conference—and for choosing Illinois. He said he agreed wholeheartedly with Dr. Riedel that Illinois has an excellent opportunity to be "the next great innovation hub." He listed the region's combined strengths

[41] <*http://www.energybiosciencesinstitute.org*>.

in academics, industry, transportation, a long tradition of manufacturing, and the added abilities of government laboratories.

For Argonne, he said, he wanted to echo the previous discussion about teamwork and community, "because that's how innovation gets done. In universities, and especially in places like Argonne and even in industry, the idea that the single inventor, like the image some people have of Thomas Edison, does things on his own. They have a dream, they create the thing, and all of a sudden we have a product which spreads across the globe."

He said that in some cases it is indeed true that basements or garages are great places for innovators to start. "And it is a fact that Edison himself liked to burnish this image and make the public think it was all about him. In fact, that's not true. Even Edison, at his first major lab in Menlo Park, New Jersey, had over 40 scientists working on his ideas, including the light bulb." He read a quote from Edison: "I tested no fewer than 6000 vegetable growths and ransacked the world for the most suitable filament material." That testing, said Dr. Isaacs, was not done by Edison alone in a lab, or anyone else alone. "His research was much, much more sophisticated than he would let on," he said. "We have to get beyond that image. In the end, the products that make a difference come from much larger networks of people."

Understanding this, he said, is essential to understanding what the national labs can do, which is to bring a bigger mission focus to the basic science we all do. Even the biggest of those labs, unfortunately, still romanticize a certain view of the way we design and fund science.

When we look at research challenges today, he said, American scientists and American engineers are facing problems of staggering difficulty—far beyond the capacity of individuals or even small groups. "Of course I'm going to give you the DoE perspective," he said. "Those challenges include questions of enormous complexity: how do we create a solar cell that costs something like a nickel per kilowatt hour? How do we do things like get the cost of an automobile battery down to 1 cent per mile? How do we cost-effectively capture carbon, store it for thousands of years, and ensure that it doesn't come out? These are all big-mission problems and global problems. Scientists will need to help solve them in large groups, or they won't be solved."

In the past, he said, we had many more corporate laboratories labs to help tackle such questions. A few effective corporate labs remain, such as those of Baxter, but the very large facilities of IBM, Xerox PARC, AT&T Bell Labs, and others were attuned to mission-driven science. "We don't have those anymore," he said. He said that he worked at Bell Labs for 15 years, and it was his favorite. "It was a place where we did great basic science," he recalled. "I was attracted there entirely because of that. I did fundamental magnetism, but in the end, it was mission driven; there were projects, but there was also a bigger vision. The world's top scientists were there, working on the transistor, the laser, UNIX, C language, and so on. But I do want to say that Bell Labs, great as it was, never had to be as efficient as we have to be today. Bell Labs was all under one roof. You had scientists, engineers, product units, businesses making

telephones. So even though these great investments occurred there, the dirty little secret is that it was never very efficient it getting things from the bench top to the telephone, or from the bench top to the transistor to the computer.

"In fact," he said, "today that kind of lab ecosystem is blown apart in many ways. Even Baxter has to rely on universities and outside labs. The question is, how do we put that ecosystem back together? Particularly in this country, where there's a bit of an allergy to public-private partnerships, how can we have today an innovative vision that Bell Labs used to have, in an intelligent way?"

He said he would make the argument that some places, such as Argonne, are beginning to do that. He reviewed the history of Argonne, which began in 1942 during the Manhattan Project. It grew out of the success of Chicago Pile-1, the first artificial nuclear chain reaction, supervised by Enrico Fermi in an abandoned rackets court beneath Stagg Field at the University of Chicago. After the experiment, the facility had to be moved because Hyde Park "was not the place to do experiments in nuclear energy," he said. Argonne was chosen as a safer alternative, in open fields 25 miles from the Loop. By 1946, it had become the first national lab. The goal was to "take all that energy wrapped up in a nucleus and figure out how to use it for power and for electricity. So mission-driven science was how Argonne started, and mission-driven science is what we still do." Today the lab has the world's third-fastest computer, he said, capable of eight petaflops, which is the fastest computer for non-defense science.[42] Many of the Argonne facilities, such as its advanced photon source, are used by Baxter and other private companies, and such public-private partnerships have become a more important part of the national labs' mission.

"The question to ask in the context of this ecosystem discussion," he said is, "how can we get the universities, the DoE labs like Argonne, and companies to work closer together at the very beginning." For start-up firms, he said, which will not get funding from venture capital, how can the national labs help their early development in a mission-driven environment? "How do we get discovery scientists to work with engineers and then with the industry people who ultimately have to make something and commercialize it."

He said he would try to give a sense of how the Argonne lab is "starting to move toward mission-driven fundamental science—but in a mission-driven environment." He chose the example of battery technology, which is a large effort around the world, but one area where Argonne has a key lead. He showed a phase diagram representing an interesting discovery started in a lab by "one bright scientist," Michael Thackeray, who was thinking about how he could

[42]In computing, FLOPS is an acronym for floating point operations per second. A petaFLOP is 1,000 teraFLOPS or 10^{15} FLOPS. The ranking of the world's fastest supercomputers changes often and brings brief bragging rights to the leader, which is currently the IBM Sequoia at Lawrence Livermore National Laboratory. In second place is Fujitsu's K Computer at the Advanced Institute for Computational Science in Kobe. The great speed of some U.S. computers is needed to simulate nuclear weapons tests for older weapons that have been stored in the U.S. arsenal.

store as much energy per volume of battery as possible, or how much weight he could store in a material. He ended up with a brand-new material.

"This particular material, discovered by one or two people in a lab very quickly, actually took 15 years to develop into something patentable in early 2003 and again in 2004 for use in an automobile. The reason I mention this story," he said, "is that even though the material was invented in a lab, the innovation after that invention occurred in collaboration with Northwestern, the Energy Frontier Research Center, the University of Illinois, and different kinds of companies. It started with small startups, and in this particular case, the battery material now is in the Chevy Volt. Even though it is still too expensive and too big to transform transportation, we still work on the technology.

"The next question we can ask is about the development time. Between the original invention around 1992, and when it was first placed into an automobile was 19 years. Is that too long? Can you make that 10 years? Or five years? I think the answer to this question is absolutely yes. But we're not there yet. It didn't happen in five years at Bell Labs, either, if you look at the transistor.

"But there are examples of faster development. The charge-coupled device was also invented at Bell Labs, and it took only five years to go from there to a spy satellite, and another few years to go into telescopes. Now, of course, we pull a phone out of our pocket and it's got a charge-coupled device in it. So how do we make sure innovation in the lab is tightly coupled to the ideas and companies outside the lab."

He showed a complex figure from the University of Chicago of a regional innovation ecosystem that emphasized the "idea side" or "push side" rather than the industry side. He said first that any ecosystem is complex, and no one can simply sit in a room and figure it out. "You can draw lines of connectivity, and so on," he said. "We all know that. But ecosystems are more complex than that." At Argonne and at the University of Chicago, he said, some bright scientists are studying this, and the challenge is to "link them up," and link them with early-stage funding. One of the challenges from the perspective of DoE and Argonne, he said, was to keep those scientists in the community. "We have 300 postdocs at Argonne, and they mostly go to universities or companies on the coasts if they don't stick here. How do we get this ecosystem to look appealing to our 20- and 30-somethings? It's fine that our technology is used in California, but we want to reinvigorate Illinois as well."

He suggested that this has started to happen in Chicago in the field of digital media. He gave the examples of Groupon and GrubHub, which he said "are doing an impressive job of getting kids to stick or even come here from the coasts because they're so excited about working there." He asked if the region could do the same thing in pharma, and in other areas of IT that are not digital, and in materials science and molecular engineering.

He ended on the issue of funding, and the scale of funding required by fast-growing young firms. He used the image of a lion, which require not funding but prey in order to grow and reproduce. Lions are capable of capturing

mice, one after the other. But if a lion tried to live exclusively on mice, it would eventually die; it takes more energy to capture the mice than the lion gains by eating them. A lion needs to find antelope, or buffalo to serve its needs.

Similarly, while small start-ups in Illinois can often find small grants and seed money of various kinds, they need to generate larger programs on the scale of the International Nanotechnology Network to ready themselves for antelope-scale funding. "Where we're really struggling," he said, "is with these efforts at larger scale, focused on outcomes, not just focused on blue-sky research. For the really complex technologies, like batteries, it will take the whole community of institutions working together."

EARLY-STAGE FINANCE AND SUPPORT IN ILLINOIS

David Miller
Illinois Biotechnology Industry Organization (iBIO®)

Mr. Miller said that much of the work of iBIO[43] was influenced by reports of the National Academies, including its "Gathering Storm" materials. He said the goal and mission of iBIO is help Chicago, Illinois, and the surrounding Midwest region become "one of the top biotech centers on the planet." In many ways, he added, "we already are." But because biotechnology itself is still early in its development, much of what iBIO does "is still ground-floor stuff."

iBIO functions at several levels. The "parent" organization, iBIO itself, promotes sound public policy at the local, state, and federal levels and on "improving our region's ability to create, attract, and retain businesses." PROPEL® and EDUCATE™—Centers within the iBIO Institute— "orchestrate industry involvement to help solve America's math and science education crisis."

To gain some perspective on how an industry develops, he said, he had looked up another transformative technology—electricity—to discover what had been accomplished when electricity was at a similar stage of development as biotechnology is today. He found it was comparable to when the first rudimentary electrical devices were being used—a large, ungainly ironing machine, for example. The electrical clothes washer had also been invented, but not the electrical clothes dryer. "So if you think of all the electrical products that followed, about radio, and TV, and all the computer applications that followed, that is about where we are in biotechnology. Some great medicines have been developed, and some great ecological and agronomic discoveries made in agriculture, but we're really at the ground floor here, so this is a very important mission."

[43]The mission of iBIO Institute, established in 2003 by the Illinois Biotechnology Industry Organization (iBIO), is "to orchestrate business leadership in delivery of world-class educational programs and job-creating new technology ventures." <*http://www.ibioinstitute.org/about-us.html*>.

To highlight the diversity of iBIO's activities, he described his own agenda for the previous day. He started the day with the EDUCATE program,[44] leading a group of Chicago Public School teachers in a program called Stellar Girls. "The idea is to get more girls involved in math and science in grade school, middle school, and high school," he said. "This was a group of about two dozen 'on-fire' teachers who were learning how to do problem-based learning. I told the teachers: Let's imagine that I'm standing in front of a group of funders—how would you convince them to invest in these programs? One said, This program is teaching us how to be creative and get our students really jazzed about math and science."

Then he returned to his office to write an article about important legislative victories over the previous week, including renewal of FDA programs for prescription drugs and for medical devices that were critical to iBIO's members and partners. That legislation also makes the FDA's procedures more speedy and transparent, and gives the agency better access to outside expertise. He concluded by visiting a program of Chicago Innovation Mentors that keeps helps mentees attract helpers by making the volunteer community aware of commercializable research. "So it was a very rich day and I came home all aglow."

A significant feature of iBIO's methodology, he said, is the teamwork between the public, private, and academic sectors. He said that essentially everything of value accomplished by the association and Institute had come about as a result of partnerships between and within those three sectors.

He defined biotechnology as "the use of what we know about biology to improve life on the planet." One regional feature that supports the work of iBIO is Illinois' unusual strengths in every sector of biotechnology, including strong companies and start-ups in medical, agricultural, and bioindustrial areas. The bio-industrial space is particularly healthy, he said, because the region significant resources through the entire value chain, from growing biomass all the way to the business end users of new bioindustrial products, which include fuels, chemicals, resins, and solvents.

Biotechnology itself has great importance to the region, generating some 82,000 jobs in companies engaged in producing biotech products and services. That figure does not include research at universities or federal labs. When indirect jobs are included, he said, the total employment outcome is about "1/3 of a million jobs," plus direct and indirect biotech jobs from universities and federal labs.

The problem, he said, is that although the region has always been strong in generating research, it has lacked a corresponding ability to translate that research into companies that are born, grow, and remain in Illinois. This problem has historically amounted to "a gigantic corporate giveaway to other states," he said. Before Illinois initiated the programs described earlier by Dr.

[44]The mission of iBIO Institute's EDUCATE Center is to deliver industry-led science and math programs for teachers and students. <*http://www.ibioed.org*>.

Riedel, he said, these companies used to leave not only for the coasts, but for Wisconsin, Indiana, Michigan, and others. These states, he said, thereby acquire more jobs, a good tax base, greater wealth creation, and more excitement.[45]

Another reason for the small-company exodus, he said, is that the state has historically relied on a big-company strategy. "I compare this to trying to win a baseball game by hitting only home runs—or, to make the example more dramatic, by hitting only grand-slam home runs. The findings are published in multiple studies year after year, and these findings are depressing, particularly because we're pretty good at recruiting large firms.[46] The Illinois Department of Commerce and Economic Opportunity (DCEO) and the City of Chicago's World Business Chicago, he said, "are very good, without using a lot of resources, at using all the natural advantages of the region to persuade firms to locate their expansions and their new locations here. But it's a risky strategy to count on just established companies, and what we're looking for is a more diversified economy that includes a small business strategy."

"Our view," he continued, "is that we don't need any more studies about what we need. If talking about this problem would solve it, we would have been problem-free long ago. Changing this situation is a top priority for Illinois." As a new strategy, he said, iBIO likes to be guided by a "theory of action"—and that theory is: the most important way iBIO can help is by assisting the discovery from the gleam in the eye of the researcher to a series A preferred (venture capital) round, where good management and real money can attach to it. He said that during the 1990s technology boom, many venture capital companies invested in Chicago companies. However, many of those business propositions were as unsound as their counterparts on the West Coast, and many failed quickly. "The point is," he said, "that when the money thinks there is something here to invest in, the money comes. So that's part of our theory of action. We believe that you need to create a supportive ecosystem, including what the Brookings Institution calls 'catalytic organizations,' and a modest amount of state assistance. With all the advantages here, we don't need the biggest, richest, fattest set of investments. We just need to be competitive."

The strategy today, he said, and the objective of iBIO is to build a strong regional ecosystem. iBIO was the driver in creating an angel tax credit, and has helped push legislation to re-fund the Technology Development Account, which, along with the Illinois Advantage Venture Fund provide

[45]He cited a recent study by the National Center for Higher Education Management (NCHEMS), which concluded: "While the Illinois economy is stronger than those of many upper Midwestern states, it has some clear weaknesses. Particularly noticeable is the region-to-region variation and the dependence on established companies, rather than emerging companies, for its economic vitality… Illinois is very much in the middle of the pack with regard to innovation assets… Illinois universities are in the top 10 states in all major fields with regard to research and development expenditures, with particular strength in math and computer science… This has not translated into entrepreneurial activity that is driving a revitalized economy."

[46]He said that studies by the Brookings Institution, Ernst & Young, the Milken Institute, and PriceWaterhouseCoopers had arrived at the same conclusions.

startups with early stage capital. As the ecosystem has strengthened, it is attracting more interested investors. When Horizon Pharma was approached by nine venture capital firms from the West Coast, for example, it accepted the investment—on the condition that it would remain in Chicago. The company succeeded in going public and now has 140 employees.

iBIO launched the PROPEL program in 2007 with funding over the years from iBIO, grants from leading companies, Searle Funds at the Chicago Community Trust, Illinois DCEO, and the City of Chicago. PROPEL offers coaching, professional services, networking, CEO roundtables, business plan competition, and PROPEL Connections, a semi-annual publication of PROPEL company snapshots for the life sciences investment community.

In addition, iBIO has been co-founder of Chicago Innovation Mentors, which sponsors team mentoring of healthcare entrepreneurs with mentors from the large universities. "This is something that we jumped on right away, and even though it wasn't in our budget when it started, with the board's support we threw money into it and a lot of time. It includes Northwestern, University of Chicago, University of Illinois, the iBIO Institute, and now Argonne."

PROPEL currently works with 44 active companies and over the years has served 67. PROPEL firms raised more than $24 million in 2011, and more than $60 million in capital, grants, and loans since joining. In 2011, 42 U.S. and international patents were issued and more than 145 patent applications were filed. Chicago Innovation Mentors currently has 27 active teams, including those serving eight PROPEL companies, and CIM has 78 active mentors. "What the program has done in only about a year and a half is phenomenal, especially in bringing entrepreneurial expertise to people."

He said that the Chicago region now has the "essential outlines of a critical mass," and that its task now is to "shore this up and bolster it." Several years ago iBIO became involved in macroeconomic issues in the state because it realized that "unless some of the macro issues got solved for the state, we had no hope of making this one of the top life sciences centers of the world."

"The principal concern is the State of Illinois' fiscal problems," he said. The cost associated with pensions is crowding out the state's ability to secure new sites and expansions. Payments on pensions and debt service are taking up funds for economic development and causing reductions in agency staffs. He said that CEO magazine ranked Illinois 48th of the 50 states in "business climate."

"However," he concluded, "I believe that we will fix these problems. The assets we have here—these amazing resources, these treasures, these research centers—they're not going to get up and walk away. We're so strong in agriculture and our great climate and soil, and these are not going to change. I believe that there will come a time when people will say, you know, top innovation centers like Boston, San Francisco, and Chicago. That will happen, and it will happen in our lifetime."

TECHNOLOGY-BASED DEVELOPMENT IN ILLINOIS

Dan Berglund
State Science and Technology Institute (SSTI)

Mr. Berglund said that the SSTI is a national non-profit organization, based in Ohio, but that he himself was born in Illinois, as were many of his relatives. "So what I'm going to say to you today is based on love and affection and hope." He said he would take a broad look at industrial research and development in Illinois, and also address the more specific advantages of the SBIR program in supporting start-up companies.

He said that the SSTI had assembled a variety of statistics and indicators for Illinois, and that several of these stood out in importance. One was that Illinois ranked fifth in the nation in population, "so that any time you see a ranking in some other category lower than five, it should be a red flag." He noted that there were "lots of numbers lower than five." One basic measure used for the general health of a state's economy, he said, is per capita personal income. From 2006 to 2011, Illinois dropped from 11th nationally to 14th in that measure—"a fairly significant drop." The good news, he said, is that the state is still above the national average, which is about $41,000; the figure for Illinois is $44,000.

"The very bad news," he said, "is that in 1998, Illinois ranked 7th in per capita personal income. That is a huge decline in 13 years." In per capita federal extramural R&D, Illinois ranked 30th. "Obviously," he said, "if you're going to have a strong technology economy and a strong innovation ecosystem, you need to have that federal R&D money coming into the state." A situation he found interesting, however, is the dichotomy between where that federal R&D money is going and where the state ranks. In 2008, Illinois ranked 8th, with federal R&D money going to universities and colleges—"a fairly strong showing." But it ranked 42nd in federal R&D going to industry. "So that's a huge caution for the state." Among other indicators, in NIH grants and contracts, the state ranked 9th in total funding in 2011. In industrial R&D intensity it ranked 14th. This was also below the national average, and a decline for the state overall.

The indicator for academic R&D expenditures from industry, he said, could serve as a key to understand how closely industry is actually working with the universities in a state. The ranking of 15th nationally was "not too bad," but again, at 3.3 percent, it was significantly below the national average of 5.8 percent.

Good news for Illinois, he said, lay in the next two indicators, "both of which are incredibly important for having an innovation-based economy." In the percentage of population with a bachelor's degree, Illinois now ranked 12th in 2010. In 2002, the state ranked only 17th, "so that is a significant increase and progress." Second, "business churning" is a statistic that reflects the rate of business creation and death in a state. "The more churning you have, according to theory, the more entrepreneurial is the climate in the state. This ranking

surprised me, 24th. It doesn't sound great, but in the early 2000s, Illinois ranked 42nd. Almost all of the Great Lakes/Great Plains states have stayed in the bottom 40s. So we looked to see if this was just a statistical anomaly. But there has actually been a steady progression from the 40s up to the mid-20s, so that's significantly good news."

Finally, he said, we come to the indicator that measures how Illinois does on SBIR awards. Overall, from 2007 to 2011, the state ranked on average 15th, which is "significantly below where you would hope and expect to see this state. I think the state does need to spend some time to understand why this is so. Why is industry in Illinois doing so poorly in receiving federal R&D money? We need to inventory who is receiving what from whom, where the money is going, and what is working. We need to look at the overall trends, try to characterize the state's industrial communities, and get a sense of their openness to working with federal government, universities and each other. There is some indication of industry's openness to work with universities, but that needs to be understood."

He said that Illinois has had an uneven record of general support for technology-based economic development programs, which ebbs and flows. This unevenness is evident in SBIR assistance in particular, he said. A common approach in response to this problem is to provide proposal development assistance and federal R&D support, encouraging the pursuit of federal R&D. Another approach is to focus on successful Phase II conversion or Phase III commercialization—"really working with those SBIR companies that have received Phase II awards and should now be ready for commercialization." He said that that kind of intensive assistance in commercializing is likely to be beneficial for Illinois. "The fact that the state, given its size, ranks so low in SBIR awards is an indication that there may not be broad understanding either of the program or of how to submit a winning proposal."

In closing, he offered several questions for his colleagues to consider: Do you believe that the data accurately reflect Illinois's standing? Does Illinois have the high-level leadership in all sectors to move the state forward? "One of the lessons we've learned in the 16 years that SSTI has been in existence," he concluded, "is that committed, high-level leadership from all sectors must agree that innovation is a high priority."

DISCUSSION

Mr. Biss, the moderator, asked the panelists if there was any relationship between the state's lag in per capita federal support for research by industry and its historic strategy of supporting large companies. He also asked if there was a connection between those two indicators and Argonne National Laboratory's relationship with industry.

Dr. Isaacs of Argonne agreed that it is important to understand how much federal funding goes to which sectors, but questioned whether the flow of federal dollars to industry is the right indicator for the health of the innovation

ecosystem. "Ultimately," he said, "you want the outcome, which is innovation and economic growth, not the input, which is the federal dollars. We want to be able to measure how much innovation gets done in Illinois rather than just measure the federal dollars going to industry and cranking that through." He said that Mr. Miller had effectively characterized a way for pharma companies to access the innovations of academia, and suggested that the relevant objective is "a much more fluid communication between universities, government labs, and industry."

Mr. Berglund said he did not disagree, and that federal dollars to industry should be only one indicator. "But I think the other indicator, showing industrial R&D intensity at 14th in the nation in 2009, down from 11th in 2000, is an indication that something is not right with industry in Illinois. I don't know exactly what that is, but I think the state needs to figure it out, because it is probably affecting the other measures that are even more important for the health of the economy. So much of the Great Lakes region is focused on big, existing companies, rather than helping to build the ecosystem for entrepreneurial startups."

Mr. Miller commented on the state's ranking of 15 in SBIR funding. He recalled that when he joined iBIO in late 2002, the state's ranking was 36th in SBIR funding, "so this current rank of 15 is actually a big step forward." He also made the point that the state had been doing hard, detailed work to lay the groundwork for future improvements. "We've been so successful with our big-company strategy over the years," he said, "that I think it's made us a little blind to the other things we have to do. These are not glamorous and not sexy—they are like blocking and tackling and flossing your teeth. But they are the kinds of things we need to keep doing to build our innovation economy."

Dr. Mirkin said that the worry about how much money the state is getting for various sectors may be the wrong worry. "In the end," he said, "if we have good ideas, we're going to get money. Perhaps we're not focusing enough on generating those ideas, whether they are from small or large companies. My concern is that we're not working closely enough together."

He added that the question of metrics can be equally misleading. "Every part of the ecosystem requires different metrics, he said, "because we're all different in the way we function. A fungus and a tree is a good example of symbiosis. They depend intimately on each other, but have very different needs and ways of judging success. In the same way, academics are judged by publications for getting tenure in a university, while industrial engineers may be judged for delivering a product. Our challenge is to put these sectors together to get the good ideas, not measure how we do it. We need to ask what the drivers are. In some cases it's federal funding, in others it has nothing to do with federal funding—it's getting ahead of the federal funding and defining where it should be. We're not very good at that yet. At Stanford, for example, there is more communication like that—a Baxter would be in there talking to a Chad Mirkin regularly. That churn has to happen, and we're a little afraid of that here."

Dr. Wessner commented that the debates over metrics and policies can be a distraction from the overarching need for action. "The rest of the world is not fighting with their federal government," he said, "or underfunding their R&D budgets. They're investing heavily in their research universities and in their small companies. Here at home, the states with the most vibrant economies, with the most venture capital, are the same ones that get the most SBIR awards: California, Massachusetts, New York, Maryland, Virginia, and Colorado. The lesson is not to argue the metrics, but make a concerted effort to get more federal funds and then to match them.

He recalled a comment by Gordon Moore, co-founder of Intel, who remarked, "You can never get well on the technology. When your sales fall, you buy new equipment." That is difficult in this budgetary environment, he said, but it must be done. "Instead, our current strategy is to borrow money from our children and grandchildren to pay our current expenditures. That is not a successful strategy for the long term."

Mr. Miller agreed that current national policy gives little importance to building innovation ecosystems. He said that numerous practices interfere with serious investment in innovation, including expenditures on foreign wars, programs of "nation building," the use of securities whose actual value is almost impossible to understand, programs of health care reform that do not include lifestyle and dietary reforms. "We talk about how we compare to Maryland, California, and Maryland, but the relevant comparisons are with China, Finland, and Singapore."

A questioner asked whether a regional innovation policy could help Illinois be globally connected and attract international investments. Mr. Miller answered in the affirmative, saying that Chicago is "the easiest place in the world to get to or from," it has leadership in every sector of biotechnology, and "for the developing countries, we can make a strong case to firms that want to locate in North America."

Matthew Small, a graduate student at the University of Illinois, said he had come to Illinois because it is one of the top-tier research institutions of the country. "But we have highly educated people, and they're leaving the state. Why? I know a lot of people who would love to stay in the Midwest but don't find something that overlaps with their skill set."

Mr. Biss replied that Illinois needs a more balanced portfolio in its economic development strategy. Until recently, it has focused on just the large companies. "The challenge," he said, "given limited resources, is to look at the whole spread of companies. Plenty of states are doing that. Michigan, for example, is reorienting their strategy from large-company recruitment to an 'economic gardening' approach. The question now is will the leaders of the three sectors in Illinois have a common vision to do this and then will the commitment stick?"

Panel V

New Initiatives and Best Practices in Innovation

Moderator:
Chris Fall
Office of Naval Research

Tim Persons
Government Accountability Office

Dr. Persons reminded his audience that the name of the GAO was changed in 2004 from General Accounting Office to Government Accountability Office. This reflected a change in policy, which began in 1970, toward more performance audits of "value for money," he said, especially studies done at the request of Congress. A major feature of the GAO, which publishes some 1,000 reports a year, has remained its political independence, which permits neither political appointees nor linkages with the executive branch. Similarly, the structure of the GAO, whose director is appointed to a term of 15 years, is designed to disentangle its work from the cycles of political elections. The long term itself is intended to expand the GAO's institutional memory, which, along with its independence, gives it credibility for one of its central functions—including that of advising new presidential administrations on federal matters.

He said that he was participating at the conference both because "so much of the federal sector is very scientific in its endeavors," and because the GAO is both an evaluator of technological change and government responses to it. Disruptive technologies, he said, are becoming as important to the federal enterprise as they have been to industry and to society at large.

He began with a brief narration of U.S. roots of innovation, as depicted in the famed "Apotheosis of Washington" (1865), the large fresco painting in the U.S. Capitol dome by Greek artist Constantino Brumidi. "This is one of the most sacred places in the United States government," he said. "But the importance is not just what's in the middle—it's what happens around the ring."

There, he said, were numerous examples of "disruptive technologies," which is in the "U.S. DNA." They begin in the era of Abraham Lincoln, he said, and include Greek gods and goddesses pointing to such innovations as a hand-cranked generator of electricity; a snake-like black shape portraying the laying of the first transatlantic cable; the first "ironsides" warships, the Monitor and the Merrimac; the use of advanced steel to construct railroad locomotives; Cyrus McCormick's reaper; and many others. If Brumidi had painted the fresco it today, he said, he might have continued with other American inventions: the telegraph, light bulb, airplane, xerography, nuclear fission, transistor, integrated circuits, ARPAnet, email, personal computer, DOS, Internet search, map of the human genome, and the iPhone. A current example of the power of disruption, he said, is digital photography, which helped hasten the end for Eastman Kodak, a 135-year-old company whose name was long synonymous with photography. Kodak filed for bankruptcy in 2012.

It is easier, he said, to recognize innovations of the past than to summon them up for what he called the "wicked" problems of the present, such as the need for renewable energy and responses to climate change. He associated this challenge "innovation gaps," such as the gap between some predictions about global warming and the ability of current models to verify these predictions. "We're pretty good at predicting weather," he said, "but how do we get from that to climate?"

How do disruptive technologies arise? he went on. As an example, he cited the increased power and use of graphics processing units (GPUs) for high-powered computation. Once confined to special designs for computer graphics, and difficult to program for other uses, today's GPUs are general-purpose parallel processors with support for a variety of functions, especially when hybridized with a general-process central processing unit, or CPU, the traditional processing hardware.[47]

Dr. Persons recalled giving a talk in 2010 when he discussed (what was then) the world's fastest supercomputer: the Jaguar installation by Cray at Oak Ridge National Laboratory. To his surprise, he recalled, within a matter of weeks the Chinese supercomputer Tianhe 1-A had jumped into the #1 spot to displace the Cray. This upgrade had achieved its speed by using Nvidia GPUs. "What was disruptive," he said, "was that graphics processing units had advanced rapidly to meet the demands of other markets, like X-Boxes and Playstations, that used parallel processing in magnificent ways. The standard architectures were not able to keep up, and the Chinese were very smart in seeing that and leveraging this GPU technology for another purpose." [48]

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[47]The GPU-CPU hybrid has quickly become the industry standard, achieving 10 to 100 times as much power as older architectures while consuming about the same amount of energy. In a hybrid, the CPU consists of only a few cores optimized for serial processing, while GPUs consist of thousands of smaller, more efficient cores designed for parallel performance. <*http://www.nvidia.com/object/what-is-gpu-computing.html*>; <*http://gpgpu.org*>.

[48]As mentioned earlier, the ranking of the top supercomputers changes as fast as the technologies driving them. Tianhe 1-A held the top spot only until July 2011, when it was replaced by the

He said that the possibility of an even more disruptive innovation was presented by the concept of quantum computation. "Think about Turing computability," he said, "and then let's try to think about *quantum* Turing computability, what that means.[49] If you can hold any number 2^n in an integer register, in quantum computing you can hold *all* 2^n numbers simultaneously in the quantum register." He attributed current advances to scientists at the University of Innsbruck, and to others at the NIST Quantum Information Program in Boulder, Colorado, where researchers are working with individual calcium ions—"shifting them around, passing light through them, entangling them, doing computations with them. That is what the marriage of materials science and computational science has brought us."

In the energy sector, he pointed to "small, modular nuclear reactors" as a potentially disruptive technology. "Why do we need to build Three-Mile-Island-size footprints? Why not build a reactor small enough to bury underground and carry on an 18-wheeler?" he said. This is the goal of a partnership between Hyperion Power Generation and Savannah River National Laboratory in Georgia, using technology developed at Los Alamos National Laboratory. A first installation is designed to produce 25 megawatts of electricity; the power module will be replaced after a 10-year lifespan. "If we are going to find scalable zero-carbon-emission-based energy in the near term, it has to be nuclear. We do have the key issue of waste management, which this doesn't solve, but it brings tremendous potential as a disruptive technology."[50]

He said that research into genetic engineering is another area where technological disruption is likely. For example, in the case of biofuels, "the key lesson we have learned is the mistake of being penny wise and pound foolish," he said. "We're using corn, but that is a petroleum intensive fuel. It needs a lot of fertilizer, and to get the fertilizer we use petroleum, so how much do we save? We're learning how to bioengineer the energy feed stocks. We're at the tip of the iceberg."

In genetic engineering, he said, we are learning how to sequence more and more data. "But that's not the metric we want. We need the information out of that data. A real breakthrough would be a 'Google' to search across these things as we sequence them."

Another area ripe for a disruption is laser fusion. One possibility he said, is the National Ignition Facility (NIF), a three-story sphere at Lawrence Livermore National Laboratory. Engineers are using 192 high-energy lasers of about 1.8 million joules to strike peppercorn-sized deuterium-tritium spheres suspended in thimble-sized chambers with just the right geometry to cause fusion. "They need to get the right geometry," he said, "so that the energy

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Fujitsu's K Computer in Japan, which was in turn surpassed by Lawrence Livermore's Sequoia in 2012. <*http://www.top500.org*>.

[49]Turing computability, named after Alan Turing, refers to computations that can be made on a "Turing machine," an early means of simulating the logic of a computer algorithm.

[50]<*http://www.nrc.gov/reactors/advanced/hyperion.html*>.

coming out is greater than the energy going in. This would last on the order of 10 picoseconds, and at its hottest point be about 100 million degrees C, hotter than center of sun. It is very technical, very bold, and very controversial, a very big bet. It could certainly be disruptive."

He concluded by mentioning several recent publications of potential value to attendees. The first, completed in 2007, is the "GAO Cost Estimating and Assessment Guide: Best Practices for Developing and Managing Capital Program Costs." Also, the GAO had just released the "GAO Schedule Assessment Guide: Best Practices for Project Schedules," published in 2012. The GAO was in the process of writing a guide for technology insertion and risk management.

"We try to be Hippocratic: we don't want to do harm to any innovation system," he said in closing. "This is not a bureaucratic process. But there have to be some metrics to measure goodness or how well things work, and that's also our domain."

INNOVATIVE APPROACHES IN ONCOLOGY: PHYSICAL SCIENCES PERSPECTIVES

Larry A. Nagahara
Office of Physical Sciences-Oncology
National Cancer Institute

Dr. Nagahara noted that he works closely with Dr. Lee of the National Cancer Institute (NCI), who spoke the previous day. Dr. Lee heads the Center for Strategic Scientific initiatives (CSSI), formed a decade ago by the NIH to pursue innovative approaches to the causes and potential cures for cancer. A central part of the CSSI is the Office of Physical Sciences-Oncology (OPSO), directed by Dr. Nagahara. "The idea of OPSO," he said, "is to invited researchers in the physical sciences to work in the cancer domain. These researchers bring a whole new approach to the questions of how cancer initiates and progresses."

Started in 2008, the OPSO met with researchers in the physical sciences and engineering, as well as clinicians, to discuss the directions from which physical scientists would approach a family of diseases as complex as cancer. From the workshops emerged four main themes, he said:

- Physics (the physical laws and principles) of cancer.
- Evolution and evolutionary theory of cancer.
- Information coding, decoding, transfer, and translation in cancer.
- "De-convoluting" cancer's complexity.

Since then, the OPSO has reaffirmed its strategy of "asking big questions." Accordingly, they challenge these new partners to do the following:

- Generate new knowledge, which may emerge from new areas.
- Pursue science that is not just better, but paradigm shifting. "That is," he said, we don't want just better sequencing tools; we want tools that are completely new."
- Build trans-disciplinary teams and infrastructure to better understand and control cancer.

He reviewed the OPSO's challenge from the point of view of the traditional "translation pipeline"—the imaginary spectrum from basic research to concept and design, prototyping, feasibility, testing, clinical trials, and finally standard of care. While such a pipeline may be useful for some purposes, he said, "innovation cannot be defined as one color or one definition."

Instead, he continued, creating an "innovation environment" within the physical sciences-oncology centers (PS-OC) network requires new approaches. These include:

- Building a team of innovators.
- Creating an innovation culture.
- Facilitation innovation leadership.
- Setting strategic direction for the long term.

Ground rules for the PS-OC network, he said, began with "lending a helping hand to each other." In other words, scientific definitions, culture, and "DNA" are so different between the physical and life sciences that communication between the two can succeed only when both sides make the effort to understand the language and values of the other.

The PS-OC network itself is now built, and funded, and it is quite large. There are 12 "virtual" centers, each of which has a principal investigator who is a physical scientist by training and a senior scientific investigator from the life sciences.[51] Over 110 institutions are represented—83 domestic and 32 foreign. More than 770 investigators and 550 trainees participate. Senior leadership is divided almost equally between physical scientists and cancer biology or clinical researchers.

Dr. Nagahara said that there is a notable precedent for what he is trying to do in the form of the "quintessential" physicist-biologist, Max Delbrück. His physical science credentials were impeccable, as he earned a PhD at Gottingen in theoretical physics and trained in quantum mechanics with Nils Bohr. Ironically, Bohr interested him in biology, where he foresaw applications of quantum theory. After the coming of the war prompted his move to the United States, where he taught at Vanderbilt University, he formed a research partnership with Salvador Luria, then at the University of Indiana. Together they

[51]One of the 12 centers is located at Northwestern University.

were instrumental in establishing the field of molecular biology.[52] There, said Dr. Nagahara, it was the physical sciences that proved "disruptive" to traditional biology.

He also offered a more modern instance of exposing experts in one field to a problem in another. Biologists had been stumped for 15 years in trying to decipher the enzyme structure of an AIDS-causing monkey retrovirus known as the Mason-Pfizer monkey virus. Players of an online puzzle video game called Foldit were invited to try their hand at unlocking the protein structure.[53] While the puzzle was available to play for a period of three weeks, players produced an accurate 3D model of the enzyme in just ten days.[54]

As exercise in bridging disciplines, the PS-OC invited a group of physical scientists who had never looked at cancer to team up with people who had spent their careers studying cancer. "An analogy is the blind men and the elephant," he said. "People from different backgrounds are going to have to learn to communicate. How do they start? Their knowledge means nothing because they don't trust each other's data. Each observes a different part of the elephant. The ability to communicate begins with respect for different perspectives. We asked the teams at every center to look at the same two cell lines, outline a research protocol, and report back. Because they were all doing the same thing, they could begin to learn a common language. And this builds trust."

Another exercise was intended to facilitate interactions among young investigators. "We gave them funds and told them they could distribute the funding in their own way. They didn't know each other, and we invited them all into the same big room, had them line up in a row, and start interviewing each other. It was like 'speed dating' for science. After that they told us whose ideas they found interesting, and they started writing a joint proposal with that person. They had a week to do that, and then we would fund it."

Five percent of the annual budget is devoted to pilot projects, he said, that enable centers to fund their own research ideas. "One complaint we always hear is, 'I sent my proposal to NIH; it got reviewed; I didn't score, but I don't know why.' This is their opportunity to think freely. For example, one student was looking at the disparity in the incidence of breast cancer in African-American and Caucasian populations in North Carolina. Rather than doing normal genomics or proteomics, we suggested, could you look at what causes

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[52]They also shared, with Alfred D. Hershey, the Nobel Prize for Physiology or Medicine in 1969 for discovering that bacteria become resistant to viruses (phages) through the mechanism of genetic mutation. <*http://www.nobelprize.org/nobel_prizes/medicine/laureates/1969/delbruck-bio.html*>.

[53]The game is part of a research project at the University of Washington's Center for Game Science in collaboration with the Department of Biochemistry. The objective of the game is to fold the structure of selected proteins to the best of the player's ability, using various tools provided within the game. The highest scoring solutions are analyzed by researchers, who determine whether or not there is a native structural configuration (or native state) that can be applied to the relevant proteins in the "real world." Scientists can then use such solutions to solve real-world problems by targeting and eradicating diseases and creating biological innovations. <*http://fold.it/portal*>.

[54]<*http://en.wikipedia.org/wiki/Foldit*>.

this. They found that a certain part of population had a very accelerated rate of development between onset and symptoms. They thought it might be based on a cause in physical science. They proposed taking tissue samples, making various measurements on those samples, and looking for a physical basis."

He closed by touching on the topic of evaluating the new PS-OC approach. "What principles do you use to show that a new community is doing something valuable? We're trying figure out the metrics for that. One way is to see if there are collaborations, a mix of teams. We can even quantify this by using some familiar numbers: cross-disciplinary publications, numbers of grant proposals. It's the blending of skills, viewpoints, and sectors that we're after."

NEW INITIATIVES AT THE UNIVERSITY OF ILLINOIS

Caralynn Nowinski
University of Illinois

Dr. Nowinski began by saying that she had been at her position for less than a year, but that her colleagues in the technology transfer office and research park had created innovative programs with strong momentum that "she had the privilege to share with the conference."

She said that these programs fell under three of the themes she had noted over the past day and half. The first is to bring companies to the point "where they're actually venture fundable." She noted the debate about whether funding is adequate, given the economic climate, but said that "we need the talented people who create good companies before we start thinking about the funding or lack of it." Doing this was possible through "establishing these collisions across the sectors" and "bringing the players together in unique ways." The third theme was to foster talent development, which "goes full circle back to the first point. If we're going to create fundable ventures," she said, "we need the talent that can do that."

The outcome of innovation, she said, is "new products or processes that ultimately change the way we do things, or live." And the goal is to get those into the market place. "What are we doing to make this happen?" she asked. "If President Lincoln didn't make it clear enough in 1862 when he signed the Morrill Act, our state legislature made it very clear in 2000 when they established economic development as the fourth mission of the University of Illinois. It truly is our mandate as a public research university to strengthen our state's economy."[55]

She said that she looks at the economic development portion of the mission "comprehensively." The university tries to enable research, transfer it into people's daily lives, incubate young companies that grow out of research,

[55]According to the university's web site, "The University of Illinois is among the preeminent public universities of the nation and strives constantly to sustain and enhance its quality in teaching, research, public service and economic development." <*http://www.uillinois.edu/about/mission.cfm*>.

and invest in those companies. She said she would focus mostly on the "entrepreneurial pieces"—technology transfer and infrastructure.

She began with "STEM ed," the idea of training pre-schoolers through grad students and even incumbent workers in the areas of science, technology, engineering and math. "How are we thinking about creating a workforce that is skilled enough for knowledge-based jobs? We know those jobs are increasing, while lower-skill jobs are on the decline." One university program is I-STEM, which brings in public funding for pre-school education, middle and high school education, and experiences for college and graduate students. The state has nearly doubled its investment in STEM education over the last few years, "but we have a long way to go to keep up with the increase in STEM-based jobs."

She said Illinois also needs to teach students how to apply STEM learning to entrepreneurial experiences. "Various groups on our campuses are trying to provide that experience to students." This includes units such as the Technology Entrepreneur Center in the College of Engineering in Urbana and the Institute for Entrepreneurial Studies in the College of Business in Chicago. A more innovative initiative is the Innovation Living Learning Community, or Innovation LLC, a dorm with 130 students from different disciplines who are interested in entrepreneurship. It has a garage where they can work on prototyping, a 3-D printer, and programs to encourage interaction and provide them with mentorship and a classroom curriculum to nurture the development of ideas.

The university has held a variety of Business Plan Competitions, she said, that have been successful in rewarding students and in providing state funding for their companies. The program introduces students with business skills to students with engineering and science skills and helps them combine skill sets and potentially find a commercial application. For example, the Tech Ventures Program in the UIC Liautaud Graduate School of Business enables students from the business school to partner with the tech transfer office, create a business plan, and try to identify a commercial application for new technologies. A winner of the first Concept Venture competition in 2006, a company called OrthoAccel Technologies, ultimately found funding, spun out from the university, and created a real management team. In 2011 the company got FDA clearance for a medical device designed to accelerate the orthodontic process, which she called "braces on steroids."

She also highlighted a program called ThinkChicago, a partnership between the University of Illinois, the City of Chicago, and Chicago Ideas Week. It brings 100 college students from across Midwest to Chicago to learn about technology entrepreneurship and see firsthand how companies function. "Hopefully," she said, "other universities in Illinois will encourage students to participate in this as well. We need to bring the talent here and show them we have a vibrant community if we want them to stay here."

"Our obligation goes beyond our students," she continued, "to programs for the faculty. Our tech transfer office has nearly doubled its royalties in the last five years, and in the last year we generated a record number of start-

up companies. We're on pace to do it again this year. We try in many ways to stimulate company formation, starting with informal conversations about IP called IP Coffee Breaks, where faculty and grad students talk about protecting IP, making disclosures, and getting help to form a company." There are also more formalized programs, such as the Proof of Concept programs in Urbana and Chicago. This provides up to $75,000 to faculty entrepreneur teams to try to fill a portion of the start-up funding gap and aims to prepare companies to file an SBIR application.

The Chicago Innovation Mentors (CIM) Program was founded by UIC, Northwestern, University of Chicago and iBIO Propel last year to link faculty entrepreneurs with mentorship teams that can help them vet market potential and develop appropriate milestones. This program will soon expand to Argonne and the Urbana campus.

It isn't enough to support people, she said; they also need "a place and a process." She showed an illustration of the incubator in Urbana, called EnterpriseWorks, which is part of the University of Illinois Research Park. The incubator offers SBIR consultation and a Mobile Development Center, among other support services. "When I came to the U of I," she said, "I had no idea we had that going on in Urbana. The research park has worked with 140 start-ups in the last 10 years, and in the last several years has helped to raise over $400 million in venture capital."

Other programs within the research park that have contributed to this success include the Entrepreneurs-in-Residence program, which pairs serial entrepreneurs, VCs, or industry executives with early-stage companies. The entrepreneurs help the companies adapt to the commercial world—to learn, for example, that the milestones that are useful in the lab are typically not the same as those that are useful in the world of venture capital or seed funding. Similarly, the I-Start Professional Launch Program is designed to help entrepreneurs avoid the distraction of all the professional services they need. It delivers those services in a suite so the entrepreneur can focus on running the company. Finally, the SBIR Consultation program has helped the university find funding for early technology ventures. In the last 10 years, 18 percent of SBIR funding that has been received in Illinois has gone to Champaign County, which has only 1.6 percent of the state's population. In the last six years, $35 million in SBIR funding has gone to companies in the Research Park.

More seed funding is needed, she said, and Illinois Ventures was established by the legislature to help. "This has been a real success story," she said. "The seed funding program gets companies to next level, and we have had follow-on investments of nearly 13 to 1. This is capital really needed to fill the gap. We have a venture fund that invests 80 percent of its capital in Illinois, compared to the 4 percent across the nation that is invested in Illinois. This is not sufficient, but we are clearly addressing the more fundamental problem: how do we create the most venture fundable businesses."

Her favorite topics, she concluded, "are the things we're looking to do next"—how to bring university technologies to industry, how to extend our reach to the Chicago area, how to reach out to other institutions.

To present U of I technologies to industry, she said, a successful technology showcase called Share the Vision was held in April 2012 on the Urbana campus. It was attended by almost 40 faculty and more than 50 venture capital and business development executives. Faculty and students from 30 start-ups presented their stories over the two days, and plans for the next Share the Vision are already underway.

She said that a next step would be to "bring some of the success we've seen in the research park and on our campus in central Illinois up to Chicago." One motivation is the increasing concentration of innovation in urban areas. EnterpriseWorks Chicago, a new incubator near the UIC campus, will open in spring 2013 not only for the U of I community but for the broader Chicagoland entrepreneurial community. She referred again to ThinkChicago, whose goals are to bring students from all of the university campuses and connect them to the entrepreneurial community in Chicago, including the activity at 1871, the technology incubator based in the Merchandise Mart.

Finally, she said, she wanted to use some of the program's physical locations as places where new business interactions could happen. She mentioned intercampus initiatives in health care and manufacturing, and expressed plans to expand both "not just on our academic campuses but on others as well. We are really excited. We hope to have great initiatives to announce over the next year or so, and we've set up a variety of communications media over the last year to tell people what we are doing."

UNIVERSITY TECHNOLOGY TRANSFER: LESSONS LEARNED FROM Lyrica™

Richard B. Silverman
Department of Chemistry
Northwestern University

Dr. Silverman, a chemist who discovered a drug called Lyrica that is effective in blocking epilepsy and other neurological disorders, said he would discuss his personal experience in shepherding this discovery through the many stages of technology transfer, including proof of concept, patenting, licensing, testing, commercialization, and ultimately marketing. From the point of view of an experimental scientist, he said, the experience was a sobering one for which his own professional training did not prepare him.

His story began with an enzyme called GABA aminotransferase, which seemed to be implicated in epileptic seizures. "We wanted to understand how it works," he said, "and we also wanted to block its activity because the blocking could be a potential treatment for epilepsy."

He noted that epilepsy was an important concern for health scientists, and had been since it was recorded in Babylonia some 4,000 years ago. "It's not just a single condition," he said. "It's a family of disorders, like cancer, with a lot of etiologies. Defined broadly, it is any disease that's characterized by recurring convulsive seizures." About 1 to 2 percent of the world population experiences some form of epilepsy, and of these, about 30 to 40 percent could not be treated by any known therapy. "So even 1 percent of 30 percent is a huge number, and a huge unmet need."

During the 1980s, he began to study GABA aminotransferase in his laboratory, and gradually discovered a series of compounds that seemed to produce the effect he wanted. On the basis of enzyme studies in vitro, they seemed to do this through a new pathway, but this needed to be confirmed in animal studies. Despite this promising situation, he had little success at interesting drug companies to test the series of compounds. "There did seem to be a bias against academic discoveries," he said. "In the view of the companies, they were the experts. What could an academic scientist contribute that we couldn't do better? This has changed in last 10 years, but in the late 1980s that's the way it was."

"So I tried the university's tech transfer office (TTO)," he continued. "Our office was quite small, and not well established." He filled out an invention disclosure form, listing what it was he had invented and why he thought it was important. He suggested some companies that might be interested; the TTO added some others and contacted all of them.

"Only two companies were interested, he said—Parke-Davis and Upjohn. We sent letters—the old-fashioned kind, with mailboxes. It took months to get answers. Eventually we heard from them. Upjohn wanted only the 'best' compound: 'Just send us one, we'll look at it.' Parke-Davis, on the other hand, wanted to test the entire set."

So Dr. Silverman signed a material transfer agreement with Parke-Davis to do anti-convulsant tests in mice. When the results came back, the company reported that one of the compounds was "off the charts" in activity, "the most potent we have ever tested." The rest were only weak anticonvulsants. Eventually Upjohn tested the "best" compound, in 1990, and found it only weakly active. "The most potent one was not the one we sent to Upjohn," he said. "The 'best' compound was best for what we were screening it for, and that may not have been related to how it actually worked. It turned out 10 years later they found out how it does work, and it works by a different mechanism than what we were screening it for."

In November of 1990 a license agreement was signed with Parke-Davis and a patent applied for. In December of 1991 a patent option agreement was signed between Warner Lambert, the parent company of Parke-Davis, and Northwestern University.

"At this point," he said, "the compound was in the hands of Parke-Davis, who did all the pharmacokinetic and metabolism studies over a period of six months in 1992. Then it took another 24 months to do chemical synthesis on

single enantiomer[56] and animal toxicology. Finally, in 1995 the compound was ready for filing with the FDA as an investigational new drug.[57]

Phase I clinical trials were performed in 1996, and Phases II and III took from 1999 to 2003. "This was one of the largest sets of clinical trials ever done for a central nervous system drug," he said, with 10,000 patients. That was because by then Parke-Davis had realized there are other indications for this molecule than just epilepsy, including neuropathic pains (diabetic neuropathy and postherpetic neuralgia). So Lyrica went into clinical trials for several indications, and then also for fibromyalgia and generalized anxiety. It was found to be very effective for epilepsy, neuropathic pains, fibromyalgia, and generalized anxiety, and just this last week was also approved for pain from spinal cord injury." The process continued beyond the United States with filing for use in Europe in 2003, where it was approved in 2004 and also in Asia.

Lyrica finally reached the U.S. market in 2005, and in its first full year of sales (2006) it reached the $1 billion "blockbuster" status by achieving $1.2 billion in revenue. "It was a very much-needed drug," said Dr. Silverman. "It had no counterpart at that point."

He said that among the many lessons he learned during this process of commercialization was a particularly painful one. In the beginning of development, when Parke-Davis was doing its testing, he was able to keep in close touch with events. "I had friends there," he said. "I would call periodically for updates, and they would tell me what was going on. As a scientist that's what you crave: scholarship, trying to understand the unknown, bringing clarity. The most rewarding thing you can do is to discuss experiments and interact with the experimenters." However, when Pfizer bought Warner Lambert and Parke-Davis in 2000, during the clinical trials, the leadership of the new company decided that the Pfizer scientists should no longer talk to anybody outside the company about the project. "This was the most frustrating thing that could happen," he said. "When they told me that, I said, even the inventor? They said yes, even the inventor. I didn't hear another word for five years until this thing reached the market."

Since that time, he said, things have changed at Northwestern. The Tech Transfer Office is now called the Innovation and New Ventures Office, or INVO, and INVO makes it clear that license agreements must include two-way collaboration with full data sharing. "Now they make it clear," he said, "that if you want to work with our scientists, you have to treat them like scientists. And you can't delay publication and oral public dissemination of results. We say you get about a month to decide if you want to patent anything in there. Of course during that month we're savvy enough to not talk about it to anyone outside because we know that then it would lose all its value."

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[56]An enantiomer is one of two chemical isomers that are mirror images of one another but not identical, like right and left hands. Different enantiomers may have different effects as drugs.
[57]The FDA's IND, or investigational new drug, program serves as a safety screen for compounds before they can enter Phase I clinical testing on humans.

Since Lyrica, he said in closing, he has collaborated with three start-up companies, all good experiences. Collaboration has become part of the fabric, he said, certainly at Northwestern. "The folks at INVO are tremendous," he said. "They go out there and try to make marriages between industry and Northwestern. We're connecting with a lot more companies. Of course we don't want to stifle innovation and scholarship along the way, but this is the direction we all have to go. So that's what I learned from Lyrica."

BUILDING AN INSTITUTE FOR ENGINEERING INNOVATION AT THE UNIVERSITY OF CHICAGO AND ARGONNE NATIONAL LABORATORY

Matthew Tirrell
Institute for Molecular Engineering, University of Chicago
and
Argonne National Laboratory

Dr. Tirrell discussed innovation of a very different kind—innovation at the institutional level. He said his talk would concern "a very local story that's just emerging. It is a story about building a new engineering program from scratch across the boundaries of two very large institutions—University of Chicago and Argonne National Laboratory."

The most innovative aspect of his program, he said, is to "create a new model for an engineering program that transcends disciplinary boundaries from the outset." The institute is being established as an autonomous academic unit of approximately departmental size. It is called an institute because it has the character of an interdisciplinary research institute, but also the autonomy and authority of an academic unit to hire its own faculty.

The name Institute for Molecular Engineering, he said, is meant to describe engineering "from the molecular level up." This is also to give "some indication of what we're not doing: we're not training people to design 787s or bridges or dams. We'll focus at the nanoscale. We want to create leading programs that couple with UC science on one hand, Argonne science and engineering on the other, and fit into this ecosystem we've been talking about. It will build on a unique structure I'll try to get across."

One feature of the Institute, he said, is to "add a new aspect to the University of Chicago (UC), which has a rich reputation for rigor and depth in science. You know that science is about nature and discovery, while engineering is about something else—invention, design, and doing things that nature never did. We don't say that one is more interesting than the other. But the idea of molecular engineering is to connect with molecular-level science and to develop solutions to problems that society cares about in energy, information, environment, and health care."

Construction of the Institute's new building has begun, he said, on the "corner of 57th and Ellis," so that the Institute can be housed in a single,

common location. It will also have a significant physical presence at Argonne, with a suite of offices and lab space.

To begin an engineering program from scratch, in a non-traditional way, he said, the Institute would bypass the traditional departmental structure. "Our target size for the initial development phase is 25 faculty," he said, "so it would be crazy to create little sections with administrative boundaries." Instead, he said he would begin by imagining the kinds of skills needed to do engineering at the molecular level. "Researchers would need to know how to make new materials—organic, inorganic, biological. Engineers are never satisfied with the rates of reactions, so catalysis will be important. They will need to know how to manipulate biology, so we will need biological engineering, including synthetic biology and both bio-inspired and bio-derived materials. We'll need to see at the molecular scale, using imaging and structure. We'll want functional assemblies to process and develop molecular systems, scaling up from the molecular level: photonic, micro-mechanical/robotic, membranes. And finally we'll need computation and modeling."

He said that this was the format he used the previous fall when he sought to recruit senior faculty. "We want to fill in as many of these skills as we can, and we're working on that through a rich planning process." He has tried to supplant the structure of departments with one of themes, and look for talent under each of those themes. Some themes suggested during the planning process, he said, were:

- Energy conversion, transport, and storage at molecular level.
- Photonic materials and systems.
- Molecular electronics and devices.
- Smart and adaptive materials.
- Bio-inspired materials and machines.
- Engineering of complex systems.
- Molecular imaging.
- Bioengineering of membranes and their applications.
- Engineering of evolvable systems.
- Molecular therapeutics.

"The only way I could plan our hiring," he said, "was to hire the best people I could find and let them create their own themes. We will probably have between three and five." He said he expected to build up the faculty over the next few years, spanning a range of technological expertise. Developing graduate and eventually undergraduate programs would follow the arrival of faculty, with the first classes forming in three to five years.

A major new strategy, he said, would be a more cooperative research relationship with industry, with incentives and collaborations to develop technological innovations with commercial promise. "We want to be a better

partner across the whole spectrum of activities we've been talking about at this conference," he said.

He emphasized the advantage of good local resources at both the university and at Argonne. "Collaboration with the local institutions will be very important," he said, "and we are eager to do that. Our aspirations are to create inventions from discovery, and create industrial impact and new ventures from inventions. Another goal is to make the Chicago area a magnet or destination for people to come to study, work, and form companies. "That is the case in California," he said, "where I spent the last 12 years. We want to do the same."

In conclusion, he acknowledged that in creating this new institute he was entering a competitive environment. "If we tried to create a traditional engineering school," he said, "with departments like those already established elsewhere, we'd be playing catch-up for many years. What we are attempting is innovation on the academic side, and it is risky. We won't worry much about what we call our engineering disciplines, but we do worry about what they can do. Hopefully we can compete alongside and complement other styles of engineering."

He closed by saying the institute had announced its first three faculty hires just a few days before the conference. "So it's no longer just me," he said. "Faculty meetings will be different; I'll have someone to talk to." The three pioneers are David Awschalom of the University of California at Santa Barbara, a physicist and engineer in quantum information: and chemical engineers Juan de Pablo and Paul Nealey, both from the University of Wisconsin at Madison. "All of them, like me, have joint appointments at Argonne. Among them they have more than 50 patents, with emerging, overlapping themes in organic materials, electronic materials and devices, and bioengineering; all have active relationships with 10-plus multinational corporations. And a key point: they are all people from outside Illinois. I believe they will begin to make this region a destination very soon."

DISCUSSION

Dr. Peterson asked Dr. Tirrell how he and his colleagues at the institutes would keep their research programs going if graduate students would not arrive for three or four years. Dr. Tirrell said that he had made explicit agreements with chemistry, physics, and biology programs for the short term, and would be advertising for students who could work for molecular engineering faculty. "It's not a perfect solution. But new faculty are also bringing interim students from programs where they are now."

Dr. Fall said he saw some similarity between the interdisciplinary programs of Dr. Nagahara at NCI and Dr. Tirrell in terms of nurturing careers and placing people. Dr. Tirrell agree that the new model of breaking down silos would also challenge people in finding their way as they work in teams and find good opportunities for professional placement.

Dr. Fall asked whether universities were thinking about how best to collaborate with other sectors in the technology clusters. Dr. Nowinski said that this was a high priority for the University of Illinois, which was learning "how to reach into industry" at the levels of both small and large companies. The university is also collaborating with multiple institutions to build a nanotechnology work force.

Panel VI

The Industry Perspective on Illinois

Moderator:
Van Crocker
AuraSense Therapeutics

Mr. Crocker suggested that this panel would give three perspectives on industry development, featuring firms of short (AuraSense), medium (Nanosphere), and long (Motorola) time spans. "These will be three cases of how innovation can succeed in Illinois and how it can be the result of academic collaboration," he said.

He began the discussion by giving the perspective of AuraSense Therapeutics, which he joined at its founding three years ago. "I like to think that AuraSense Therapeutics represents a terrific success story in Illinois Innovation," he began. "I think we are a coalescence of industry, government, and academic participation. Our technology comes from Illinois, a huge chunk of our financing is from Illinois corporate and state sources, and the vast majority of our employees come from here. I think it's the coalescence of all those things that gave rise to a company with a powerful technology, a good growth trajectory, and great prospects." Of the core management team and the company's advisor base, most were either educated in the state or continue their education there.

The company's mission, he said, is to develop "the spherical nucleic acid platform, which is a revolutionary platform to target disease using gene regulation. This is an extremely powerful therapeutic class, one where AuraSense has a therapeutic advantage. Many consider gene regulation a fundamental advance in pharmaceuticals, and one that will give rise to a number of drugs across different therapeutic areas."[58]

[58]According to the company web site, "AuraSense Therapeutics' uniquely engineered Spherical Nucleic Acid (SNA™) constructs possess unparalleled biocompatibility and versatility as therapeutics. They hold great promise for combating the most threatening diseases, including heart

The technology, he said, was the result of a decade of work at Thaxton Laboratories of Northwestern University and at Merck, and the portfolio has grown to about 70 patent filings in multiple countries. "Because the platform is so powerful," he said, "it addresses a large number of market opportunities, not just cancer or cardiovascular disease, but also dermatology, infections, and neurology. Industry interest has been high, and not confined to pharmaceuticals or biotech, but extending to cosmetics."

A series B financing round has been completed. It was led by Abbott Labs, and joined by the Illinois Innovation Venture Fund, "a powerful way for the state government to participate directly in growing companies here in the state." The company has relocated to the new Illinois Science and Technology Park in Skokie, and increased the size of the staff.

He offered a brief overview of genetic regulation as a therapeutic tool. Small molecule drugs have dominated pharmaceuticals for well over a century, he said, until about 30 years ago. Small molecules continue to be effective for many areas, but their drawbacks include side effects and lack of precise targeting. The next innovation, he said, was biologics, which were natural products that could be "exquisitely and naturally targeted." They were also useful in reducing some side effects, as well as in countering disease in unusual ways. Some of the largest drugs in production today are biologic drugs.

The enthusiasm around gene regulation, he said, is that it delivers genetic material directly into cells. This is important because so many diseases can be traced directly to the genetic and protein manufacturing components inside cells. This material is targeted at least as well as any biologic, and its side-effect profile could theoretically be at least as good.

"Big pharma got excited about this," he said, "and began investing lots of money. But they kept running into problems. Efficacy, immune response, and delivery were barriers that prevented such a promising new therapeutic class from getting into the market fully."

The AuraSense technology circumvented these problems, he said, by being easy to manufacture, use, and transport across natural barriers; accommodating across a variety of tissue and cell types; and effective without additional technology. "So with a single technology," he said, "this industry, with all this enthusiasm, may be rescued from its lack of success. That's the idea and the value proposition of the company."

One of the benefits of the technology, he said, is that it can be applied topically with a conventional over-the-counter ointment, allowing the drug to cross the stratum corneum[59] and be effective through the skin. A potential target,

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disease, cancer, skin conditions and bacterial infection…SNA™ constructs overcome one of the most difficult obstacles to gene regulation: safe and effective delivery into cells and tissues. SNA™ constructs exhibit high stability, high binding specificity, and unparalleled transfection efficiency into numerous cell and tissue types. Needing no carriers or transfection agents, they provoke minimal immune response and no known toxicity."

[59]The stratum corneum is the outermost layer of the skin, consisting of dead cells, that forms a protective barrier.

for example, is psoriasis, "where a topical target of therapy would be world changing."

Looking back over the development of AuraSense, he surveyed the partnerships and resources that had benefited the company. He identified four factors of importance:

- Core technology: "The platform itself. We also developed a flexible licensing relationship that benefits not just Northwestern but also the company and our partners."
- Employee and advisory talent: "We have never had to look far afield for talented people, and we are growing quickly."
- Critical infrastructure: "This came at the right time. We had a basic lab facility available in Evanston, near the university, and now we have a much larger opportunity at the Illinois Science and Technology Park in Skokie. The state's facilities grew with us; they didn't confine us or make us move."
- Equity and other financial resources: "Financing was available largely within Illinois, which allowed us to stay where we want to be."

"This is a great story," he said, "with great benefits and a lot of success. But we want to make sure we don't remain unique in this regard." He urged a good understanding of the benefits received by AuraSense, and available in the state, so that other companies would be able to take advantage of them and extend the region's success. "We don't want to be a one-off story," he said. Among the features that can lead to success for companies such as his, said Mr. Crocker, were streamlining of technology transfer, minimizing the bureaucracy of licensing relationships, training talent locally for local employment, and easing access to critical infrastructure of real estate and instrumentation.

He closed by reiterating the importance of partnerships between government, industry, and academia. "This is what worked for us. The ecosystem was favorable for state government, private institutions like Abbott Laboratories, and a number of individuals to come together and invest in a technology that was sourced here in Illinois. That can happen again here, and it can happen elsewhere. Our technology is great, but it's not unique."

INDUSTRY PERSPECTIVE ON ILLINOIS

Roger Moody
Nanosphere

Mr. Moody opened his talk by describing Nanosphere as a molecular diagnostics company founded by Dr. Mirkin and his colleague Dr. Robert Letsinger, also a professor at Northwestern. The founding science, he said, combined gold nanoparticles and nucleotides to create a powerful "Verigene"

detection system for nucleic acids and proteins. The system, mounted on a simple glass micro-array, enables hospital labs to achieve rapid sample-to-result molecular tests for critical diseases.

Based on that discovery, he said, Nanosphere had been able to raise more than $100 million privately, and more than $180 million in public funding. The good news," he said, "is that we've just entered the rapid growth stage after an extended period developing the invention so that it works reliably; passing through the regulatory process; and introducing it to hospitals."

Nanosphere matters, he said, because it "addresses critical unmet medical needs resulting in saving lives and reducing healthcare spending." A test had been approved that week, he said, for detection of bloodstream infections. The nation spends some $15 billion on these infections each year, making them the leading inpatient cost in hospitals. The technology can save approximately $21,000 per patient, he said, by reducing the time required to detect bloodstream infections from 2.5 days to 2.5 hours.

Through partnership with Northwestern, the company has been awarded 170 patents, and has 25 patents pending. This creates an "important defense against other people coming into the market," he said, "and doing things similar to what we do." The company also benefits from continuing innovations from Dr. Mirkin's lab, he said, that not only allowed Nanosphere to capitalize on investments already made, but also to make use of discoveries that may be significant catalysts to future growth.

The company now employs 140 people, mostly in Illinois. Employment is growing significantly in its manufacturing operation, in Northbrook, Illinois, and in sales and customer support. Over the past four quarters the customer base has grown by 156 percent. "With the recent FDA approval of the bloodstream infection test, plus other tests for infectious diseases we hope to bring to market in the next 12 months, we expect that growth rate to accelerate."

He predicted that the company finally has a clear path to profitability. This follows a period when investors and others have seen the large amount of money raised by the company and asked, "When's the good part going to start? Now it's starting, and with that cash we will produce more investments and development activities."

Sustaining the company's momentum, he said, depends on ideas and innovation. "Not only do we have our internal research efforts," he said, "but we continue to collaborate with the nanotech institute here." He also said that "leadership is critical" to this effort—not just the top few people, but in people throughout the organization. "Funding, leadership, and innovation all drive growth, and from that yields cash flows that we can reinvest in future growth."

Local innovation has been critical for Nanosphere, he said. "The company has hired people out of the lab who were actually part of discovering the science and technology. In fact, a couple of ex-lab people on our team, who are still here after eight to 10 years of service, might be the only people in the company who know the nuances of the technology."

Investor interest is also critical, he said, for companies in the early stage when "it's not clear what's going to make them work, if they do work. We've known for five years that we had great technology, but we haven't been sure which application was going to take off. We now know, but we need local investors who can understand the business well and don't just fly in for board meetings." He added that they did need public capital as well, "because VC funding in Illinois is not as high as we would like."

Finally, he said, the company counted on global partnerships as well. "We don't have the money or people to get investments overseas. We have been fortunate in establishing a partnership with Thermo Fisher, which distributes our products in Europe, and others that have helped us expand."

He concluded by saying that Nanosphere was "lucky to be part of an improving start-up environment in Illinois. Nanotechnology has reached an inflection point, and we are finally growing at a rate we have long hoped for."

MOTOROLA SOLUTIONS

Heidi Hattendorf
Motorola Solutions

Dr. Hattendorf, the third speaker in giving the industry perspective for Illinois, reviewed the large-company experience from the point of view of Motorola Solutions. She said it was an exciting time at her company, with substantial changes that amounted to a "reinvention of the company."

Motorola Solutions was formed as a new company in January 2011 when Motorola, Inc., a multi-national firm with an 83-year history, spun off its Mobile Devices and Home businesses. These became Motorola Mobility Holdings, Inc., which then changed its name to Motorola Solutions, or MSI. "It's exciting to see it get back to its roots," she said. The other part of the business was its cellular division, which "we had developed," she said. That division became Motorola Mobility, and was then acquired by Google. The other part of the cellular business—"the infrastructure"—became part of the new Nokia Siemens.

Motorola has also been a pioneer in the semiconductor industry, "where we fostered many innovations." This division was spun off several years ago as Freescale. "We've had a history of fostering innovation, creating industries, and moving them to the next level," she said.

It has also been a pioneer in radio, which is still part of its mission, blended with its data business. For example, one of its major markets is first responders and public safety. Motorola products are designed to "provide these people with the right data they need to be safer and do their job effectively. Motorola acquired Symbol Technologies several years ago, which brought the technology of bar code scanning into the company. "This is critical for the retail segment that tracks inventory, runs the purchases, and organizes warehousing and management. "Once we combine those two technologies," she said, "it gives

us much more we can do with other companies, universities, and research institutes."

The two key areas of the company now, she said, are government and industry. Government includes public safety, but also municipalities and utilities. On the enterprise side, the company provides "business critical solutions, enabling retailers to do their jobs better by having the right information, knowing what's going on, and being able to serve customers. This is a lot of the technology that you wouldn't see when walking into the retail space."

In the same way, she said, much of the MSI technology is "technology out of view"—helping people be the best they can be, providing a video feed of a store that has just been robbed, providing the most relevant technology as well as the most up to date.

She gave an idea of the company's scale and global presence. It now has some 23,000 employees, 5,000 of whom work in Illinois. Motorola's headquarters in Schaumberg just announced creation of 400 new jobs in Chicago. It supports research and development in six countries, manufacturing in three, and sales in more than 100. Last year the company spent $1 billion on R&D, and maintains an IP portfolio of thousands of patents, many for mission-critical and wireless tech. It is a world leader in supporting standards development and driving mission-critical technology. Revenues for MSI come both from governments (65 percent) and enterprise customers (35 percent), with 57 percent coming from North American customers and the rest from Europe, APAC countries, and Latin America.

She said that the company takes pride in its customer focus. "We need partnerships and relationships, because we can't do it all. "We ride along with the police, and with the first responders, looking at everything. Where should the buttons be so an EMT can reach them easily in an emergency?"

Motorola also invests continually in innovation, including organic CTO technologies, incubation campuses, and the MSI Emerging Business Office. It invests in companies through MSI Venture Capital. "We don't just make acquisitions, or focus on large firms; we invest in SMEs and bring partners together through incubation centers."

The company is also concerned with equipping the next generation of public safety personnel. The emphasis is on developing the technologies that make their jobs safer and more effective, including integrated communications, smart devices, and systems that bring only essential information. "We are there with the officers on duty to prevent data overload. We are designing the police car of the future, here in Illinois, so that officers can spend more time actually solving crimes instead of working with technology."

Finally, a core objective is to improve the retail experience for both purveyors and customers. "For the next-generation enterprise," she said, "we are working for the connected consumer, who is carrying a smart phone and wants to know more about prices than the sales person. We are also working for that

same sales people, so they are able to track every product and price through simplified analytics and data handling opportunities."

In closing, she said, "we're proud to be a leader in markets we serve. We are well positioned for growth, with steady investment in R&D and a vision for where it is moving us. We work better together by bringing more investments into the community. We want students to have a place to go after they finish the STEM programs and fantastic schools in this region. We're in it for the long term, and prepared to make investments that enable market forces and continue good collaboration."

DISCUSSION

Dr. Mirkin asked Mr. Moody what, "in an ideal world, might be removed or added that would make a substantive difference to your business." Mr. Moody addressed this at "three different levels." For a small, prototype manufacturing plant, he said, each time it grows a little larger the company has to spend time with the local municipality on the same basic things, such as applying for permits and gaining permission to use substances they are not familiar with. This burdensome process could be made much easier, he said. Local authorities don't seem to understand, he said, "what we do is bring people into the community and hire them. If they could be more responsive, it would be a big help."

At state level, he continued, "I would talk about cost, in particular the franchise tax. Usually a CFO doesn't even think about that, and in every state where I've worked, the franchise tax is an afterthought. In Illinois it is a significant expense. You are essentially penalizing these small growth companies for raising money that is being used to employ people and grow the business."

At the federal level, he said, the list of potential improvements is long. He cited one example, the company's experience at working with two groups within the FDA. One is "extremely responsive," he said, often bending over backward to help. The other is "the polar opposite. No matter what we present to them, the answer is no. We need consistency from agencies if we are to move viable medical products into the market. "

Mr. Crocker said that as a start-up company, AuraSense was not as sensitive to issues at the state and federal level, but very sensitive to the local environment. For example, any small firm can benefit greatly from incentives to make real estate investment for R&D or R&D infrastructure. "This lowers the costs of an organization," he said.

Mr. Moody said that his company was not yet paying income tax, but pays a great deal in other taxes. "When a company wants to relocate," he said, "a lot of states offer tax incentives. If they could translate those incentives into grants instead of tax breaks, they could help emerging, fast-growing companies."

Mr. Crocker added that the Obama administration had offered a grant program in 2011 that benefited small firms. "That improvement made it relevant for organizations in our position." Mr. Moody said that his firm, too, had participated. Another helpful incentive, said Mr. Crocker, was the angel tax credit that "indirectly benefits us through our investors. This is an example of a common-sense innovation to reward people who invested in innovation here in the state." Ms. Hattendorf said that a large multi-national company like Motorola looks for a stable tax environment when selecting a site a facility. "Having a predictable environment is critical for us," she said.

Roundtable

Best Practices, Lessons, and Opportunities

Moderator:
Charles Wessner, The National Academies

Tim Persons, Government Accountability Office

Jerry S. H. Lee, Center for Strategic Scientific Initiatives, National Cancer Institute, National Institutes of Health

Chad Mirkin, Northwestern University

Andy Ross, Office of the Governor

Dr. Lee began the roundtable with the topic of how to facilitate the transition of investigators from one agency or program to another. Within his own collaboration between cancer biologists and physical scientists, he said he had found some of the "handoffs" to be easy, as between the nanotechnology and physics program. "But what happens when you have to reach out to FDA and other places?" he asked. "There's a lot of discussion about local-level handoffs, students transitioning from academia and perhaps free-form structures, and how to reconcile entrepreneurial and academic metrics when designing a tenure track." He said that his agency was struggling to do as well with these issues as Northwestern and some other Illinois institutions.

Dr. Nagahara asked whether the "smooth handoff" to the two companies started by Dr. Mirkin—AuraSense and Nanosphere—was due to the presence of students in his lab who moved to the companies.

Dr. Mirkin agreed that the students are vital in the innovation process. "They do the experiments for the great discoveries that form the basis for the companies. At the same time," he said, "I typically don't mix students with companies. We in the university focus on solving fundamental problems; some

of them pertain to what a company will need, but the mission of the company is different from the mission at Northwestern, and we need to keep them separate."

"That said, many people trained within the lab environment are naturals as employees of a company, while others will want to do something completely different. For those who choose a company, that's ultimately a relationship they establish on their own. This has worked extremely well. We have had a remarkable ten years of productivity and inventions, and many of those inventions have led to important commercial products. The story is still being told. I wouldn't describe any of these companies as incredible successes, or failures. We're not going to know how far they will go for another decade. But it's looking pretty good."

A participant remarked that the United States is having troubling attracting enough people to careers in science and technology. "If they could see this pathway we're talking about," he said, "where you go through college, come to graduate school, and then have a choice of the academic route or this other venture capital route, it could be a major draw for more students."

Dr. Persons said he favored the use of prizes as incentives to innovators. He referred to the success of the X-Prize, the DARPA Grand Challenge for driverless vehicles, and others. "The brilliance of most of these," he said, "is the high return on investment they trigger, and the inspiration for young people who participate all over the world. When you have a clear vision, like President Kennedy wanting to send a person to the moon, there are all the derivative benefits of this dream of going to space and what it means to students from K-12 up."

Mr. Ross of the State of Illinois referred to Governor Quinn's emphasis on STEM education, and the Illinois Pathway Initiative, a public-private partnership that strives to interest school children in S&T careers. He also emphasized that most such needs in Illinois were "on hold" until the state took strong measures to resolve its pension crisis. "Right now," he said, "we have $83 billion in unfunded pension liabilities, and every day it grows larger."

Dr. Mirkin asserted that the current strategy for teaching secondary and tertiary science was poorly designed. In biology and chemistry, he said, students are not exposed to laboratory work—where the hands-on excitement begins—until the third or fourth year of college. "Up to that point, we tell them to read about it, and we'll test you on it; then read some more we'll test you on that. It's like setting out the bases for a baseball game and saying, Okay, for the next nine years we're going to study each of the positions. Once you've learned all those, we'll play a game. How many people will be excited by baseball?" He acknowledged that exposing students to labs was a lot of work and responsibility. "But it changes their view of science and maybe their lives. We have to give some thought as to how do that earlier."

Dr. Persons made the parallel point about emphasizing the vision for STEM education. "Yes, we're putting money into STEM ed. Will it go to internet access for classrooms? What is that for? Why is this important? We need to be saying, Here's what you can do to help change the world."

Dr. Wessner suggested bringing "some local heroes" into the classroom. "When you talk to people in public service, or maybe an astronaut, they still remember the time a leader came to their classroom and talked about an interesting life."

Dr. Mirkin agreed, saying he had done this many times. "But there's a flip side. You put on big shows for these kids, and they get excited. Then after it's over you ask how many want to be a scientist, and not a single hand goes up. You ask why, and they say it's too hard, it's too much work. That's the perception."

Michael Rosen, of the Illinois Science and Technology Park, spoke of a comprehensive effort to generate a more diverse S&E work force. "They don't all have to be PhD scientists," he said. "Our goal is to interest them in many different jobs of the future, such as nanotechnician. They can see there is employment in interesting work. We have been working with Oakton Community College, nine local high schools, the village of Skokie, the State of Illinois, the Illinois Science and Technology Coalition, and technicians from the company NanoInk to create a curriculum for high school students and community college students. Hopefully this will drive our training center at the Park and help us prepare people for jobs in what will be a growth industry for our state."

A graduate student spoke of his own efforts to interest high school students in STEM careers. "I love doing outreach myself, and the kids love to talk about it. But as a grad student you get buried under the work load and have to publish papers; it's hard to get out of the lab for a day, and have to explain to my boss that I'm going to do outreach that day. Grad students get paid for teaching; maybe part of their stipend should be for outreach to school kids."

Dr. Wessner noted that many U.S. trading partners were succeeding in building their innovation programs—"with a lot of help from government. In our country," he said, "we resist." He asked Mr. Ross if the governor's office could do more.

Mr. Ross said he totally agreed on the need to continue investing in infrastructure, both physical and human. He said that the governor, within his first 10 weeks in office, had shepherded through a capital program, some of which would go to universities. The state had also launched Advantage Illinois to spur small business growth. "We're doing what we can," he said. "At the same time, our needs are growing exponentially. We have to get our fiscal house in order, and then we can make the investments we need to help spark new companies." He also noted the need to celebrate the achievements that have been made.

Dr. Mirkin agreed that "we do the worst job in celebrating the successes that come out of this area, including the state level and the university level. Partly, it's a mindset, from being in the Midwest. Here, Lyrica is the biggest deal, and no one knows about it. I've sat through so many PCAST meetings where people brag about the things MIT and Harvard have done. On

the West Coast it's the same. We don't understand how important it is to communicate about achievements."

Dr. Wessner said that many countries found enormous advantages in communication and collaboration among the sectors: "They are setting up one-stop shops and are assigning special administrators from the government or universities to ease problems. So what they are doing is more than just easing taxes or other specific incentives—They are promoting ease of establishment for early-stage companies."

Mr. Taylor, who had worked in many capacities for NASA, asked Mr. Persons whether GAO had all the tools it needs to address the growing need to translate science "faster, better, and cheaper." Mr. Persons said that from a strategic—as opposed to an accounting—point of view, "there needs to be accountability at all levels, including the basic R&D. I think we have to get beyond the 'I'm a smart person, just shut up and give me the money' to better metrics to measure the effectiveness of R&D. The bottom line is that more work needs to be done."

Dr. Lee said that he had talked with GAO and shared some of his program's best practices and lessons learned in an effort to improve R&D metrics. "We have different types of models we shared with Tim, unofficially as a scientist, asking him to look at what we are doing. We said, "this is what we are seeing, what do you think? Is it a reasonable model system to support different sectors of cancer research? We do want feedback on this."

Dr. Wessner said that he had been impressed by the diversity and quality of programs in Illinois, including the efforts to address the Valley of Death and to ease the translation of technologies toward the market place. He said he was also impressed by the small scale and relative newness of those efforts, and urged that more be done to set up a policy framework that encourages those programs. "We have been impressed by the strong leadership at the state level," he said, and urged the legislature to bring in foundations as a major participant in building the Illinois innovation ecosystem.

He concluded the region has an effective asset base, and has achieved the essential step of sharing facilities between large companies and small. He reaffirmed the call to subsidize the early activities of start-up firms, not in the form of tax relief, which does not benefits firms too small to earn profits, but in the form of grants and R&D credits. "Where will that come from," he said, "I'm sure you wrestle with on daily basis. A larger argument is that we have to stop arguing with ourselves. It is other countries we're competing with, and they are playing hard."

Dr. Mirkin closed the proceedings by thanking the Academies and the many local organizers for a successful conference.

III

APPENDIXES

Appendix A

Agenda

Building the Illinois Innovation Economy

Organized in cooperation
with
Northwestern University, Illinois Science & Technology Coalition,
Office of Naval Research, Department of Energy,
and National Cancer Institute

June 28-29, 2012

The Allen Center
Northwestern University
Evanston, Illinois

DAY 1: JUNE 28

8:30AM **Welcome and Introduction**
Chad Mirkin, Northwestern University
Jay Walsh, Northwestern University

9:00AM **Opening Keynote: The Illinois Innovation Opportunity**
The Honorable Patrick Quinn, Governor of Illinois

9:30AM **Panel I: The Overall Innovation Challenge**
Moderator: Alicia Loffler, Northwestern University

The Global Innovation Imperative
Charles Wessner, The National Academies

An Overview of Federal Cluster Policy
John Fernandez, SNR Denton

10:30AM **Coffee Break**

10:45AM **Panel I Continued**

Challenges and Opportunities for the Illinois Innovation Economy
Mark Harris and Edward Fetters, Illinois Science & Technology Coalition

A Perspective from the IT Industry
Dennis Roberson, Illinois Institute of Technology (IIT)

11:45AM **Keynote: Innovation and the Clean Energy Challenges**
Eric Toone, Advanced Research Projects Agency for Energy (ARPA-E)

12:15PM **Working Lunch: How to Improve the Northwest Nano Cluster**

1:15PM **Panel II: Federal R&D Strategies**
Moderator: Tyrone Taylor, Capitol Advisors on Technology

New Innovation Models at the National Science Foundation
Thomas Peterson, Directorate for Engineering, National Science Foundation

ONR: A Unique Innovation Organization
Chris Fall, Office of Naval Research

The National Cancer Institute Innovation Strategy
Jerry S. H. Lee, Center for Strategic Scientific Initiatives, National Cancer Institute, National Institutes of Health

2:30PM **Coffee Break**

2:45PM **Panel III: Illinois Innovation Initiatives**
Moderator: William Testa, Federal Reserve Bank of Chicago

Inspiring Innovation
Julio Ottino, McCormick School of Engineering and Applied Science, Northwestern University

Engaging the Public in Support of Science and Technology
David Mosena, Chicago Museum of Science and Industry

Driving Entrepreneurship in Illinois
Robert Wolcott, Kellogg School of Management, Northwestern University

Disruptive Environments that Seed Discovery and Promote Translation
Thomas O'Halloran, Chemistry of Life Processes Institute, Northwestern University

The Bench to Bedside Story of Oncofertility
Teresa Woodruff, Northwestern University

4:30PM **Closing Keynote: Bringing Innovations to Market**
Chad Mirkin, Northwestern University

5:00PM **Adjourn**

DAY 2: JUNE 29

9:00AM **Welcome and Introduction**
Julio Ottino, McCormick School of Engineering and Applied Science, Northwestern University

9:05AM **Keynote Address**
Norbert Riedel, Baxter International

9:35AM **Panel IV: Innovation in Illinois: A Regional Case Study**
Moderator: Daniel Biss, Representative, 17th District, State of Illinois

The Role of Illinois Universities
Robert Easter, University of Illinois

The Federal Laboratory Contribution
Eric Isaacs, Argonne National Laboratory

Early-Stage Finance and Support in Illinois
David Miller, Illinois Biotechnology Industry Organization (iBIO®)

Capitalizing on the SBIR Opportunity for Illinois
Dan Berglund,
State Science and Technology Institute (SSTI)

11:00AM **Coffee Break**

11:15AM **Panel V: New Initiatives and Best Practices in Innovation**
Moderator: Chris Fall, Office of Naval Research

Disruptive Innovation: Measuring Success and Federal Role
Tim Persons, Government Accountability Office

Unconventional Innovative Approaches in Oncology via Physical Sciences Perspectives
Larry A. Nagahara, Office of Physical Sciences-Oncology, National Cancer Institute

New Initiatives at the University of Illinois
Caralynn Nowinski, University of Illinois

University Technology Transfer: Lessons from Lyrica™
Richard B. Silverman, Department of Chemistry, Northwestern University

Innovation Partnerships:
The University of Chicago-Argonne Case
Matthew Tirrell, Institute for Molecular Engineering, University of Chicago; and Argonne National Laboratory

12:45PM **Working Lunch: How to Improve the Northwest Nano Cluster**

1:45PM **Panel VI: The Industry Perspective on Illinois**
Moderator: Van Crocker, AuraSense Therapeutics

Roger Moody, Nanosphere
Heidi Hattendorf, Motorola Solutions

2:45PM **Roundtable: Best Practices, Lessons, and Opportunities**
Moderator: Charles Wessner, The National Academies

Tim Persons, Government Accountability Office
Jerry S. H. Lee, Center for Strategic Scientific Initiatives, National Cancer Institute, National Institutes of Health
Chad Mirkin, Northwestern University
Andy Ross, Office of the Governor

3:45PM **Adjourn**

Appendix B

Biographies of Speakers
(as of June 2012)

DAN BERGLUND

Dan Berglund is the President and CEO of SSTI, a non-profit organization that leads, supports, and strengthens efforts to improve state and regional economies through science, technology, and innovation.

SSTI is the most comprehensive resource available for those involved in technology-based economic development. Leading SSTI since its inception in 1996, Mr. Berglund has helped SSTI develop a nationwide network of practitioners and policymakers dedicated to improving the economy through science and technology. SSTI works with this network to assist states and communities as they build tech-based economies, conduct research on best practices and trends in tech-based economic development, and encourage cooperation among and between state and federal programs.

Prior to joining SSTI, Mr. Berglund worked as a consultant and for the Ohio Department of Development in a variety of positions, including Acting Deputy Director of the Division of Technological Innovation. Mr. Berglund holds a B.A. in Economics and Political Science and a B.A. in History from Ohio University.

DANIEL BISS

Daniel Biss represents the 17th House District in the Illinois General Assembly. Daniel is a former math professor at the University of Chicago and is serving his first term in the House of Representatives. He is currently the Democratic candidate for the Illinois State Senate in the 9th District.

Since he was elected to office in 2010, Daniel has passed legislation on a variety of issues, including environmental policy, high-tech economic growth, political reform, equal rights for individuals with autism and consumer protection. He rapidly emerged as an acknowledged leader on fiscal matters,

pushing both parties to overhaul the budget process to align spending with available revenue while preserving our top priorities. He won an uphill battle to pass legislation that doubled the amount of electronic waste manufacturers are required to recycle. Daniel also played a pivotal role in passing legislation to support Illinois's high-tech entrepreneurs by tripling investments in Illinois venture capital at no cost to taxpayers, an effort that had stalled in the House in previous years.

In just his first term, Daniel has already earned broad acclaim for his leadership and accomplishments. The Illinois Recycling Association recognized Daniel as a Recycling Hero; he won the Legislator of the Year award from the Illinois Association of Park Districts and was given the John W. Maitland Award by the Illinois Biotechnology Industry Organization. Daniel served as a co-chair for a bipartisan working group to explore solutions to address the state's pension crisis and was recently appointed to chair the state's Digital Divide Elimination Advisory Committee.

Daniel serves on seven House Committees: Higher Education Appropriations, Elementary and Secondary Education Appropriations, Bio-Technology, Consumer Protection, International Trade and Commerce, Personnel and Pensions, and Small Business and Empowerment and Workforce Development.

With State Senator Jeff Schoenberg's retirement at the end of the 2012 legislative session, Daniel is running for the open 9th State Senate district seat. The 9th district includes Golf, Kenilworth, Northfield, Wilmette, and Winnetka, and parts of Evanston, Glencoe, Glenview, Morton Grove, Northbrook and Skokie.

Daniel is married to Karin Steinbrueck, a doctoral candidate in history at Northwestern University. Daniel and Karin live in Evanston with their two young children, Elliot and Theodore. Daniel holds a doctorate in mathematics from MIT and an undergraduate degree in mathematics from Harvard University.

VAN CROCKER

Percy "Van" Crocker brings extensive licensing, partnership, and strategic experience to AuraSense Therapeutics. After a 10-year career in consulting and business development, he joined AuraSense, LLC in 2009 as Vice President of Commercial Development and joined AuraSense Therapeutics in the same role at its founding. From 2006 to 2009, Van was a member of the Healthcare Practice at Booz Allen Hamilton/ Booz & Company, where he engaged Fortune 500 clients in strategic initiatives including corporate restructuring and M&A. Prior to Booz & Company, Van was the first employee and Associate Director of Business Development at NanoInk, Inc., a nanotechnology firm founded by Dr. Chad Mirkin in 2000. While at NanoInk, he closed multiple funded license and co-development partnerships in the

pharmaceutical and electronics industries. He was also a member of the senior management team and directed the company's patent portfolio of 100+ filings.

Van began his career as a Senior Consultant at Oracle Corporation, where he oversaw the implementation of complex financial software for multiple Fortune 500 corporations. Van holds an MBA with honors in Finance, Management & Strategy and Entrepreneurship from the Kellogg School of Management at Northwestern University and a Bachelor of Science degree in Commerce from the University of Virginia.

ROBERT EASTER

Robert A. "Bob" Easter was appointed president-designate of the University of Illinois in March 2012, and will become the University's 19th president on July 1, 2012. Through June, he will work with outgoing President Michael J. Hogan, leading the University's campuses in Chicago, Springfield and Urbana-Champaign—with more than 77,000 students, 22,000 faculty, and staff, a $5 billion annual budget, and a nearly $800 million research portfolio. Easter has spent his entire 36-year career as a senior administrator and faculty member on the Urbana-Champaign campus, where he earned his doctorate in animal science in 1976. He was interim chancellor from 2009 to 2011, serving as chief executive officer of the 42,000-student campus, and also has served as interim provost and interim vice chancellor for research.

From 2002 to 2009, he was dean of the nationally ranked College of Agricultural, Consumer and Environmental Sciences (ACES). Before that, he served for five years as head of the Department of Animal Sciences, where he has been a faculty member since 1976.

An expert in swine nutrition, Easter has co-authored a book on swine production and has written more than 90 peer-reviewed articles, 11 book chapters, four monographs and numerous papers for conferences and industry publications. He also has spoken to audiences in the U.S. and 27 foreign countries on swine nutrition.

In 2006, he was appointed by President George W. Bush to the Board for International Food and Agricultural Development (BIFAD), and was appointed as interim chair of BIFAD in 2007. He also is a member of the American Society of Animal Science, the British Society of Animal Science, The American Registry of Professional Animal Scientists, The Council for Agricultural Science and Technology and the Illinois Council for Food and Agricultural Research (C-FAR).

Reared on a grain and livestock farm in southwest Texas, Easter earned an undergraduate degree in agricultural education in 1970 and a master's degree in animal nutrition in 1972, both from Texas A&M University. He completed a doctorate in animal science at the University of Illinois in 1976 and immediately joined the Animal Science Department as an assistant professor of swine nutrition and management. He presently holds the rank of Professor.

His teaching has been recognized by the Midwest Section of the American Society of Animal Science and at the departmental and college levels. In 1992, Easter received the American Feed Industry Association Award in Nonruminant Nutrition Research from the American Society of Animal Science. In 1994, the University of Illinois College of Agriculture awarded Easter with the prestigious Paul A. Funk Award for contributions to Illinois agriculture.

CHRIS FALL

Chris Fall is the Director of the International Liaison Office for the Office of Naval Research—Global. Most recently, Chris was the ONR Innovation Fellow, serving as a senior advisor for innovation policy and practice. Because ONR fosters and supports a range of missions from diverse basic research, through development of advanced prototypes, to transition of technology for urgent operational needs—all in one integrated organization—it is a unique model of innovation for the Federal government. As the ONR Innovation Fellow, Chris was the ONR liaison for the Director of Innovation to the rest of government, industry and academia, and he worked both to disseminate the important lessons ONR has learned over a long and distinguished history, and to bring back to ONR the best new ideas in innovation.

Chris serves at ONR under the Intergovernmental Personnel Act. He is on loan from the BioEngineering department at the University of Illinois at Chicago, and is on leave as a senior scientist from the biotech company Informed Simplifications. Earlier, Chris earned his Ph.D. from the University of Virginia in Neuroscience and completed research fellowships at the University of California at Davis Institute for Theoretical Dynamics and the New York University Center for Neural Sciences. While in Washington, Chris continues part-time research and teaching at Georgetown University, where he is visiting faculty in the Department of Computer Science.

JOHN FERNANDEZ

John Fernandez serves as SNR Denton’s Innovation Strategy Director and Partner in the Public Policy and Regulation practice. Prior to joining the firm, he served as President Barack Obama's Assistant Secretary of Commerce for Economic Development.

As Innovation Strategy Director, John leverages his experience effectively transforming complex organizations to compete in the 21st century global economy. He works closely with the firm's lawyers and professionals to identify and deploy client service solutions that fully capitalize on SNR Denton’s diverse legal expertise, industry thought leadership, global footprint and entrepreneurial spirit.

With more than 13 years of executive experience, John has earned a reputation as a strategic thinker and creative problem solver. The United States

Senate unanimously confirmed President Obama's appointment of him in 2009 to head the Economic Development Administration ("EDA"), where John was the chief architect of the administration's regional innovation strategies. During his tenure, he launched new coordinated federal initiatives to accelerate innovation-based growth strategies, including the "i6 Challenge" and the "Jobs and Innovation Accelerator Challenge." Additionally, John re-engineered the business processes at the EDA, reducing grant-making decision cycles from 128 business days to less than 20.

While at the U.S. Department of Commerce, John represented the United States government at the Organization for Economic Cooperation and Development ("OECD") where he served as Chairman of the Territorial Development Policy Committee.

Prior to his appointment, John led the new development and acquisition team at First Capital Group, an Indiana-based real estate investment firm. He played a critical role in expanding the firm's regional and national investment footprint. John also served as of counsel for an Indianapolis-based law firm, where he advised private and governmental organizations on economic development, public finance and policy issues.

John also served as the mayor of Bloomington, Indiana, from 1996 to 2003. Under his leadership, Bloomington's economy thrived, despite facing significant changes arising from globalization. John worked with business and Indiana University leaders to launch Bloomington's Life Sciences Partnership, securing more than $243 million in private investments and creating more than 3,700 jobs. He also developed an aggressive downtown revitalization plan resulting in more than $100 million in new investments.

MARK HARRIS

Mark Harris joins the Illinois Science & Technology Coalition with more than a decade of experience in government, economic development, and higher education. As President and CEO, Mark is focused on building upon the ISTC's highly collaborative public-private partnerships to advance Illinois as a hub for research, innovation, and investment. Prior to his leadership with the Coalition, Mark served as a deputy chief of staff for Illinois Governor Pat Quinn and also held senior positions at the Illinois Department of Commerce and Economic Opportunity. He also worked as the associate director for the Polsky Center for Entrepreneurship at the University of Chicago Booth School of Business. Mark currently co-chairs the Illinois Workforce Investment Board's Entrepreneurship Task Force, which focuses on promoting entrepreneurial education at the state and local level. He is Chilean-American and is fluent in Spanish. Mark holds a B.S. from the University of Illinois Urbana-Champaign and an M.A. from the University of Chicago.

HEIDI HATTENDORF

Heidi Hattendorf is the Director of Innovation Development at Motorola Solutions in the Emerging Business Office, part of the Chief Technology Office. She brings over 20 years experience in Telecoms from Public Safety and two-way radio to consumer mobile phones and network solutions on 3G/4G. Heidi led several new business areas and managed from customer requirements to product development through to promotion including full P&L management. She has an undergraduate degree in Business and an MBA in Global Marketing Management. She has extensive global experience having lived and worked overseas in both Madrid, Spain, and London, UK, where she held Global portfolio management roles. She spent the past 11 years overseas and repatriated to the United States a year ago to focus on driving Innovation. She is fluent in English and Spanish.

Heidi is now taking her broad ranging communications expertise, multiple vertical market and extensive customer facing experience plus global presence having lived and worked in 3 countries plus roles spanning over 40 countries towards driving Innovation. She heads up an Innovation team focused on identifying, creating opportunities and investments in adjacent markets and technologies to drive growth. Heidi is also responsible globally for the Innovation framework which harnesses and drives ideas from within the teams to create new solutions for the market. She is currently based in the Chicago area working at the Motorola Solutions Global headquarters.

ERIC ISAACS

Eric D. Isaacs, a prominent University of Chicago physicist, is President of the University of Chicago Argonne, LLC, and Director of Argonne National Laboratory.

Before becoming Argonne Director, Isaacs served as Argonne's deputy laboratory director for programs, with responsibility for leading the laboratory's strategic planning process and overseeing the laboratory-directed research and development program as well as its educational programs. Earlier he distinguished himself both as director of the Center for Nanoscale Materials at Argonne and as professor of physics in the University of Chicago's James Franck Institute. During his 13-year tenure at Bell Laboratories, he was a member of the technical staff, director of the Materials Physics Research Department and director of the Semiconductor Physics Department.

He received a Ph.D. degree from the Massachusetts Institute of Technology in 1988 in the area of magnetic semiconductors and was a postdoctoral fellow at Bell Laboratories (1988-1990) studying magnetism and correlated electronic systems, mostly with synchrotron-based X-ray techniques. He is a fellow of the American Physical Society and served on a number of national scientific advisory committees, including the Basic Energy Sciences

Advisory Committee. He is author or co-author of more than 140 scientific papers and presentations.

JERRY S. H. LEE

Jerry Lee serves as the Deputy Director for the National Cancer Institute's (NCI) Center for Strategic Scientific Initiatives (CSSI). He provides scientific input to the planning, development, and deployment of programs to carry out the Center's mission to build exploratory initiatives focused on the integration of advanced technologies, trans-disciplinary approaches, infrastructures, and standards, to accelerate the creation of publicly available, broadly accessible, multi-dimensional data, knowledge, and tools to empower the entire cancer research continuum for patient benefit. Dr. Lee serves and leads various trans-NCI working groups and also represents CSSI at various NIH, HHS, and external committees and other activities to develop effective partnerships across Federal agencies, and to build collaborations with key external stakeholders.

Through the CSSI Office of the Director, he is responsible for scientific, programmatic, and operational management of CSSI's broad scientific portfolio (~$145 million per year) carried out by more than 80 staff members within CSSI offices including: The Cancer Genome Program Office (TCGA PO), Office of Cancer Nanotechnology Research (OCNR), Office of Biorespositories and Biospecimen Research (OBBR), Office of Cancer Genomics (OCG), Office of Cancer Clinical Proteomics Research (OCCPR), and Office of Physical Sciences-Oncology (OPSO). Dr. Lee also currently serves as Acting Director of TCGA PO. Dr. Lee's efforts facilitate the execution of cross-disciplinary strategies and synergies in key areas of research and training to support these emerging fields. His past experience at NIH includes serving as a program manager for the NCI's Innovative Molecular Analysis Technologies (IMAT) program and the NCI Alliance for Nanotechnology in Cancer program, where he was Program Director of fellowships to support multidisciplinary training in cancer nanotechnology. Dr. Lee's previous research experiences in coordinating collaborations among the Naval Research Laboratory, NCI-Frederick Laboratory, Johns Hopkins University Medical Oncology Division, and the Institute for NanoBioTechnology also contribute to carrying out his current efforts.

Scientifically, Dr. Lee has extensive research experience in using engineering-based approaches to examine mechanisms of age-related diseases and cancer progression focused on combining cell biology, molecular biology, and engineering to understand various cellular reactions to external stimuli. Specifically, Dr. Lee's research has emphasized increasing the understanding of RhoGTPase-mediated nuclear and cellular mechanical responses to fluid flow, 3D culture, and contributions to laminopathies such as progeria. He has co-authored numerous papers, two book chapters, one book, and has spoken at various cell biological and biomedical conferences.

Dr. Lee currently serves as adjunct assistant professor at Johns Hopkins University, where he also earned his bachelor's degree in biomedical engineering and Ph.D. degree in chemical and biomolecular engineering.

ALICIA LÖFFLER

Alicia Löffler is globally recognized as a leader in biotechnology education and life science entrepreneurship. She consults widely with start-ups in the United States, Asia and Europe. Dr. Löffler is the Director of the Kellogg Center for Biotechnology Management. The center is an educational and research organization focused on management of the biotechnology, pharmaceutical and medical device sector. Dr Löffler launched the center in 2001 and is responsible for the center's strategies and operations.

Previous to this position, she directed the University-wide Northwestern University Center for Biotechnology (sciences, engineering and Medical School). Dr. Löffler created the Center's educational programs including the Master's Program in Biotechnology, the Summer Biotechnology Institute, and career development programs.

Dr. Löffler served as advisor of: Baird Venture Partners; founding Board Member of the Biotechnology Institute, Washington, DC; Biopharmaceutical Center at the WHU in Koblenz, Germany, and multiple biotechnology companies. She consulted extensively on technology assessment issues for major pharmaceutical companies and Universities in the United States. She also served at as the Board Member and Past-Chair, Council for Biotechnology Centers (BIO), and Board Member, Emerging Companies, Biotechnology Industry Organization and the Governor's Edgar Council for Biotechnology.

She was recently named one of the Tech 100 stars by Crain's Chicago Business and received the "Women in Black" I-Street award. She is completing her second book, *Rethinking the Biotechnology Model*. Dr. Löffler received her B.S. from the University of Minnesota, Ph.D. from the University of Massachusetts, and post-doctoral in biochemical engineering from Caltech.

DAVID MILLER

David Miller is President and chief executive officer of the Illinois Biotechnology Industry Organization—better known world-wide as iBIO®. iBIO's mission is to make Illinois and the surrounding Midwest one of the world's top life sciences centers: a great place to do business, and a great place to grow new technology ventures. iBIO's membership develops and markets agricultural, industrial, and medical applications.

Miller is also President, chief executive officer, co-founder and a member of the Board of Directors of the iBIO Institute, a public charity. The mission of the iBIO Institute is to orchestrate business leadership in delivery of world-class educational programs and job-creating new technology ventures.

Prior to joining iBIO, Miller held executive positions for technology startups in Silicon Valley, Chicago, and Wisconsin. Before that, he served as business aide for the Mayor of Madison, Wisconsin, where he initiated a world-first quality-productivity effort and drove the City's establishment of the heralded University of Wisconsin Research Park. Miller also led successful projects for major divisions of Fortune 500 companies.

He is the recipient of the 2009 Abraham Lincoln National Agriculture Award for Technology, and a member of the Board of Governors of Chicago Innovation Mentors, a joint undertaking in support of entrepreneurs founded by iBIO Institute, Northwestern University, the University of Chicago and the University of Illinois at Chicago,. He is also a member of the External Advisory Board of the Chicago Biomedical Consortium, a collaboration among scientists at those three universities funded by $50+ million in grants from the Searle Family Funds at the Chicago Community Trust.

Miller earned his B.A. degree from Tufts University and his J.D. from the Case Western Reserve University School of Law.

CHAD MIRKIN

Chad A. Mirkin is the Director of the International Institute for Nanotechnology and the George B. Rathmann Professor of Chemistry, Professor of Chemical and Biological Engineering, Professor of Biomedical Engineering, Professor of Materials Science and Engineering, and Professor of Medicine.

Professor Mirkin is a chemist and a world-renowned nanoscience expert, who is known for his development of nanoparticle-based biodetection schemes, the invention of Dip-Pen Nanolithography, and contributions to supramolecular chemistry, nanoelectronics, and nanooptics. He is the author of over 440 manuscripts and over 400 patents and applications, and the founder of three companies, Nanosphere, NanoInk, and Aurasense which are commercializing nanotechnology applications in the life science and semiconductor industries. Currently, he is listed as the most cited (based on total citations) chemist in the world with the second highest impact factor and the top most cited nanomedicine researcher in the world. At present, he is a member of President Obama's Council of Advisors for Science and Technology.

Dr. Mirkin has been recognized for his accomplishments with over 60 national and international awards. These include the $500,000 Lemelson-MIT Prize, the Taylor Award, Havinga Medal, the Gustavus John Esselen Award, the Biomedical Engineering Society's Distinguished Achievement Award, a Department of Defense NSSEFF Award, the Pittsburgh Analytical Chemistry Award, the ACS Inorganic Nanoscience Award, the iCON Innovator of the Year Award, a NIH Director's Pioneer Award, the Collegiate Inventors Award, the National Inventors Hall of Fame (2002, 2004), an Honorary Doctorate Degree from Dickinson College, the Pennsylvania State University Outstanding Science Alumni Award, the ACS Nobel Laureate Signature Award for Graduate Education in Chemistry, a Dickinson College Metzger-Conway Fellowship, the

2003 Raymond and Beverly Sackler Prize in the Physical Sciences, the Feynman Prize in Nanotechnology, the Leo Hendrick Baekeland Award, Crain's Chicago Business "40 under 40 Award," the Discover 2000 Award for Technological Innovation, I-Street Magazine's Top 5 List for Leading Academics in Technology, the Materials Research Society Young Investigator Award, the ACS Award in Pure Chemistry, the PLU Fresenius Award, the Harvard University E. Bright Wilson Prize, the BF Goodrich Collegiate Inventors Award, the Camille Dreyfus Teacher-Scholar Award, the Alfred P. Sloan Foundation Award, the DuPont Young Professor Award, the NSF Young Investigator Award, the Naval Young Investigator Award, the Beckman Young Investigator Award, and the Camille and Henry Dreyfus Foundation New Faculty Award.

He is a member of the National Academy of Engineering, the National Academy of Sciences, and the Institute of Medicine. Dr. Mirkin has served on the Editorial Advisory Boards of over twenty scholarly journals. At present he is a member of the Editorial Advisory Boards of *Journal of American Chemical Society*, *Angewandte Chemie* (International Edition), *Accounts of Chemical Research*, *Advanced Materials*, *BioMacromolecules*, *Macromolecular Bioscience*, *SENSORS*, *Encyclopedia of Nanoscience and Nanotechnology*, *Chemistry-A European Journal*, *Chemistry & Biology*, *Nanotechnology Law & Business*, *The Scientist*, *Journal of Materials Chemistry*, and *Journal of Cluster Science, Plasmonics*. He is the founding editor of the journal *Small*, one of the premier international nanotechnology journals, and he has co-edited two bestselling books on nanobiotechnology.

Dr. Mirkin holds a B.S. degree from Dickinson College (1986, elected into Phi Beta Kappa) and a Ph.D. degree in chemistry from the Pennsylvania State University (1989). He was an NSF Postdoctoral Fellow at the Massachusetts Institute of Technology prior to becoming a chemistry professor at Northwestern University in 1991.

ROGER MOODY

Roger Moody joined Nanosphere in 2007 as Chief Financial Officer and Vice President of Finance & Administration. He also serves as the Company's Treasurer and Secretary. Mr. Moody has more than 20 years of experience in leading finance, corporate development and operations for high-growth healthcare and technology companies. Previously, Mr. Moody spent six years at Medsn, a medical education company where he joined as chief financial officer and chief operating officer. Mr. Moody also served as chief financial officer and led corporate development for two private venture-backed companies sold to strategic partners. Additionally, Mr. Moody provided mergers and acquisition and strategic advisory services to technology and healthcare companies for Volpe Brown Whelan & Company. Mr. Moody began his career at IBM. Mr. Moody received his B.S. from Syracuse University and his M.B.A. from the University of Chicago, Graduate School of Business.

DAVID MOSENA

David R. Mosena is the sixth President and CEO of Chicago's Museum of Science and Industry, which opened in l933. One of the world's largest, most popular and well-known science and technology museums, MSI welcomes an average of 1.5 million guests annually, presents a wide range of iconic and cutting-edge exhibits and offers strong education programs designed to inspire and motivate student interest in science and technology and train teachers to improve science instruction in primary and secondary schools.

In December 2010, the Museum concluded a $205 million capital campaign to renew its permanent exhibitions, transform its education programs and reinvent the guest experience. The Museum's new exhibitions have won international acclaim, and its education programs provide life-changing experiences to 5,000 inner city youth each year. Courses provided to up to 1,000 science teachers annually are changing how science is taught in the classroom and improving student achievement. Mr. Mosena currently serves on the Board of the Association of Science Technology Centers in Washington, DC.

Active in Chicago's civic and business community, he served as Chairman of the Interim Board of the Metropolitan Pier and Exposition Authority (which owns and operates McCormick Place and Navy Pier), Co-Chaired the Transition Committee for Chicago Mayor Rahm Emanuel, is a member of the Board of Directors of the Chicago Convention & Tourism Bureau, a member of the Illinois Institute of Technology's College of Science and Letters Board of Overseers and a member of the Metropolis Strategies Board. He is also a member of the Commercial Club and the Economic Club of Chicago. He served as Chairman of the Commission on Chicago Landmarks from 1999 to 2010 and Chairman of the Board of the University of Chicago's K-12 Laboratory Schools from 1993 to 1999.

Before his appointment to lead MSI in 1997, Mr. Mosena was President of the Chicago Transit Authority, the nation's second largest transit system delivering bus and train service to the City of Chicago and 38 suburbs and providing 1.5 million rides per day.

From 1992 to l996, Mr. Mosena served as Chicago Commissioner of Aviation, overseeing the expansion and operations of Chicago's airport system, including O'Hare and Midway Airports. During his leadership of Chicago's airports, O'Hare's International Terminal was completed, along with the automated people mover system. At Midway Airport, he initiated the design, financing and construction of $1 billion in landside improvements, including the new terminal and its 41 gates.

Prior to being appointed Aviation Commissioner, Mr. Mosena served as Chicago Mayor Richard M. Daley's Chief of Staff, coordinating the activities of all city departments, as well as focusing on issues of city development, and before that as Chicago's City Planning Commissioner.

He holds an M.A. in city planning and a B.A. in business administration, both from the University of Tennessee.

LARRY NAGAHARA

Larry Nagahara is Acting 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 three 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.

CARALYNN NOWINSKI

As the Associate Vice President for Innovation & Economic Development at the University of Illinois, Caralynn promotes strategic relationships between the University community and external stakeholders to foster technology commercialization, talent development and retention, and overall economic impact. She offers a unique perspective to the University's efforts to foster innovation and stimulate the Illinois economy, drawing from her past experiences as an entrepreneur, physician and venture capitalist.

Prior to joining the University, Caralynn was a Senior Vice President in the Chicago Office of Sikich Investment Banking, offering corporate finance and M&A advisory services to high-tech clients. Previously, she was a Principal with early-stage venture capital firms ARCH Development Partners and Midwest Venture Partners. As a graduate student, she co-founded SanoGene

Therapeutics, an early-stage biotechnology company, where, as CEO, she led the company's spin-out from the University of Illinois and raised a strategic equity investment. Caralynn is a Governor-appointed member of the Illinois Innovation Council. Among her honors, she was named to the Crain's Chicago Business 2008 "Forty Under Forty" List, and she is a frequent guest speaker on technology entrepreneurship and investment.

THOMAS O'HALLORAN

Thomas O'Halloran, Ph.D., is widely known for his interdisciplinary research program which involves chemical synthesis, inorganic chemistry, biochemistry, molecular biology, and cell biology. He is currently the Charles E. and Emma H. Morrison Professor in the Department of Chemistry and in the Department of Biochemistry, Molecular Biology and Cell Biology at Northwestern and serves as Director of the Chemistry of Life Processes (CLP) Institute at Northwestern. The CLP, established in 2005, brings together investigators in chemistry, engineering, biology and medicine, fostering a new wave of innovation, and providing both basic and real world scientific outcomes derived from the molecular basis of life. Strong collaborations between the CLP and the Lurie Cancer Center represent the unique strength of Northwestern.

Dr. O'Halloran's research interests focus on the regulatory biology and chemistry of intracellular metal receptors involved in signaling, trafficking and differentiation pathways. Recent work in his group has led to the development of new types of therapeutic agents for the targeted delivery of well established cytotoxic agents (organic and inorganic) to cancer cells. These ongoing nanotechnology studies have led to new multifunctional anticancer agents. Dr. O'Halloran's research also focuses on how metals control cellular growth and proliferation. The interdisciplinary approach employs genetics, structural biology, synthetic chemistry and biochemistry to understand the function of novel intracellular regulatory and trafficking receptors for zinc, copper and iron. These studies reveal mechanisms of oxidative damage, mechanisms of metal trafficking by metallochaperones and molecular mechanisms of gene regulation by metalloregulatory proteins. Results from his lab provide a basis for understanding the mechanisms of anticancer drugs, such as those containing platinum and arsenic, and guides the development of agents with improved therapeutic index.

Dr. O'Halloran's scientific recognitions include the NSF Presidential Young Investigator Award, National Searle Scholars Award, an Alfred P. Sloan Research Fellowship, the Camille and Henry Dreyfus Foundation Teacher-Scholar Award, and the American Society of Biochemistry and Molecular Biology Schering-Plough Scientific Achievement Award. He is a Fellow of the American Association for the Advancement of Science, a John Simon Guggenheim Fellow, and received a MERIT award from the National Institutes of Health. Dr. O'Halloran has served in leadership positions within the Lurie Cancer Center since 1999.

JULIO OTTINO

Dr. Julio M. Ottino is currently dean of the Robert R. McCormick School of Engineering and Applied Sciences at Northwestern University and holds the titles of Distinguished Robert R. McCormick Institute Professor and Walter P. Murphy Professor of Chemical and Biological Engineering. Prior to his tenure as dean, Ottino cofounded the Northwestern Institute on Complex Systems (NICO). He is a member of both the National Academy of Engineering and the American Academy of Arts and Sciences.

TIMOTHY PERSONS

Timothy M. Persons was appointed the Chief Scientist of the United States Government Accountability Office (GAO—the investigative arm of the U.S. Congress) in July of 2008. He was also appointed as the Co-Director of GAO's Center for Science, Technology, and Engineering (CSTE) in October of 2008, a group of highly specialized scientists, engineers, mathematicians, and information technologists. In these roles he is an expert advisor and chief consultant to the GAO, Congress, and other federal agencies and government programs on cutting-edge science and technology (S&T), key highly-specialized national and international systems, engineering policies, best practices, and original research studies in the fields of engineering, computer, and the physical and biological sciences to ensure efficient, effective, and economical use of science and technology in government programs. He also works with GAO's Chief Technologist to lead the production of Technology Assessments for the U.S. Congress.

In 2007, Dr. Persons was awarded a Science and Technology Fellowship focusing on computational imaging systems research. He was also selected as the James Madison University (JMU) Physics Alumnus of 2007. He has also served as a radiation physicist with the University of North Carolina at Chapel Hill. He received his B.Sc. (Physics) from JMU, a M.Sc. (Nuclear Physics) from Emory University, and a M.Sc. (Computer Science) and Ph.D. (Biomedical Engineering) degrees from Wake Forest University. He is a senior member of the Institute for Electrical and Electronic Engineers (IEEE), Association for Computing Machinery (ACM), and the Sigma Xi research honor society and has authored or co-authored an array of journal, conference, and technical articles.

THOMAS PETERSON

Dr. Thomas W. Peterson is assistant director for the Directorate for Engineering at the National Science Foundation (NSF). Prior to joining NSF, he was dean of the College of Engineering at the University of Arizona. He received his Bachelor of Science from Tufts University, his Master of Science from the University of Arizona and his doctorate from the California Institute of

Technology, all in chemical engineering. He has served on the faculty of the University of Arizona since 1977, as head of the chemical and environmental engineering department from 1990 to 1998, and as dean from 1998 until January 2009.

During his service as dean, Peterson was a member of the executive board for the engineering deans' council (EDC) of ASEE and was vice-chair of EDC from 2007 to 2008. He has served on the board of directors of the Council for Chemical Research and on the Engineering Accreditation Commission (EAC) of the Accreditation Board for Engineering and Technology (ABET). He was one of the founding members of the global engineering deans' council, and at Arizona, he made global education experiences a high priority for his engineering students. He is a fellow of the American Institute of Chemical Engineers and a recipient of the Kenneth T. Whitby Award from the American Association for Aerosol Research.

The ENG Directorate at NSF provides critical support for the nation's engineering research and education activities, and is a driving force behind the education and development of the nation's engineering workforce. With a budget of approximately $640 million, the directorate supports fundamental and transformative research, the creation of cutting-edge facilities and tools, broad interdisciplinary collaborations, and through its centers and Small Business Innovation Research programs, enhances the competitiveness of U.S. companies.

PATRICK QUINN

Pat Quinn was sworn in as the 41st Governor of Illinois on January 29, 2009. He won election to a full term on November 2, 2010.

Governor Quinn has focused on restoring integrity to state government and, in his first official act, signed an executive order establishing the Illinois Reform Commission to examine ethics rules and practices in state government. He also led passage of fundamental legislation to return integrity to the state pension boards, ensure state agency compliance with Freedom of Information laws and increase transparency of state boards and commissions.

Dedicated to investing in Illinois' economy, Quinn worked with the General Assembly to pass a $31 billion capital construction jobs program to create and retain more than 436,000 jobs over six years. Since taking office he has made tough, responsible choices to ensure that the state of Illinois can afford to pay its bills.

The Governor's efforts to boost the Illinois economy include passing business and tech-friendly legislation that strengthens Illinois' place as capitol of the Midwest. He created the Illinois Innovation Council to promote and attract innovation-driven entrepreneurs to the state. For his work increasing Illinois' economic, scientific, and technological output, Quinn was named the 2011 Governor of the Year by the Biotechnology Industry Organization. In addition to working to double state exports by 2015, he has also made significant

investments in transportation, education and healthcare infrastructure that will create jobs and keep Illinois competitive in the 21st century global economy.

Quinn has served the people of Illinois for more than 30 years as both a citizen and a public official. He has organized grassroots petition drives signed by more than four million voters, walked across the state in support of decent health care for all, and proposed historic tax reform for working families. He was elected Lieutenant Governor in 2002 and re-elected in 2006, serving until his succession as Governor in January 2009, and served one term as State Treasurer from 1991 to 1995. He also served as commissioner of the Cook County Board of (Property) Tax Appeals and as revenue director for the City of Chicago.

As Lieutenant Governor, Quinn created the Illinois Military Family Relief Act, which provides financial assistance to families of Illinois National Guard members and reservists called to active duty. The fund has distributed more than $10 million to Illinois military families.

Quinn was born in Chicago and raised in Hinsdale and graduated from Northwestern University School of Law and Georgetown University School of Foreign Service. He is the father of two sons.

NORBERT RIEDEL

Norbert G. Riedel is corporate vice president and chief science and Innovation officer of Baxter International Inc., having served in that capacity since March 2001. Before assuming this role, Dr. Riedel served as president of the recombinant proteins business unit and vice president of research and development within Baxter's BioScience business. Prior to joining Baxter in 1998, he was head of worldwide biotechnology and worldwide core research functions at Hoechst Marion Roussel, now Sanofi-Aventis.

Dr. Riedel is a member of the Board of Directors of Medigene AG, ARIAD Pharmaceuticals Inc., and the Illinois Biotechnology Industry Organization. He also serves on the Advisory Board of Northwestern University's Kellogg School of Management Center for Biotechnology, the McCormick School of Engineering and was most recently appointed by Illinois Governor Pat Quinn to the newly formed Illinois Innovation Council. He is also a member of the board of trustees of the Chicago Symphony Orchestra.

Dr. Riedel received his Ph.D. in biochemistry from the University of Frankfurt in 1983. He was a postdoctoral fellow at Harvard University from 1984 to 1987, assistant professor and associate professor of medicine and biochemistry at Boston University School of Medicine from 1987 to 1991, and a visiting professor at Massachusetts Institute of Technology in 1992. He remains affiliated with Boston University as an adjunct professor and also serves as an adjunct professor of medicine at Northwestern University's Feinberg School of Medicine. In 2009, Dr. Riedel was elected into the Austrian Academy of Sciences.

DENNIS ROBERSON

Dennis Roberson is an accomplished executive, educator, and engineer with a strong semiconductor background and a proven track record in technology leadership and business management. Currently active in academia, government and the private sector, Roberson joined Zarlink's Board in November 2004.

Roberson is Vice Provost, Executive Director, and Research Professor with the Illinois Institute of Technology, where he is responsible for providing leadership for a new undergraduate business school focused on entrepreneurship and technology, as well as developing research centers and business ventures in association with public and private sector partners.

Previously, Roberson held Vice President and Chief Technical Officer positions with Motorola and NCR Corporation, and held senior executive positions with AT&T and Digital Equipment Corp. He spent 18 years with IBM in a variety of R&D roles, including director of IBM's labs in Endicott, New York, and Burlington, Vermont.

Roberson also serves on the FCC's (Federal Communications Commission) Technology Advisory Committee, the Board of Directors for FIRST Robotics, and as a technology advisor to government agencies in Japan and Malaysia.

RICHARD SILVERMAN

Richard B. Silverman is the John Evans Professor of Chemistry at Northwestern University. Professor Silverman received his B.S. degree in chemistry from The Pennsylvania State University in 1968 and his Ph.D. degree in organic chemistry from Harvard University (David H. Dolphin, mentor) in 1974 with time off for a two-year military obligation from 1969 to 1971. After two years as a NIH postdoctoral fellow in the laboratory of the late Professor Robert H. Abeles in the Graduate Department of Biochemistry at Brandeis University, he joined the chemistry faculty at Northwestern University. In 1986 he became Professor of Chemistry and Professor of Biochemistry, Molecular Biology, and Cell Biology. In 1996 he was named the Arthur Andersen Professor of Chemistry for a period of two years and since 2004 he has been the John Evans Professor of Chemistry.

Professor Silverman's research can be summarized as investigations of enzyme mechanisms and the molecular mechanisms of action, rational design, and syntheses of potential medicinal agents, particularly for central nervous system diseases. Dr. Silverman has formulated and tested new enzymatic hypotheses with the use of novel organic chemical approaches to elucidate enzyme-catalyzed reactions, to design mechanism-based inactivators of enzymes, and to understand the molecular mechanisms of inactivation of enzymes. The enzymes that he studies are not only mechanistically interesting, but also highly relevant to pharmaceutical inhibitor design. For example, with

the use of a variety of novel mechanism-based inactivators, Dr. Silverman pioneered and developed the mechanistic work that led to a radical mechanism for the enzyme monoamine oxidase. When he first reported his results in 1980, radical involvement in enzyme-catalyzed reactions was rarely proposed and poorly understood. It is now apparent that radical intermediates in enzyme-catalyzed reactions are quite prevalent.

Professor Silverman has received numerous awards for research: DuPont Young Faculty Fellow (1976), Alfred P. Sloan Research Fellow (1981-1985), NIH Research Career Development Awardee (1982-1987), Fellow of the American Institute of Chemists (1985), Fellow of the American Association for the Advancement of Science (1990), Arthur C. Cope Senior Scholar Award of the American Chemical Society (2003), Alumni Fellow Award from The Pennsylvania State University (2008), and the Perkin Medal from the Society of Chemical Industry (2009). He also is the recipient of several teaching awards including the E. LeRoy Hall Award for Teaching Excellence (1999), the Excellence in Chemistry Education Award from the Northwestern University Chapter of Alpha Chi Sigma Chemistry Fraternity (1999), the Northwestern University Alumni Teaching Award (2000), and the Charles Deering McCormick Chair in Teaching Excellence (2001). Professor Silverman also was awarded a U.S. Army Commendation Medal for meritorious service (1971).

Editorial Advisory Boards on which Professor Silverman has served include the following journals: *Current Enzyme Inhibition* (2004-present), *Bioorganic & Medicinal Chemistry* (2003-present), *Bioorganic & Medicinal Chemistry Letters* (2003-present), *Letters in Drug Design & Discovery* (2003-present), *Archiv der Pharmazie- Pharmaceutical and Medicinal Chemistry* (1995-present), *Journal of Enzyme Inhibition and Medicinal Chemistry* (1988-present), *Archives of Biochemistry and Biophysics* (1993-2003), and *Journal of Medicinal Chemistry* (1995-2000).

Dr. Silverman has published over 250 research articles and reviews, holds 41 domestic and foreign patents, and has written four books (one translated into German). His book entitled *The Organic Chemistry of Drug Design and Drug Action* is in its second edition. From 1992 to 2006 he gave two-day short courses on drug design and drug action at the national meetings of the American Chemical Society, as well as at various pharmaceutical companies. He has been a lecturer at the Residential School on Medicinal Chemistry (Drew University) since 1995, presenting lectures on enzyme inhibition and on lead modification. He was elected nominating committee (1990), treasurer (1993-1996), and program chair (2001) of the Division of Biological Chemistry of the American Chemical Society and canvassing committee (1982-1987; chair 1987) and long-range planning committee, Division of Medicinal Chemistry of the American Chemical Society.

TYRONE TAYLOR

Tyrone C. Taylor is the President of Capitol Advisors on Technology, a technology management and consulting firm. He brings an exceptional combination of hands on experience in technology development and commercialization. He has held senior management positions in the federal government and the private sector and worked extensively in the R&D community. He is the former Director of Washington Relations at the West Virginia High Technology Foundation where he was responsible for developing and managing strategic partnerships with public, private, and academic representatives in the field of technology commercialization. He has provided technical support for technology transfer programs for the Department of Defense, the Department of Commerce, and the Department of Homeland Security, as examples. He also serves as the Chair of the Small Business Division at the National Defense Industrial Association. Mr. Taylor is well known within the federal research and development (R&D) organizations and small business community as an authoritative source with hands on experience in technology transfer and commercialization.

Reflecting his broad experience, Mr. Taylor has been asked to serve on numerous technology advisory committees at organizations such as the National Research Council, the National Science Foundation, and the Center for Commercialization of Advanced Technologies, and others. Congressional science and technology committees have also called on him to assess the impact of potential legislation affecting the technology community.

As an executive on loan, Mr. Taylor represented the entire federal R&D community as the Washington, DC, Representative for the Federal Laboratory Consortium for Technology Transfer, a congressionally chartered organization. In this capacity, he provided leadership in developing legislation that governs the private and public sectors' ability to collaborate in R&D activities, manage intellectual property, and commercialize technologies. Recognized for his efforts by Congress, Mr. Taylor often addresses audiences throughout the United States and abroad on technology development, transfer, and commercialization issues.

Mr. Taylor also served as President, Government Operations, and Senior Vice President for Marketing and Business Development for Unisphere, Inc., a technology assessment firm responsible for assessing and transitioning technologies with defense and commercial applications. In this capacity, he aided in the expansion and growth of small businesses and their clients, helping to generate over $25 million in revenue and produce over $64 million in cost savings. Due to his broad technology background, he is able to interact effectively with all aspects of the technology commercialization community including inventors, attorneys, acquisition managers, test and engineering, and marketing, as examples.

Mr. Taylor's technology management experience covers such areas as homeland security, medical technologies, energy and environment, advanced materials, infrared imaging, and aerospace.

Before joining Unisphere, Mr. Taylor served in the Senior Executive Service in a variety of executive management positions at NASA. He brings extensive program/project experience having managed almost $1 billion in contracts and grants for systems engineering, information systems, facilities management, and technical and administrative services as a member of the International Space Station program, which included Japan, Canada, and the European Space Agency.

Tyrone Taylor has a Masters in Business Administration from Southeastern University. He earned an A.B. in business administration from Wilmington College, and has served as Adjunct Professor for numerous technology transfer and commercialization courses. Other activities include serving on the board of Pediatric AIDS/HIV Care in Washington, DC, and nurturing businesses in the assistive technology arena.

BILL TESTA

Bill Testa is a vice president and director of regional research in the economic research department at the Federal Reserve Bank of Chicago. Testa has written widely in the areas of economic growth and development, the Midwest economy and state–local public finance. He directed a comprehensive long-term study and forecast of the Midwest economy, *Assessing the Midwest Economy: Looking Back for the Future*, and has fashioned a series of conferences on school reform.

Testa currently serves as economics editor of the *Chicago Fed Letter* and on the editorial board of *Economic Development Quarterly*. His weekly "Midwest Economy" web column, which can be found on the Federal Reserve Bank's web site, has become a widely read and nationally quoted feature.

Testa also serves in an advisory or director's capacity to a variety of professional journals, nonprofit organizations, advisory boards and economic development initiatives in the Midwest. He chairs the Board of Trustees of the Illinois Council on Economic Education and serves on the boards of the Global Chicago Center of the Chicago Council on Global Affairs and the Economic Development Council of Chicago.

Prior to joining the Chicago Fed in 1982, Testa was a visiting faculty member in the economics department at Tulane University in New Orleans and a graduate research fellow at the Academy for Contemporary Problems in Columbus, Ohio. He currently lectures at DePaul University's College of Commerce. A native of Cleveland, Ohio, Testa received his undergraduate degree from Northwestern University in 1975 and a Ph.D. in economics from the Ohio State University in 1981.

MATTHEW TIRRELL

Matthew Tirrell, a pioneering researcher in the fields of biomolecular engineering and nanotechnology, is the founding Pritzker Director of the Institute for Molecular Engineering. Tirrell specializes in the manipulation and measurement of the surface properties of polymers, materials that consist of long, flexible, chain molecules. His work combines microscopic measurements of intermolecular forces with creation of new structures. His work has provided new insight into polymer properties, especially surface phenomena such as adhesion, friction, and biocompatibility, and new materials based on self-assembly of synthetic and bio-inspired materials.

Tirrell comes to UChicago from the University of California at Berkeley, where he has served since 2009 as the Arnold and Barbara Silverman Professor and chair of the Department of Bioengineering, as professor of materials science and engineering and chemical engineering, and as a faculty scientist at the Lawrence Berkeley National Laboratory. He has received many honors, including election to both the National Academy of Engineering and the American Academy of Arts and Sciences. Prior to his appointment at Berkeley, Tirrell served for a decade as dean of engineering at UC Santa Barbara, where he helped build the program's national prominence.

Tirrell began his academic career in 1977 at the University of Minnesota, where he served as Shell Distinguished Chair in Chemical Engineering, Earl E. Bakken Professor of Biomedical Engineering, director of the Biomedical Engineering Institute, and head of Chemical Engineering and Materials Science. Tirrell moved to the University of California, Santa Barbara, in 1999, where for a decade he was Professor of Chemical Engineering, Materials, Biomolecular Science and Engineering, and Richard A. Auhll Professor and Dean of the College of Engineering. He received his bachelor's degree in chemical engineering from Northwestern University in 1973 and his doctoral degree in polymer science and engineering from the University of Massachusetts in 1977.

ERIC TOONE

Eric Toone is the Principal Deputy Director of the Advanced Research Projects Agency—Energy (ARPA-E), responsible for oversight of all of ARPA-E including direct oversight of ARPA-E’s Electrofuels program. In addition to his role at ARPA-E, Toone is currently the Anne T. and Robert M. Bass Professor of Chemistry and Professor of Biochemistry at Duke University.

Toone is a scientific founder of two venture-backed companies: Aerie Pharmaceuticals, a research-based ophthalmology company, and Vindica Pharmaceuticals, a nitric oxide delivery company.

He has served as a permanent member of the Bioorganic and Natural Products Study Section at the National Institutes of Health, and is currently a member of the NSERC Organic & Inorganic Review panel (Canada).

Toone has authored over 100 scientific papers and over 30 patents. He is an associate editor of the journal *Biopolymers* and the editor in chief of the monograph series *Advances in Enzymology*.

He studied chemistry as an undergraduate at the University of Guelph, graduating in 1983. That same year he moved to the University of Toronto to begin graduate studies with Professor J. Bryan Jones. Toone graduated from the University of Toronto in 1988 and moved to Harvard University to continue his studies with Professor George Whitesides.

JOSEPH WALSH

Joseph (Jay) Walsh began his service as the University's Vice President for Research on December 1, 2007. Walsh formerly served as senior associate dean of McCormick School of Engineering and Applied Science (MEAS), where he is a professor of biomedical engineering.

Walsh received a bachelor's and master's degree in electrical engineering from Massachusetts Institute of Technology. Immediately following receipt of his Ph.D. in medical engineering from Harvard Medical School and Massachusetts Institute of Technology, Walsh joined the Northwestern faculty in 1988. He played an increasingly important role at McCormick, first as associate dean for graduate studies and research and later as senior associate dean.

Walsh's early research on laser-tissue interactions helped frame the understanding of laser ablation; this work formed the scientific foundation for now standard laser-based procedures in medicine and surgery. In the past decade, his research has focused on diagnostic and therapeutic applications of light.

Walsh and collaborators in otolaryngology have demonstrated the optical stimulation of sensory nerves with one goal being high spatial resolution stimulation for improved cochlear prosthetics. He is also working with a team of investigators from his home department and chemistry to develop optical sensors for quantification of analytes such as glucose with the goal of improving diabetes management. In collaboration with clinicians in obstetrics and gynecology, dermatology, and urology on the Chicago campus and at Evanston-Northwestern Healthcare, he has developed a polarization-based optical imaging system for improved detection of various lesions. His current projects are each supported by the National Institutes of Health.

Walsh has also excelled as a teacher and University citizen. In 1997 he was recognized as McCormick's Teacher of the Year; in 2005 he was designated Advisor of the Year. Among Walsh's broader University service has been his service as chair of the Program Review Council; his leadership of the committee that developed the current (RAS) model for graduate student tuition; and his

membership on The Graduate School Administrative Board and the Evanston Campus Planning Advisory Committee. External to Northwestern, Walsh has played active roles in service as the president of the American Society for Lasers in Medicine and Surgery (2003 to 2004) and as the chair for six international conferences.

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 his work with a wide variety of countries around the world.

Dr. Wessner's work addresses the linkages between science-based economic growth, entrepreneurship, new technology development, university-industry clusters, regional development, small-firm finance and public-private partnerships. His program at the National Academies also addresses policy issues associated with international technology cooperation, investment, and trade in high-technology industries.

Currently, he directs a series of National Academy studies centered on government measures to encourage entrepreneurship and support the development of new technologies and cooperation among industry, universities, laboratories, and government to capitalize on the nation's investments in research. Foremost among these is a congressionally mandated study of the Small Business Innovation Research (SBIR) Program, reviewing the operation and achievements of this $2.5 billion award program for small companies and start-ups. The National Academies will release in July a major study on best practice in global innovation programs, entitled *Rising to the Challenge: U.S. Innovation Policy for the Global Economy*. Today's meeting on "Building the Illinois Innovation Economy" forms part of a complementary analysis entitled Competing in the 21st Century: Best Practice in State & Regional Innovation Initiatives. 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.

TERESA WOODRUFF

Teresa K. Woodruff, Ph.D. (Thomas J. Watkins Professor of Obstetrics & Gynecology, Feinberg School of Medicine and Professor of Biochemistry, Molecular Biology and Cell Biology, Weinberg College of Arts and Sciences. Ph.D. 1983, Northwestern University). As a reproductive endocrinologist, Dr. Woodruff has spent the better part of her research career focusing on female reproductive health and infertility. To that end, she was made Chief of the newly created Division of Fertility Preservation at the Feinberg School of Medicine. Combining this effort with her work on two R01 NIH grants, a P01 grant and core facility, and her work as director of two NIH funded center grants: The Center for Reproductive Research (U54) and the Oncofertility Consortium (UL1), Dr. Woodruff has established a team of oncologists, fertility specialists, social scientists, educators and policy makers to translate her research to the clinical care of women who will lose their fertility due to cancer treatment. To describe this effort, she coined the term oncofertility, a word that is now officially recognized as a new 'slang' term in the English language. She has edited two books on the topic, the first titled simply *Oncofertility* (Springer, 2007) where the scope of the problem and current technology, clinical practice tables, procedural guidelines and patient stories are collected. Her second book, to be released in 2010, is titled *Oncofertility: Ethical, Legal, Social, and Medical Perspectives* (Springer Publishing) and discusses the ethical, religious, economic, and legal issues surrounding fertility preservation.

She has been an advocate for sex- and gender inclusivity and study in basic science, translational studies and clinical trials and is the Founder and Director of the Institute for Women's Health Research. As an educator and mentor, she encourages young women to pursue careers in the sciences, and has developed the Oncofertility Saturday Academy in conjunction with the Young Women's Leadership Charter School as a way to involve high school girls in college level science. She serves on the Endocrine Society Council and the Society for the Study of Reproduction Board of Directors. Her awards include the Distinguished Teaching Award (2000), the Mentor of the Year Award (2009) and the Distinguished Woman in Medicine and Science (2009) from Northwestern University. She was also honored by the Alumnae of Northwestern University with their Distinguished Alumnae Award (2008). She has been honored nationally with awards from the American Women in Science (AWIS) (2008) Innovator Award, the American Medical Women Association (AMWA) Gender Equity Award (2009), and the "Speaking of Women's Health" Distinguished Service Award (2007). She was elected a fellow of the American Association for the Advancement of Science (2005) and awarded the Endocrine Society's Richard E. Weitzman Memorial Award (2000). She is the 2010 recipient of the Feinberg School of Medicine Tripartite Legacy Award, the inaugural recipient of the Young Women's Leadership Charter School's Girl

Power Award, and is the recipient of an honorary doctorate from Bates College in Lewiston, Maine.

ROBERT WOLCOTT

Robert Wolcott is the Executive Director of the Kellogg Innovation Network (KIN) and a Senior Lecturer of Entrepreneurship & Innovation at the Kellogg School of Management, Northwestern University. He teaches corporate innovation and entrepreneurship for Kellogg in Evanston, Miami, and Hong Kong (with HKUST). Formerly a Visiting Professor at the Keio Business School (Tokyo, Japan). Advisor to NORDEN, the Nordic Innovation Center, Nordic Council of Ministers, Oslo, Norway, and a member of the Global Technology Council of Kraft Foods, Inc.

His new book, with Dr. Michael Lippitz, *Grow From Within: Mastering Corporate Entrepreneurship and Innovation* (McGraw-Hill) launched in October, 2009. Wolcott's work has appeared in *MIT Sloan Management Review*, *The Wall Street Journal*, *Advertising Age*, *BusinessWeek*, *The Financial Times* (UK/European Edition) and *The New York Times*. He is a frequent speaker at events worldwide.

In 2003, Wolcott began leading the Kellogg Innovation Network, created as a key program within Professor Mohan Sawhney's Center for Research in Technology and Innovation. The KIN's annual summit, KIN Global, takes place in late Spring and includes leaders from around the world from business, government, academia, non-profits and the arts who collaborate around issues of significance for their organizations and for humanity. <*http://www.kinglobal.org*>.

Wolcott also co-founded and serves as Managing Partner of Clareo Partners LLC, a corporate strategy and innovation management consultancy specializing in new business creation and growth (<*http://www.clareopartners.com*>). Subsidiary Clareo Capital owns equity in companies in social enterprise and luxury markets. Clareo's headquarters, Clareo Studio, created in partnership with Herman Miller, Inc., serves as a collaboration space for special events, corporate off-sites and performances dedicated to innovation, entrepreneurship, social awareness and general inspiration.

Wolcott received a B.A., European and Chinese History; and an M.S. and Ph.D., Industrial Engineering & Management Science, Northwestern University, Evanston, Illinois. He and his wife, Ada Yung, have a young daughter, Jolie, and reside in Chicago, Illinois.

Appendix C

Participants List
(speakers in italics)

Kandis Abdul-Aziz
University of Illinois at Urbana-Champaign

Andrew Adair
Office of Senator Mark Kirk

Irfan Ahmed
University of Illinois

Guillermo Ameer
Northwestern University

Nancy Auyeung
Northwestern University

Emily Ayshford
Northwestern University

Allison Bedell
Northwestern University

Michael Beltran
Northwestern University

Karen Bender
University of Illinois at Urbana-Champaign

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State Science and Technology Institute (SSTI)

Daniel Biss
Representative, 17th District
State of Illinois

Keith Bowman
Illinois Institute of Technology

Jim Bray
Northwestern University

Kasey Brink
Northwestern University

Linda Broadbelt
Northwestern University

Grant Bunker
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Louise Burton
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University of Illinois at Urbana-Champaign

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Northwestern University

Venkat Chandrasekhar
Northwestern University

McAlister Clabaugh
The National Academies

Lori Clark
Northern Illinois University

Dick Co
Northwestern University

Jeffrey Coney
Northwestern University

James Conley
Northwestern University

Margaret Connolly
Northwestern University

Kathleen Cook
Northwestern University

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The Castleton Marketing Group

Pamela Cox
Marshall, Gerstein & Borun

Van Crocker
AuraSense Therapeutics

David Dawson
The National Academies

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Vinayak Dravid
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Husch Blackwell LLP

John Fernandez
SNR Denton

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Jane Fischer
Illinois Science and Technology Coalition

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Emily Greenspan
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Tolga Gulman
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Department of Energy

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Museum of Science & Industry

Ford Harrington
Northwestern University

Mark Harris
Illinois Science & Technology Coalition

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Motorola Solutions

Ben Hernandez
NuMat Technologies

Adam Hock
Illinois Institute of Technology

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University of Illinois at Chicago

Eneda Hoxha
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Sarah Hurst
Northwestern University

Eric Isaacs
Argonne National Laboratory

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Michael Jewett
Northwestern University

Sheila Judge
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Kevin Lynch
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Northwestern University

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Nanosphere

Nicole Moore
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Caralynn Nowinski
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Northwestern University

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Northwestern University

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Northwestern University

Julio Ottino
McCormick School of Engineering and Applied Sciences,
Northwestern University

Tuncay Ozel
Northwestern University

Tim Persons
Government Accountability Office

Thomas Peterson
Director for Engineering
National Science Foundation

Karl Putz
Northwestern University

Patrick Quinn
Governor of Illinois

Brian Quist
Northwestern University

Mark Ratner
Northwestern University

Norbert Riedel
Baxter International

Dennis Roberson
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Billie Scales
University of Illinois at Urbana-Champaign

Carlo Segre
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Sujai Shivakumar
The National Academies

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Frank Stabile
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Nancy Sullivan
University of Illinois at Chicago

George Sweeney
State of Illinois

Tyrone Taylor
Capitol Advisors on Technology

William Testa
Federal Reserve Bank of Chicago

Sammy Tin
Illinois Institute of Technology

Matthew Tirrell
Institute for Molecular Engineering
University of Chicago
and Argonne National Laboratory

Eric Toone
Advanced Research Projects
Agency for Energy (ARPA-E)

Howard Tullman
Tribeca Flashpoint Media Arts
Academy

Katelyn Tye
State of Illinois

Keith Tyo
Northwestern University

Robert van Lith
Northwestern University

Jay Walsh
Northwestern University

Patricia Ward
Museum of Science & Industry

Mike Wasielewski
Northwestern University

Mark Werwath
Northwestern University

Charles Wessner
The National Academies

Chris Wilmer
Northwestern University

Robert Wolcott
Kellogg School of Management
Northwestern University

Chris Wolverton
Northwestern University

Teresa Woodruff
Northwestern University

AnTu Xie
Northwestern University

Fruma Yehiely
Northwestern University

Nanjia Zhou
Northwestern University

Appendix D

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